ROAD GEOHAZARD RISK MANAGEMENT
HANDBOOK

GFDRR Global Facility for Disaster Reduction and Recovery
THE WORLD BANK IBRD • IDA | WORLD BANK GROUP

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ROAD GEOHAZARD RISK MANAGEMENT

HANDBOOK

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ACRONYMS & GLOSSARY

AMIS	asset management information system(s)
BCR	benefit-to-cost ratio
DMDU	decision making under deep uncertainty
EIRR	economic internal rate of return
Geohazard-prone road subsection	Particular part of a road section with a concentration of endangered road locations due to the presence of geohazards
GIS	geographic information system
Hazard-indicating map	A hazard-indicating map is not too detailed, is provided at a large scale (1:10,000 to 1:50,000), and identifies all historical and susceptible hazard areas in the vicinity of the proposed new route options.
Hazard maps	Hazard maps are different from hazard-indicating maps, which display a specific hazard or several hazards for an identified endangered road location. They are very detailed and provided at a scale smaller than 1:5,000, which is the scale used during the structural measures design stage.
ICT	information and communication technology
IDF	intensity-duration-frequency
ISO	International Organization for Standardization
LCC	life-cycle cost
LiDAR	Light Detection and Ranging, referring to a remote sensing method for locating an object. It is similar in operation to radar but emits pulsed laser light instead of microwaves
NPV	net present value
OM	operation manual
Road section	Length of a road between main intersections or between starting and end points, which can extend for several tens of kilometers or even for several hundred kilometers
ToR	terms of reference
VOC	vehicle operation cost

PREFACE

Geohazards can be defined as *"events caused by geological, geomorphological, and climatic conditions or processes which represent serious threats to human lives, property, and the natural and built environment"* (Solheim et al. 2005). They cover almost all hazards affecting road infrastructure, such as slope slides, slope collapses, earth flows, debris flows, floods, and erosion.

Geohazards may result in the loss of human life, extensively damaged infrastructure, and suspended or disturbed traffic and services such as water and energy supply. Generally speaking, roads should be robust (able to withstand the geohazard) and resilient (able to quickly restore function following an event) to provide reliable access to emergency services and to be used as evacuation routes; they should also contribute to an efficient local recovery process after a geohazard event.

Most geohazards are linked to climate activity such as rainfall and thawing of ice and snow or associated with earthquakes that cause large-scale ground movement independent of any underlying climatic conditions. For many locations around the world, climatic changes have increased the intensity of rainfall and raised the mean temperature, in turn increasing flow-type geohazard events such as debris or earth flows and floods. This has resulted in a long-term increasing rate of geohazard impacts and associated road damage.

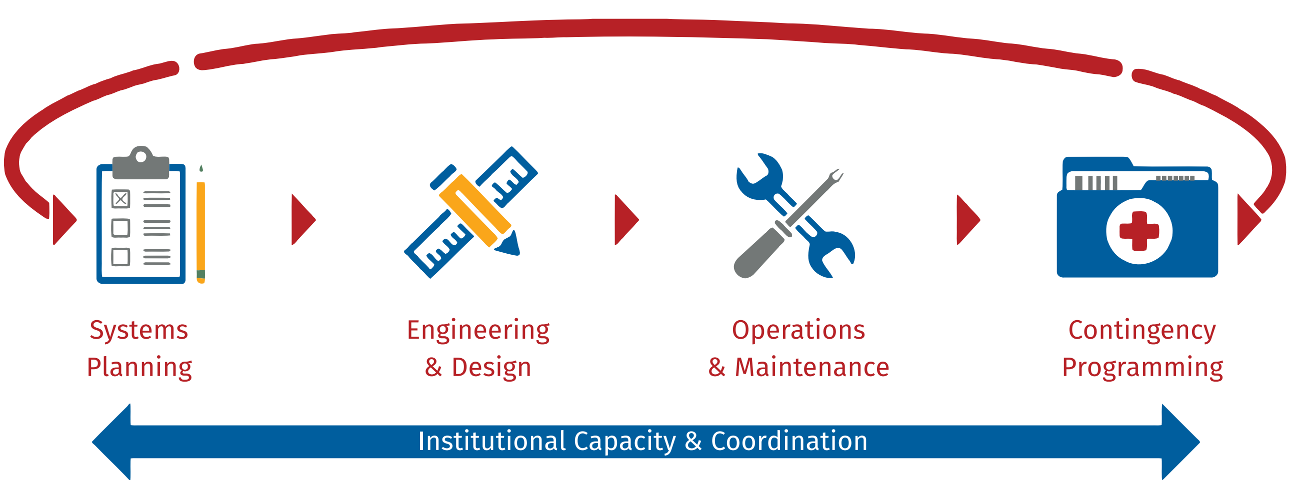
Road geohazard risk management has the following principal aims:

- To minimize the risks and effects of geohazards on roads, road users, and the people living within the wider zone of influence of the geohazard
- To support decisions on the alignment of new roads, or the realignment of and preventive actions on existing roads, to ensure that the full life-cycle costs (construction costs, risk-based maintenance costs, and associated impact on traffic disturbances) associated with differing levels of geohazards are accounted for
- To help protect road users through precautions such as early warning and precautionary road closures
- To contribute to the speedy recovery and reconstruction of roads after geohazard events and to the mitigation of future geohazard events.

Road geohazard risk mitigation is technically challenging, typically involving structural measures or road realignments that are costly. This handbook considers a stepwise approach that begins with the institutional setup:

- For low-budget, low-capacity countries, the focus is on retaining the usability of critical roads (often the all-weather road network) to the maximum extent possible, while accepting that noncritical roads can be closed during certain times of the year. This split approach, along with efficient postdisaster activities as short-term targets, forms the basis of the geohazard risk management approach.
- For low-budget, moderate-capacity countries, medium-term targets should focus on nonstructural measures such as emergency road information and low-cost structural measures such as rock support at the toe of slips.
- For moderate-budget, moderate-capacity countries, long-term targets can focus on structural measures for the management of all-weather roads.
- Long-term targets include the mainstreaming of road geohazard risk management. Such management contributes to local geohazard mitigation—as in the case of dike embankments for flood mitigation, which can function as roads for emergency transportation during catastrophic disasters.

The handbook reflects the World Bank's disaster-resilient infrastructure life cycle (Figure P.1). Each part is devoted to a stage of the life cycle, including the underlying institutional capacity and coordination aspects.



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1

FRAMEWORK FOR ROAD GEOHAZARD RISK MANAGEMENT

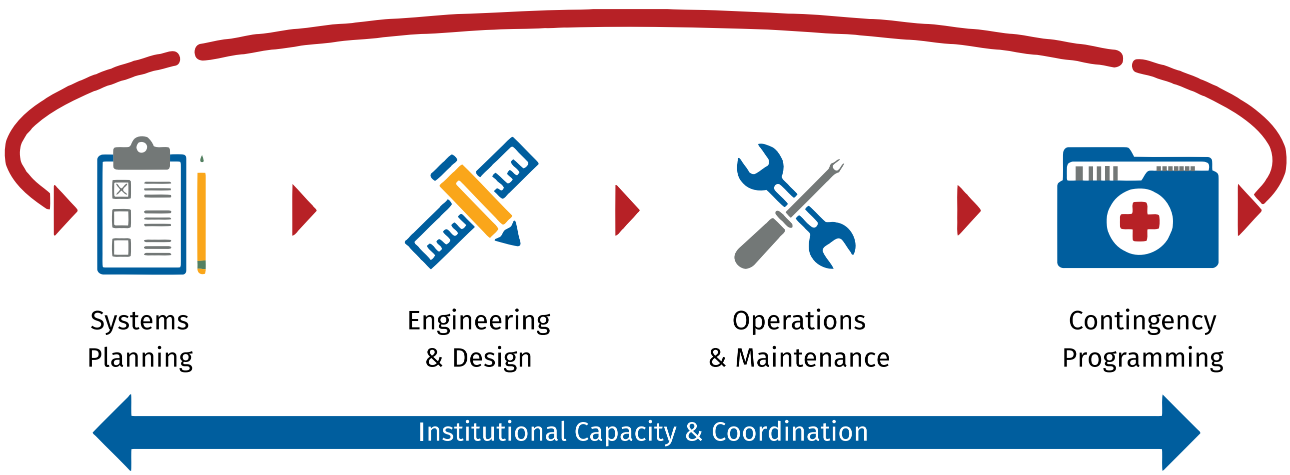
1.1 INTRODUCTION TO ROAD GEOHAZARD RISK MANAGEMENT

This handbook outlines an approach to proactively manage the risks of geohazards on roads, road users, and the people living near and affected by roads through

- Improving understanding of the risks of geohazards throughout the road infrastructure cycle;
- Promoting risk avoidance on the alignment of new roads or the realignment of existing roads to manage construction costs, maintenance costs, and losses from geohazard-induced traffic disruptions;
- Protecting road users through preparedness, including measures for early warning, precautionary road closures, and access to emergency services and evacuation routes; and
- Contributing to the speedy recovery and reconstruction of roads after geohazard events and to the mitigation of future geohazard events.

The World Bank disaster-resilient infrastructure life cycle (Figure 1.1) represents the overall approach of the guidelines presented in this handbook.

Figure 1.1: World Bank Disaster-Resilient Infrastructure Life Cycle Approach



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In Part I, the handbook

- Introduces the overall framework;
- Defines and classifies the geohazards addressed in this handbook;
- Proposes a series of strategies to manage the risks posed by these hazards;
- Describes the opportunities to better integrate geohazard risk management into road engineering and administration; and
- Explains how the handbook is structured to support road geohazard risk management, including the standard terms of reference and operations manual in this work.

The classification does not include the effects of certain lower-probability, higher-impact triggers or inducing events such as large earthquakes, extreme storms, and so on. The handbook focuses mostly on geohazard events with a much higher likelihood (probability) but with lower impact magnitudes, such as those triggered by relatively common storm events—wherein engineered solutions or localized route realignments can significantly mitigate or eliminate the hazards. However, the overall framework of geohazard management and mitigation presented in this handbook is equally applicable to all geohazards.

1.2 CORRELATION BETWEEN ROAD CONSTRUCTION ACTIVITIES AND INCREASED GEOHAZARD RISK

In addition to what is mentioned in this handbook, there is a clear link between road construction and maintenance activities and the adjoining areas' susceptibility to geohazard. Road construction often worsens the landslide problem in hilly areas by altering the landscape, slopes, and drainages and by changing and channeling runoff, thereby increasing the potential for landslides. These slides and other forms of ground failure also have adverse environmental consequences, such as increased soil erosion, siltation of streams, blockage of stream drainages, and loss of valuable watershed and grazing lands.

Road development often also results in an adverse impact on the ecological balance. The cutting for roadwork results in destabilizing of the hill slopes and also loss of vegetation. The road construction activity releases greenhouse gases and other pollutants because of the deployment of machinery for various construction stages and for the arrangement of required materials. These activities affect environmental sustainability at a time of global warming and climate change—although these effects can often be offset by reducing the emissions on existing, less-efficient routes. The net result is a likely increase in geohazard risk in the vicinity of the roads constructed or under construction, either in the short term or permanently.

1.3 ROAD GEOHAZARD RISK MANAGEMENT HANDBOOK STRUCTURE

This handbook is structured to support road geohazard risk management sequentially and systematically:

- ***Part I, Framework for Road Geohazard Risk Management,*** helps users understand the framework for road geohazard risk management, introduces some basic concepts, and provides context to the overall handbook.
- ***Part II, Institutional Capacity and Coordination,*** covers the institutional arrangements that are necessary for the successful implementation of geohazard management.
- ***Part III, Systems Planning,*** covers the systems planning aspects, pertaining to the identification, assessment, and evaluation of risks, along with raising awareness of disasters.
- ***Part IV, Engineering and Design,*** deals with the engineered solutions to address geohazard risks, giving examples of different solutions to particular risk types.
- ***Part V, Operations and Maintenance,*** focuses on the operations and maintenance aspects of geohazard management—whether the maintenance of previously engineered solutions or the nonengineered solutions available to mitigate the impacts of geohazard risks.
- ***Part VI, Contingency Planning,*** addresses contingency programming issues, such as postdisaster response and recovery, and the important issue of funding arrangements.
- ***Part VII, References and Resource Materials,*** contains the reference list and additional online resources.

Additionally, this handbook includes standard templates for terms of reference (ToRs) that can be adapted for technical assistance projects for road geohazard risk management (see Appendix A) and an operation manual (OM) for the practitioners involved with road geohazard risk management (see Appendix B). Table 1.1 shows the framework and workflow for project activities of road geohazard risk management, incorporating references to the corresponding ToRs and OM.

Table 1.1: Framework and Workflow for Road Geohazard Risk Management

PART OF HANDBOOK	KEY CONCEPTS	TERMS OF REFERENCE (TOR) (REFER TO APPENDIX A)	OPERATION MANUAL (OM) (REFER TO APPENDIX B)
Part II: Institutional Capacity and Coordination	Institutional setup • Laws, regulations, and technical standards • National or subnational plans or strategies • Mechanisms for implementation	ToR 1: Institutional Capacity Review and Target Setting	
Part III: Systems Planning	Risk identification, assessment, and evaluation of geohazard Disaster awareness	ToR 2: Systems Planning: Risk Identification, Assessment, and Evaluation ToR 3: Development of Manual for Promotion of Road Disaster Awareness and Partnership	OM 1: Economic Risk Estimation and Cost-Benefit Analysis
Part IV: Engineering and Design	Geohazard risk management planning • For new roads • For existing roads	ToR 4: Design of Structural Measures	
Part V: Operations and Maintenance	Operations and maintenance of engineered solutions Nonengineered solutions Asset management as a response	ToR 5: Development of Manual for Operation and Maintenance for Road Geotechnical Assets, and Implementation of a Road Geotechnical Asset Management Information System (AMIS) ToR 6: Development of Emergency Information System	
Part VI: Contingency Programming	Postdisaster response and recovery	ToR 7: Development of Manual for Postdisaster Response and Recovery	

1.4 DEFINITION AND CLASSIFICATION OF ROAD GEOHAZARDS

This handbook defines road geohazards as *"events caused by geological, geomorphological, and climatic conditions or processes that represent serious threats to human lives, property, and the natural and built environment"* (Solheim et al. 2005).

The handbook addresses the typical types of geohazard that adversely affect roads, classifying them based on their combination of location, movement, and the materials involved in the movement (Table 1.2). The typical risk management method is different for each type of movement, location, and material involved in a geohazard affecting a slope or landscape ecosystem.

Table 1.2: Road Geohazards, by Location, Movement, and Material Type

LOCATION AND MOVEMENT TYPE	MATERIAL FACTORS			
	BEDROCK	SOIL		WATER
		DEBRIS	EARTH	
Mountainside fall or collapse[a]	Mountainside rock fall or collapse	Mountainside debris collapse	Mountainside earth collapse	n.a.
Valley-side collapse or river erosion	Valley-side rock collapse or river erosion	Valley-side debris collapse or river erosion	Valley-side earth collapse or river erosion	n.a.
Slide[a]	Rock slide	Debris slide	Earth slide	n.a.
Flow	n.a.	Debris flow	Earth flow	Flash flood or inundation

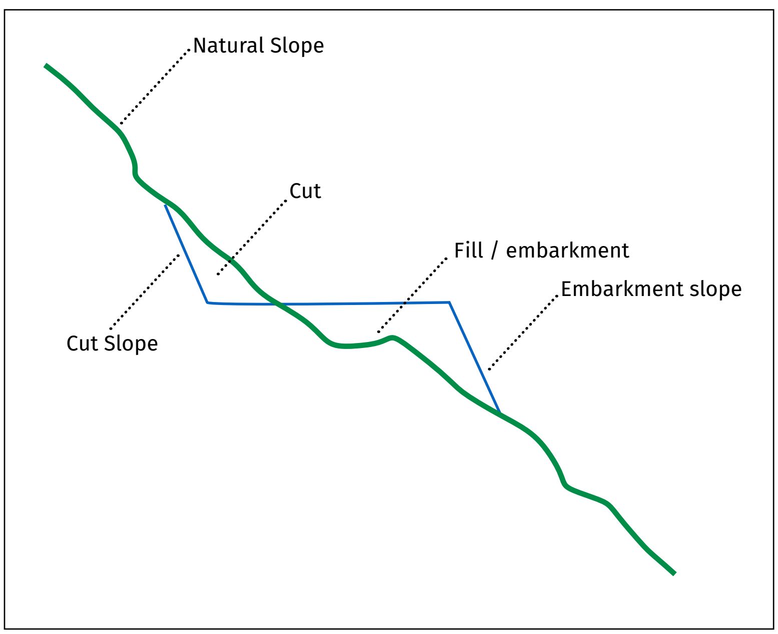
Notes:
n.a. = not applicable. The classification boundaries of hazard movement and material types are transitional. Some disasters involve complex hazard types. For example, a 'debris slide' on a mountain slope can change into an 'earth flow' after meeting with a torrent.
a. Geohazard movements also include topple and spread (Cruden and Varnes 1996). Here, topple is considered a type of collapse, and spread is considered a special case of slide.

Although Table 1.2 focuses on the impact of the geohazard on the road network, the cause (or trigger) of the geohazard can be from a range of natural and man-made factors. These include earthquakes, initiating landslides; changes in climate, altering soil moisture levels; volcanic activity, creating debris flows (lahars); removal of vegetation as part of land-use changes; altered river alignments; and the like. This handbook initiates the investigation from the point of view of the geohazard that manifests itself on the road network (as per Table 1.2) and then requires the investigations to determine the cause of those geohazards. The handbook does not, therefore, contain a specific section on earthquakes, volcanoes, or the like—because, in their own right, these may not result in a geohazard to the road network.

The role of water is quite predominant; it adds weight to the slope by replacing the air voids in the soil or rock, thereby leading to slope instability; reduces the friction along a sliding surface; and changes the angle of repose. If there is loose sediment, it becomes oversaturated during heavy rain, causing individual grains to lose grain-to-grain contact with one another as the water gets between them, resulting in slide, and liquefaction may occur through vibrations in a soil saturated with water. Water has a contributory role in most landslides. For a granular flow, the percentage of water may vary from 0 percent to around 20 percent, and for slurry flow, it could be 20–40 percent. If the water exceeds 40 percent, the slurry flow would convert into a stream.

A mountainside slope or valley-side slope refers to either an engineered slope (cutting slope or embankment slope) or a natural slope above or below the road surface (Figure 1.2). A "crossing stream or river" is another type of location (not included in Table 1.2) where flooding, debris flows, and similar events need to be carefully considered in the design, construction, and maintenance of the crossing infrastructure. River crossings can be broadly grouped into the three categories: (a) fords (where the road is designed to have water flow over it, either occasionally or permanently); (b) culverts; and (c) bridges. In worst-case scenarios, the river crossing may block, then release as a flash flood, resulting in a devasting inundation of downstream communities and infrastructure (including other roads and river crossings farther down the valley).

Figure 1.2: Nomenclature of Cuts and Fills



The material factors affecting road geohazards include the following (as also illustrated in Photos 1.1–1.8):

- ***Bedrock:*** hard or firm rock that was intact and in its natural place before the movement began
- ***Soil:*** any loose, unconsolidated, or poorly cemented aggregate of solid particles—generally of natural mineral, rock, or inorganic composition and either transported or residual—together with any interstitial gas or liquid
- ***Debris:*** soil that contains a weight proportion of more than 20 percent of coarse material greater than 2 millimeters in size (pebble, cobble, and boulder stones)
- ***Earth:*** soil that contains a weight proportion of more than 80 percent of fragments smaller than 2 millimeters in size (sand, silt, and clay)
- ***Water:*** material that is more than 50 percent water by volume, with the remaining volume composed of soil or other materials.

The handbook further defines five general movement types as follows:

- ***Fall:*** a rapid downward movement of a mass of rock or soil that travels mostly through the air by free fall, leaping, bounding, or rolling, with little or no interaction between one moving unit and another (Figure 1.3, panel a)
- ***Collapse:*** a gradual or rapid downslope movement of soil or rock under gravitational stress, often because of artificial factors, such as removal of material from the foot of a slope (Figure 1.3, panels b and c)
- ***Slide:*** a mass movement of earth, snow, or rock under shear mode along one or several sliding surfaces (Figure 1.3, panel d)
- ***Flow:*** a movement that exhibits a continuity of motion and a plastic or semifluid behavior, usually requiring considerable amounts of water (Figure 1.3, panel e)
- ***Erosion:*** a movement of rock fragments or soil particles from one place to another, mostly by water flow (Figure 1.3, panel f).

Figure 1.3: Road Geohazard Types

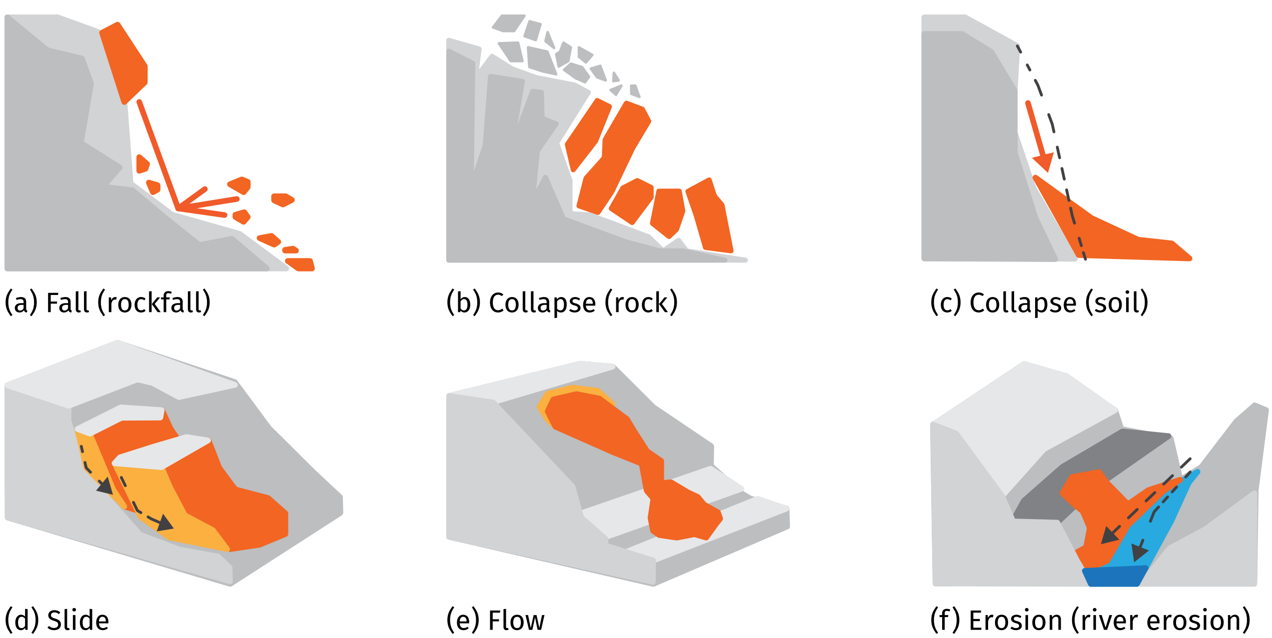


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Photo 1.1 Example of Mountainside Rockfall or Rock Collapse

A heavy monsoon rainfall of 446 millimeters in 24 hours was recorded on July 30, 2003, in southern central Nepal.

The collapsed rock slope blocked the main access road to Kathmandu from India.

Source: ©Department of Water Induced Disaster Prevention (DWIDP), Ministry of Irrigation, Government of Nepal. Reproduced, with permission, from DWIDP; further permission required for reuse.

Photo 1.2 Example of Mountainside Soil Collapse

In the second half of November 2008, the recorded rainfall totaled 600 millimeters in five days in the mid-downstream area of the Itajaí River basin, Santa Catarina State, Brazil.

The soil on a steep slope collapsed at the boundary of the bedrock on State Road SC-470. This common phenomenon occurs as a failure at the boundary with bedrock because the water content of the boundary soil increases and deteriorates easily with the infiltrated stormwater.

Source: ©Civil Defense, Gaspar Municipality, Santa Catarina State, Brazil. Reproduced, with permission, from Civil Defense, Gaspar Municipality, Santa Catarina State, Brazil; further permission required for reuse.

Photo 1.3 Example of Valley-Side Collapse or Erosion from Mountainside and Roadside Rainfall Inflow

Extreme rainfall of 1,800 millimeters in seven days during the first half of October 2009 (historically, the biggest seven-day rainfall in the past 10 years) closed vehicle traffic to Baguio City, Philippines, completely for three days.

The collapse cut a section of road that was 65 meters long by 65 meters high, closing the main access. The cause of the soil collapse was inflow and infiltration of stormwater from the roadside to the valley side of the road.

Source: © World Bank. Further permission required for reuse.

Photo 1.4 Example of Valley-Side Collapse from River Erosion

In the second half of November 2008, the recorded rainfall recorded totaled 600 millimeters in five days in the mid-downstream area of the Itajaí River basin, Santa Catarina State, Brazil.

This riverside road collapse, on a federal road, occurred in two stages that form a general pattern for riverside road collapses:

- *First stage: primal collapse from river water infiltration and saturation of the road foundation and erosion of the road riverside by floodwater*
- *Second stage: secondary collapse from rapid drawdown of river water, residual water pressure of the roadside ground, and seepage failure of the soil foundation.*

Source: ©National Department of Infrastructure and Transport (DNIT), office of Rio do Sul, Santa Catarina State, Brazil. Reproduced, with permission, from DNIT; further permission required for reuse.

Photo 1.5 Example of Slide-Type Geohazard

In January 2009, a slide-type geohazard occurred on a bypass of the Pan-American Highway in the metropolitan area of San Salvador, El Salvador.

The road was closed because of sliding earth for about three months after the rainfall season ended. The sliding surface (bottom of the sliding mass) was 11 meters deep and consisted of deeply weathered paleosol (fossil soil), overlaid by a new pyroclastic flow deposit (fragmentation from volcanic or other igneous action). A slide-type geohazard of deep sliding surface can sometimes lag heavy rainfall by several months.

Source: ©Ministry of Public Works, Transport, Housing, and Urban Development (MOPTVDU), El Salvador. Reproduced, with permission, from MOPTVDU; further permission required for reuse.

Photo 1.6 Example of Flow-Type Geohazard (Debris)

A heavy monsoon rainfall of 446 millimeters in 24 hours was recorded on July 30, 2003, in southern central Nepal.

Debris flow blocked roads affecting the main access to Kathmandu from India.

Source: ©Department of Water-Induced Disaster Prevention (DWIDP), Ministry of Irrigation, Nepal. Reproduced, with permission, from DWIDP; further permission required for reuse.

Photo 1.7 Example of Flow-Type Geohazard (Flash Flood)

In a flash flood event on July 3, 2008, in the metropolitan area of San Salvador, El Salvador, floodwater completely covered this bus and dragged it into a flooding urban river, killing all 31 people aboard, including the driver and the man shown on the roof of the bus.

The rapid urbanization or deforestation of a landscape ecosystem area may increase stormwater runoff and flash flood hazard.

Source: ©*El Diario de Hoy*, El Salvador. Reproduced, with permission, from *El Diario de Hoy*; further permission required for reuse.

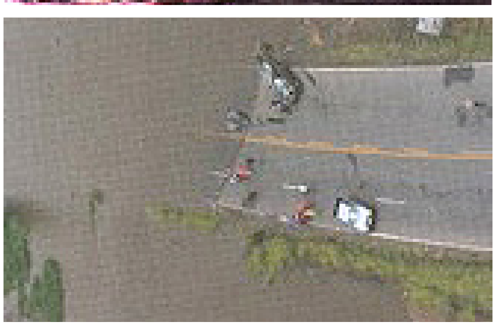


Photo 1.8 Example of Flow-Type Geohazard (Inundation)

A November 2008 storm inundated the high-traffic Federal Road BR-101 in the downstream area of the Itajaí River basin, Santa Catarina State, Brazil.

The road inundation interrupted traffic completely, generating great economic losses. The submergence of the road caused great deterioration.

Source: ©Archive Secom, Santa Catarina State, Brazil. Reproduced, with permission, from Santa Catarina State; further permission required for reuse.

1.5

1.5 ROAD GEOHAZARD RISK MANAGEMENT STRATEGIES

Road geohazard mitigation measures fall into two broad categories: (a) *proactive*, applied before a disaster; and (b) *response* and *recovery*, applied after a geohazard event to manage secondary damage and recovery.

Road geohazard risk management entails three main elements covered by this handbook: (a) institutional setup, (b) road geohazard risk management for new roads, and (c) road geohazard risk management for existing roads.

An adequate institutional framework is a necessary condition to guarantee proper road geohazard risk management, whose activities typically follow road project management stages of preconcept, concept, design, construction, and operations and maintenance. However, depending upon the contractual models in use, two or more of these stages may be combined into a single contractual arrangement. This, in turn, will necessitate that the institution have access to a multidisciplinary team (either employed or engaged as consultants).

The road geohazard risk management processes for new and existing roads differ only in *the risk assessment and geohazard risk management* planning stages. The measures common to both new and existing roads include (a) proactive structural measures (retaining walls and so on, as discussed in Part IV); (b) proactive nonstructural measures (operations and maintenance activities including monitoring of geohazards, as discussed in Part V); (c) postdisaster response; and (d) recovery.

This handbook is designed for application across all road types and road hierarchies. Although the precise categorization of roads varies from country to country, roads are generally subdivided into urban, interurban, and rural roads; primary, secondary, and tertiary roads; paved and unpaved roads; and high (traffic)-volume and low-volume roads. The importance of this categorization of roads within the context of this handbook is that the recommended road geohazard risk management strategy varies by road type. For the more-critical road types, the approach is to ensure the road remains functional and open at all times; for the less-critical road types, the approach is to minimize closures and ensure rapid recovery after the event. There is, of course, a range of road types and recommended strategies between these two extremes, but the main point is that geohazard risk management is not predicated on 100 percent of the road network being available 100 percent of the time.

1.6

1.6 STANDARD APPROACH TO RISK MANAGEMENT

This handbook is based on standard risk management approaches and aligns with the practices in the International Organization for Standardization (ISO) 31000 standard (“Risk Management—Guidelines”).[1] Risk management is generally considered to involve a process aligned with the stages in Figure 1.4, with each risk assessed against the probability (or likelihood) and consequence (or impact) of occurrence (Figure 1.5).

[1] See ISO 31000:2018, “Risk Management—Guidelines”: https://www.iso.org/standard/65694.html.

Figure 1.4: Generic Risk Management Stages

Source: ©World Bank. Further permission required for reuse.

Figure 1.5: Generic Risk Matrix

CONSEQUENCE (impact) if risk occurs	**PROBABILITY** (likelihood) of risk occurrence		
	LOW	**MEDIUM**	**HIGH**
HIGH	Medium	High	High
MEDIUM	Low	Medium	High
LOW	Low	Low	Medium

It is further noted that the ISO/AWI 21499[2] Security and Resilience group is working on the following (Gasiorowski-Denis 2016):

[The] community-based landslide early warning system will serve to empower individuals and communities who are vulnerable to landslides to act in sufficient time in appropriate ways to reduce the possibility of injuries, loss of life, and damage to property and the environment. It is designed to encourage communities to play a much more active role in their own protection.

The guidelines will be used by communities vulnerable to landslide, government agencies, and non-governmental organizations at central, provincial, municipality/district, sub-district, and village levels. Its recommendations will include the following:

- *Risk assessment*
- *Dissemination and communication*
- *Establishment of disaster preparedness and response team*
- *Development of evacuation route and map*
- *Development of standard operating procedures*
- *Monitoring, early warning, and evacuation drill*
- *Commitment of the local government and community on the operations and maintenance of the whole system.*

Such a standard aligns well with Part III (Systems Planning), Part V (Operations and Maintenance), and Part VI (Contingency Planning) of this handbook. The proposed ISO document is focused on the ways communities are exposed to landslides and covers a spectrum of soft and hard infrastructure responses, whereas this manual focuses on a broader range of geohazard risks but confined to road infrastructure only.

[2] ISO/AWI (approved work item) 21499, "Security and Resilience—Community-Based Landslide Early Warning System," is to be developed by the ISO/TC (ISO Technical Committee) 292 on Security and Resilience. For more information, see the ISO/TC 292 home page: http://www.isotc292online.org/.

1.7 INDICATORS OF NEED TO ENHANCE ROAD GEOHAZARD RISK MANAGEMENT

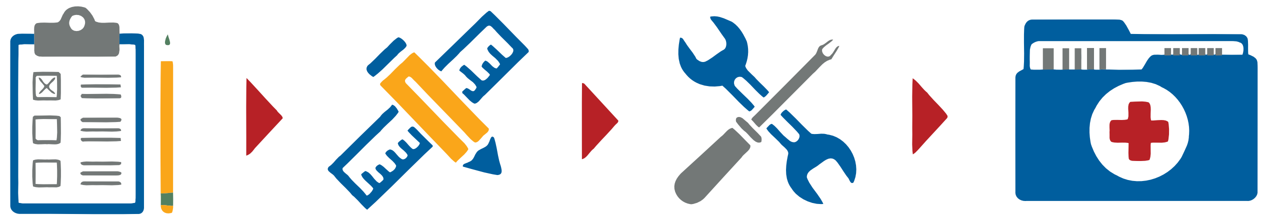
For most countries, there are significant opportunities to enhance the existing means of geohazard management, covering all stages of the life cycle, as outlined in Figure 1.1 and further expanded in Table 1.3.

Table 1.3: Opportunities for Enhancing Road Geohazard Risk Management, by Life-Cycle Stage

STAGE	INSTITUTIONAL ASPECT	TECHNICAL ASPECT
Systems Planning (institutional setup)	No or insufficient laws, regulations, or technical standards, including assignment of responsible organizations No or insufficient national or subnational government plans or strategies No or insufficient mechanisms, funding	No or insufficient expertise, or lack of essential data, for road geohazard risk management (such as historical weather data and disaster records) No or insufficient risk evaluation practices
Engineering and Design	No or insufficient mechanisms or funding for proper design and construction	No or inappropriate highway and risk management planning No or insufficient engineering investigation for design Lack of proper design and construction
Operations and Mainte-nance	No or insufficient mechanisms or funding for proper nonstructural measures or for operations and maintenance responses	No or insufficient mechanism and system (staff, machinery, equipment, asset management information system [AMIS], information gathering and communication systems, guidance manuals, training, coordination, and partnership system) for nonstructural measures Weak or nonexistent domestic road maintenance contracting industry
Contingency Programming	No or insufficient mechanisms or funding for proper postdisaster response and recovery	No or insufficient contingency planning for both technical and physical response to events, including intelligent transport systems (ITS) and related AMIS

2

INSTITUTIONAL CAPACITY AND COORDINATION



2.1 OVERVIEW

Without an appropriate institutional framework within which to implement the geohazard risk management tasks, there is little chance of a successful outcome. The institutional framework covers two primary aspects:

- The appropriate laws, regulations, and technical standards to enable (or, in some cases, require) geohazard management
- The appropriate capacity and capability of human resources to deliver an appropriate geohazard risk management program.

While the underlying laws, regulations, and technical standards may be largely similar from country to country regarding the need to manage the road network in a safe and efficient manner, the amount of human capital expended on geohazard management will reflect the relative risk exposure in each country (or part of a country). For instance, a road authority managing a road in a mountainous country with high rainfall will reasonably be more concerned about geohazards and hence invest more time and effort in their management than will a road authority operating in an area of dry plains. The guidance below should be considered appropriate for a country with a moderate to high exposure to road geohazards.

2.2 GEOHAZARD MANAGEMENT AS PART OF ASSET MANAGEMENT

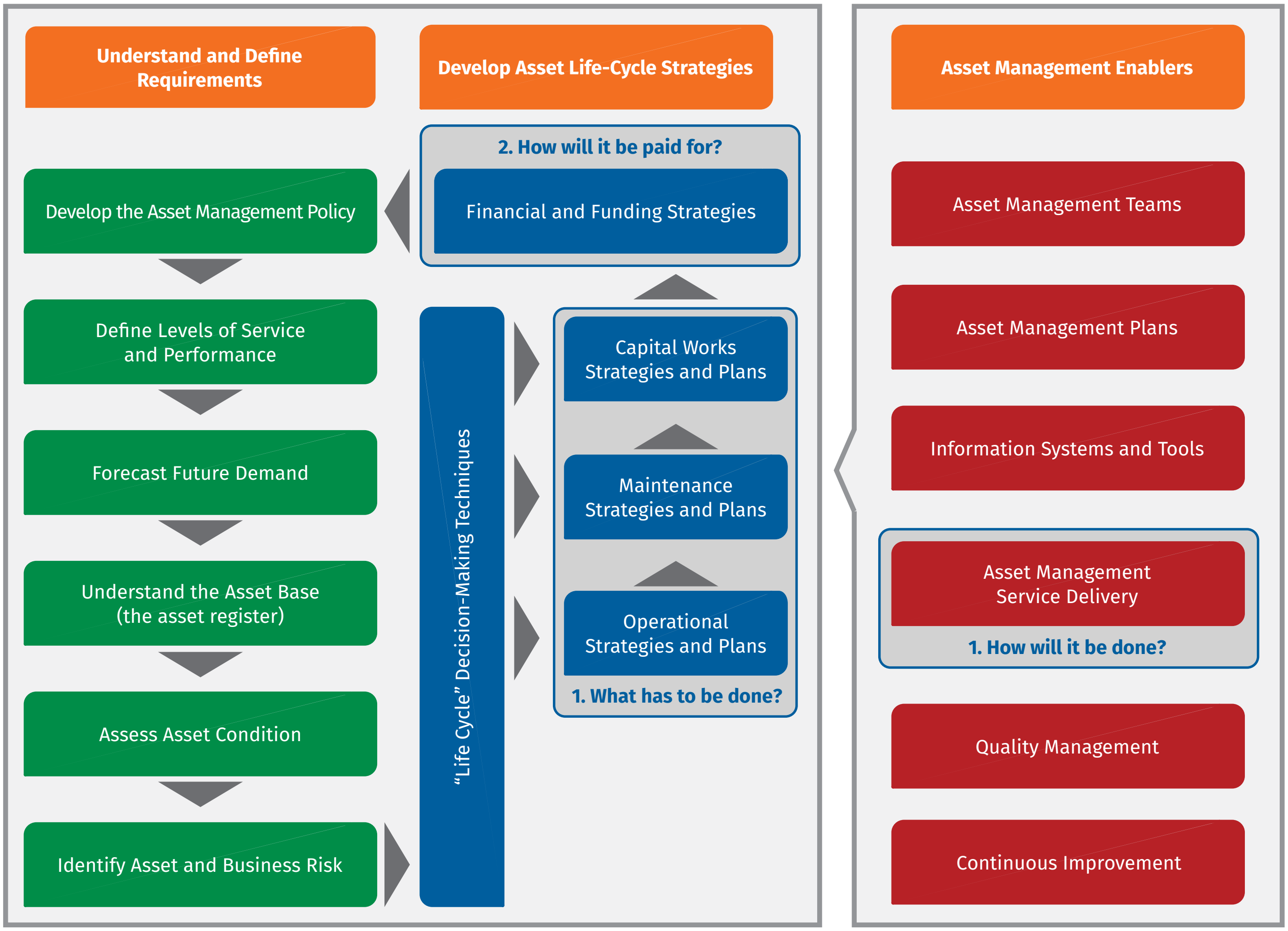
Although this handbook focuses specifically on geohazard management, it is necessary to also understand the larger, overarching asset management process that should be in place within any road authority. Asset management is the all-encompassing framework within which geohazard risk management occurs, as defined by the American Association of State Highway and Transportation Officials (AASHTO).

> *"Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives."*

Source: AASHTO Subcommittee on Asset Management, January 2006

A typical asset management process spans all aspects of a road authority's activities (Figure 2.1). Different road authorities will have variations on this process in place, but most competent asset management authorities will have the various steps in the process identified as part of their management processes (especially those that have ISO 55000 certification in place or intending to achieve it).[3]

Figure 2.1: Asset Management Process



Source: NAMS 2011. ©World Bank. Further permission required for reuse.

It is important that geohazard management activities fit within the road authority's overarching asset management framework. For instance, risk-rating methodologies should be consistent across all aspects of the road authority; the information systems used to manage geohazards should ideally be part of the organization-wide asset management information system (AMIS), and improvement plans for geohazard management should be prioritized and managed within the overall improvement plan processes.

The aim of this handbook is not to place geohazard management above asset management but rather to explain how the key aspects of geohazard risk management should occur—such that these can then be incorporated into the overarching asset management processes.

[3] See ISO 55500:2014, "Asset Management—Overview Principles and Terminology": https://www.iso.org/standard/55088.html.

2.3 INSTITUTIONAL ARRANGEMENTS

Part II of the handbook

- Defines an institutional framework for road geohazard risk management; and
- Explains a process for conducting an institutional capacity review and target-setting exercise based on this framework.

The reader is also advised to refer to the following reference document:

- Terms of Reference 1 (ToR 1): Institutional Capacity Review and Target Setting (in Appendix A) is a standard terms of reference (ToR) to determine the existing institutional capacity to implement road geohazard risk management, assess the gaps, and establish the step-up target to strengthen the capacity.

The achievements after using this Part II are

- To understand the institutional processes associated with road geohazard management; and
- To assess the current institutional capability for road geohazard management and to set a target institutional capability.

2.3.1 INSTITUTIONAL FRAMEWORK

An integrated and effective institutional setup may promote a systematic and efficient approach to road geohazard risk management. The institutional framework comprises (a) laws, regulations, and technical standards; (b) national and subnational government plans and strategies; and (c) mechanisms for implementation.

2.3.1.1 LAWS, REGULATIONS, AND TECHNICAL STANDARDS

Governments may or may not have laws, regulations, and technical standards that govern road geohazard risk management.[4] If they exist, the laws and regulations stipulate the responsibility and authority of the actors involved (such as road management authorities, traffic police, and rescue agencies) to ensure the implementation of road geohazard risk management. Moreover, the various laws and regulations related to roads and disasters ideally define disaster risk management, geohazard risk management, and road geohazard risk management consistently.

The main actor involved in road geohazard risk management is the road management authority[5]—the government office responsible for managing road transport assets, including planning, setting road standards, road design, road construction, operations, maintenance, road safety management, and traffic management. The road management authority develops the road management policies and strategies that dictate how (among other things) road geohazard management will occur within its jurisdiction. Other actors or stakeholders include the traffic police, emergency response units, road users, communities and roadside residents, public transport operators, logistics providers, business personnel, volunteers, insurance providers, and bus and taxi management organizations and associations.

The laws and regulations also define the road management authority's roles, its scope of liability for road geohazard risk management, and its power and authority to protect road users and road infrastructure from geohazard damage. The role of the road management authority regarding geohazards, as defined in this handbook, involves the administration of risk evaluations, risk management planning, the implementation of structural and nonstructural measures, and postdisaster response and recovery (that is, prevention and mitigation of secondary damage and recovery).

[4] This chapter draws on the experience noted in the case studies—in particular those of Japan and Serbia (see Appendix C)—combined with the authors' own experience.
[5] National and subnational road management authorities are mostly government entities, but sometimes they are public or private organizations established as road management foundations or companies with concession contracts with the government.

The national road management authority develops technical standards regarding road geohazard risk management, and sometimes the subnational governments modify them to meet the subnational conditions and restrictions. These technical standards support an appropriate process on road geohazard risk management. The development of technical standards requires a specific minimum level of technical capacity. Therefore, this handbook considers the development of technical standards to be an intermediate target.

Whether at a national or regional level, laws and regulations surrounding forestry, horticulture, soil conservation, farming, and related activities all have the potential to dramatically influence (for the better or worse) the risk of geohazards.

2.3.1.2 NATIONAL AND SUBNATIONAL PLANS AND STRATEGIES

The development of national and subnational plans and strategies is essential to promote proper road geohazard risk management, and therefore this handbook considers such development to be an essential target of the national and subnational governments. When national governments formulate development plans and strategies, the management plan for road geohazards must be incorporated as well. Conversely, plans and strategies focusing on road geohazard risk management should ideally be formulated and subsequently integrated into the overall national development plans and strategies. It is acceptable to incorporate or integrate the road geohazard risk management plans and strategies into the higher-level plans and strategies for disaster risk management, geohazard risk management, road management, or transport sector management.

The road geohazard risk management plans and strategies should include the following assessments: (a) the current state of road geohazards, (b) the details of prior failures, (c) risk evaluation results, and (d) mitigation targets for specific probability levels of potential damages. The government or road management authorities also formulate specific investment programs and projects to support geohazard risk management.

Some of the national and regional planning activities pertain to the evaluation of the criticality of roads. It may be that a relatively low-traffic-volume road is of high importance to society if that road serves the local water treatment plant or the like. Hospitals, emergency services, and evacuation facilities (schools or other public buildings) may well be located off the busiest roads and are equally critical. Many bridges around the world not only provide vehicle crossing on top of the bridge but also attach core utilities (water, power, gas, and so on) under the bridge. The planning tasks seek to establish what is often referred to as “lifeline routes” that are the highest priority for providing both a high degree of protection from hazards and a high level of resilience for their opening after a disaster.

2.3.1.3 MECHANISMS FOR IMPLEMENTATION

Because geohazard management is part of the road authority’s overall road network management activities, the organizational structure will not be determined solely by geohazard management risk requirements. There are good and bad examples (often within the same country) of geohazard risk management, and these different outcomes are often unrelated to any specific organizational structure or approach toward the outsourcing of professional and physical works. In other words, the organizational structure should be seen as neither a hindrance nor a beneficial factor in addressing geohazard risk management; rather, it is a factor to be worked into the management processes and practices.

The recommended practice is that geohazard risk management be fully integrated into every practice of the organization and that it does not result in a separate functional arrangement and duplication of staff roles. Geohazard risks are just one among the many types of risks to keeping a road network open and operational. Responses to road closures, for instance, should be largely consistent whether the closure is caused by a geohazard, a vehicle crash, or a structural failure of a bridge—they all require information to be communicated to road users and stakeholders, road closures to be put in place, and actions to be taken to secure and reopen the road as soon as practical.

That being said, for the purpose of this manual, three layers of an organization are referred to as follows:

- ***National office:*** Nationwide administration that is responsible for nationwide policy making, target setting, planning, and coordination of road management including road geohazard risk management
- ***Regional offices:*** Responsible for national or local government roads, with jurisdiction over a significant portion of the road network (typically a greater length than can be delivered through a single maintenance yard or maintenance contractor); implementation of the national policies; and achievement of the targets set
- ***Local offices:*** Responsible for national or local government roads, with jurisdiction over roads that form a maintenance yard or maintenance contractor responsibility. The local offices (potentially delivered by a consultant or contractor engaged by the regional office) manage and deploy patrols and maintenance staff, assess and monitor the geohazards within their road networks, and complete the physical works. The district office is important for timely postdisaster activities to ensure recovery, including reopening of damaged or closed roads. To achieve prompt recovery or reopening, it is important to ensure that preparedness measures for road geohazard events are in place, including arrangements for the availability of machinery and equipment, staff training, and a framework for standby contracts (indefinite delivery contracts).

In large countries and states such as Japan (see the Japan case study in Appendix C), these three levels (and possibly more) can be readily identified owing to different physical locations of the teams and clear role definitions. In smaller countries, the three levels may all be delivered from within one team, with staff sharing their time between the different roles—for example, developing policy one day, and applying it the next.

It is worth noting that, at the “local office” level, many countries fully outsource the physical works (and many of the management tasks) to the private sector. The management and response to geohazards are not restricted by the service delivery model in use (Table 2.1). For instance, a country may maintain a fleet of equipment for use in response to geohazards, or it may have contracts in place with the private sector that can be called upon if a geohazard occurs. What is important is to recognize that there are distinct levels, each with different roles ranging from governance, to strategy, and on to operational activities—and that these different levels must be working for a common purpose. To achieve efficient recovery and reopening, it is important to ensure that preparedness includes having preexisting arrangements to expeditiously access personnel, plant, and materials. Such arrangements may include ensuring that in-house staff (in particular, a nodal officer for coordination) are available and properly trained or ensuring that contractual arrangements are in place that can be activated quickly when geohazard events occur.

Table 2.1: Typical Allocation of Tasks for Road Geohazard Risk Management, by Level of Road Management Authority

NATIONAL TASKS	REGIONAL TASKS	LOCAL TASKS
Establishment of policy and protocols for resilience measures and geohazard responses National road management planning, including roads under local government management Budget planning and allocation Administration of postdisaster activities and reactive measures for roads in the event of widespread disasters Establishment (if not already done) of the parameters for dividing the country into logical local regions, and setup of local or regional road bureaus Establishment of the headquarters for disaster control administration for abnormal conditions and disaster events (including preparedness) for roads	Road management and budget planning Implementation of condition assessments, road inventory collection, and vulnerability assessments—as required to establish road information management systems Risk evaluation and management planning regarding road geohazards Design, cost estimation, and construction management for structural measures Operation of nonstructural measures for road geohazard disasters Establishment of the regional office for disaster control administration for abnormal conditions and disaster events (including preparedness) for roads	Management and deployment of patrol and maintenance resources for vulnerability assessment, monitoring, and emergency response Contribution to implementing or constructing measures that may prevent or mitigate the impacts of geohazard events Establishment of the task team with jurisdiction over road disaster control for abnormal conditions and disaster events (including preparedness)

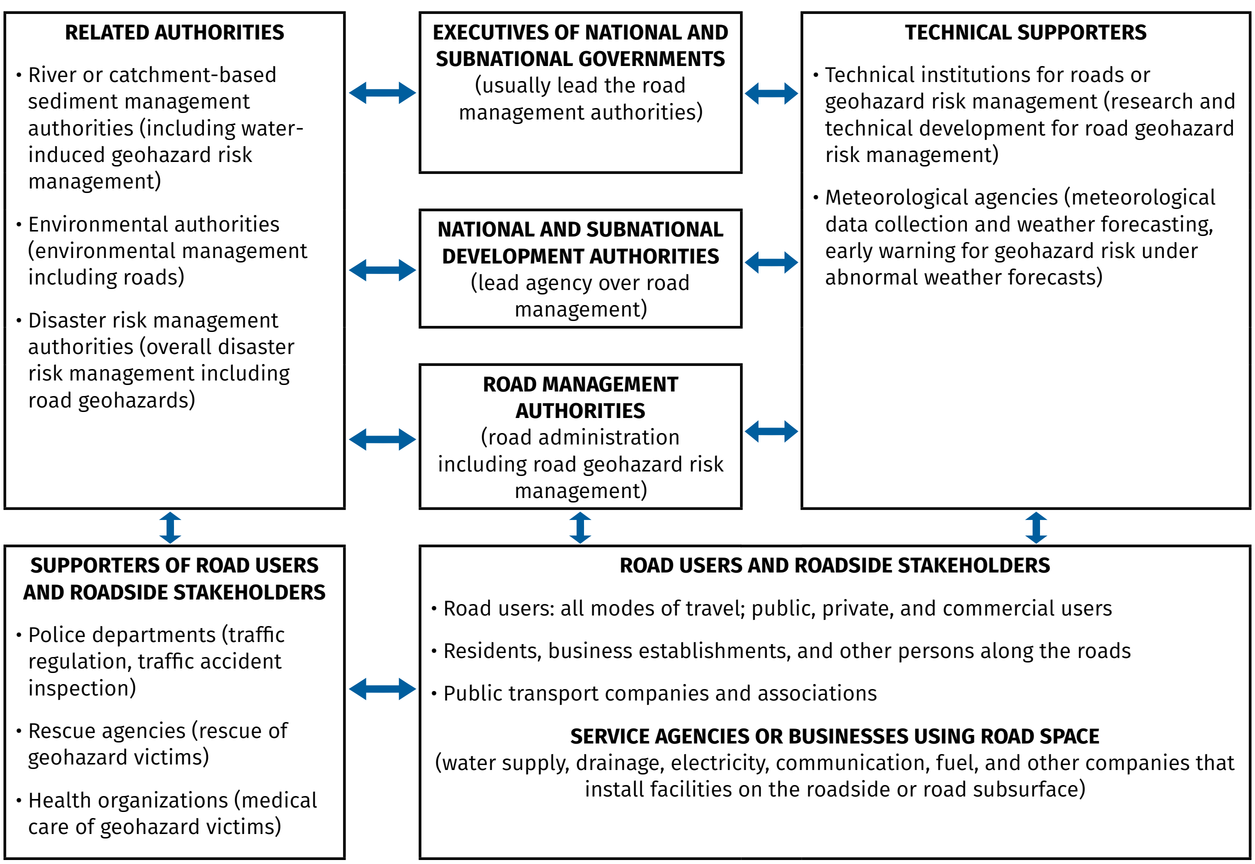
The national road management authorities formulate mechanisms for information communication and coordination with road users and the other public institutions (local government, community, meteorological agency, police, disaster prevention or rescue agency, school, and so on); private organizations (such as bus operators); and roadside business establishments. The agreements for road geohazard risk management should include a clear information communication chart. In turn, both national and local road authorities formulate the mechanisms for the efficient implementation of road geohazard risk management. These mechanisms are divided into institutional, technical coordination, and funding mechanisms.

The national road authority formulates the road geohazard risk management mechanisms at the national level, including the national and local coordination mechanisms. These mechanisms are sometimes expressed as operation guidelines for road geohazard risk management. The local government road management authority formulates the local road geohazard risk management mechanisms.

Institutional and technical coordination mechanisms require coordination between the road management authorities and several public and private organizations (Figure 2.2). These organizations may include the following (noting that different arrangements exist in different countries):

- Local road management authorities
- Disaster risk management authorities
- Technical institutions for roads or geohazard risk management
- Police, emergency services, and trauma care services
- Rescue agencies
- Meteorological agencies
- River (landscape ecosystem) management authorities
- Executives of national and local governments
- Environmental organizations
- Urban and rural development organizations
- Road users
- Residents, business establishments, and other persons along the roads
- Public transport companies, freight companies, and relevant associations
- Utility providers: water, power, telecommunications, and the like
- Consultants and contractors involved in the management and maintenance of the road network.

Figure 2.2: Structure of Institutions and Stakeholders in Coordination Mechanisms for Road Geohazard Risk Management



2.3.2 FUNDING MECHANISMS

National road management authorities usually define the funding mechanisms for the whole country. The national governments coordinate the budget allocation for road geohazard risk management based on the available national budget and international grants or loans. The funding arrangements need to cover the following four areas (although separate line items in the budget may not be explicitly specified and may be included within more-general budget allocations for emergency response, emergency road maintenance, capital works budget, and routine road maintenance):

- Funding for risk evaluations for road geohazards
- Funding for road geohazard risk management planning
- Funding for proactive measures
- Funding contingencies for postdisaster activities and reactive measures.

Of significance is that funds need to be available for the management and preventive activities of geohazard management, not just for the remedial postdisaster and reactive measures.

The coordination agreements (which define the purpose of road geohazard risk management activities and roles of each organization) are recorded as memorandums of understanding or similar other documents. A council, committee, or similar organization sometimes manages the coordination mechanism. The main institutions and stakeholders involved are shown in Figure 2.2. All the major institutions will typically have both national and local structures, and these should be duly accounted for.

When a geohazard event does occur that requires funding beyond that of the road authority's day-to-day activities, contingency funds will need to be accessed. Common approaches to contingency funding include

- ***Contingent projects:*** Having some capital projects that are not commenced until near the end of the financial year and that can be deferred should a major event occur;
- ***Disaster recovery fund:*** A central (or regional) fund, increased continuously, that can then be drawn down in the event of a disaster;
- ***Insurance:*** Used as applicable for significant structures such as bridges and tunnels; and
- ***Budget reallocation:*** Moving money from other budget items (potentially from outside the road sector) to cover the necessary repairs.

The case studies (Appendix C) provide examples of the funding models used in Brazil, Japan, and Serbia to address geohazard risks.

2.3.3 HUMAN CAPACITY: EXPERTISE REQUIRED FOR ROAD GEOHAZARD RISK MANAGEMENT

The expertise required for road geohazard risk management, the logic behind these requirements, and the necessary activities from each expert field are as follows:

- ***Rural and urban planning and traffic engineering experts*** evaluate geohazard risk, especially the estimation of the damage due to traffic interruption and the evaluation of road geohazard impacts on the local and social economy.
- ***Economic modelers and disaster risk management experts*** conduct risk evaluations and cost-benefit analyses for the existing or planned alignment and the investment in required measures as well as damage estimates for postdisaster activities.

- ***Information and communication technology experts*** set up emergency road information systems for collecting and providing geohazard information to road users and other stakeholders.
- ***Engineering geotechnical experts*** identify and evaluate hazard-prone road locations, evaluate the geohazard mechanisms, and suggest and provide proactive measures as well as other design conditions for the ground or soil.
- ***Hydrological specialists*** identify both current and future weather events and ensure that engineered structures have the appropriate capacity.
- ***Civil engineers*** plan and design proactive measures and recovery.
- ***Social and environmental assessment experts*** assess the social and environmental aspects of the required or suggested measures for the geohazard, study the social and environmental considerations, and monitor the actual impact.

The need for these areas of expertise in full-time roles within a road authority will largely depend on the country's geohazard risk exposure. Where road networks have significant exposure to geohazards, then having geotechnical experts on staff or prearranging accessibility to them from the private sector may be prudent. Road networks with much less exposure may just engage consultants as required (although a basic level of skill will need to be retained in-house to enable procurement of the specialists and understanding of their outputs). The main point is that road geohazard risk management requires a multidisciplinary approach if it is to deliver the maximum benefit to road users and the community at large.

2.3.4 EFFECTIVE IMPLEMENTATION

Effective road geohazard risk management relies on the institutional capacity to execute each of the following activities:

- Disaster risk management
- Geohazard identification and evaluation
- Design and construction of structural measures and ongoing maintenance
- Implementation and operation of nonstructural measures
- Postdisaster activities immediately after (or during) the geohazard event
- Recovery tasks to return the facilities to full function.

Geohazard management will often require the formulation of new technical standards for road geohazard risk management—covering everything from engineering design to the economic evaluation of risk-based costs.[6] If human resource development is needed, for example, the design and implementation of technical assistance projects or human resource management programs are considered. Also, equipment, software for geohazard investigation, and analysis are required for the training for and implementation of proactive measures and recovery. During the initial stage, training experts, equipment, and software are considered to support international technical assistant programs. An adequate information and communication technology (ICT) infrastructure is also a requirement for nonstructural measures enabling early anomaly detection; for road condition emergency information systems (including an early warning or precautionary road closure); and for prompt implementation of postdisaster response and recovery for road geohazards.

[6] The inclusion of operations and maintenance costs in life-cycle cost evaluations is standard practice in many countries, but the means of addressing low-frequency (and often unpredictable) yet high-cost scenarios into economic evaluations is less commonly practiced.

Underpinning all aspects of the activities listed above is the central role that asset management information systems (AMIS) play in (a) the management of geohazard risks, including holding historical data on hazards and investments made to mitigate them; (b) the performance of maintenance to minimize risks and ensure that structural measures perform as designed; and (c) the development and management of emergency response plans and information distribution to response teams and the general public. AMIS and ICT infrastructure is a common requirement not only for road geohazard risk management but also for overall road infrastructure asset management and traffic management. If the ICT infrastructure is insufficient, technical assistance from international donors to improve policies and procedures is an excellent target to help in the evolution of a more sophisticated road management system, including nonstructural measures for road geohazard risk management.

The following systems are vital for effective AMIS: geographic information systems (GIS) incorporating mapping of geohazard locations along with inventory data and mapping of vulnerable infrastructure or services; closed-circuit television (CCTV) at critical nodes; two-way communication systems (radio, mobile, data, and systems); public communication systems (VMS, intelligent transport system [ITS] gantry messages, mobile phone messages, websites, and media announcements); and links to existing ITS infrastructure (for example, through tolling, weigh-in-motion infrastructure, or traffic management centers that can be used to ensure the public is notified of events). The systems can also be used for maintenance decision making, prioritizing structural interventions, maintenance scheduling, and monitoring of expenditures (useful when justifying structural interventions on a life-cycle-cost basis). Further discussion on ICT is covered under Part III (Systems Planning), Part V (Operations and Maintenance), and Part VI (Contingency Programming).

2.4

2.4 INSTITUTIONAL CAPACITY REVIEW

2.4.1 OBJECTIVE OF THE REVIEW

The objective of the institutional capacity review is to measure how the road authority addresses geohazard risk and risk mitigation at the national and subnational levels, considering the following aspects:

- Existence and level of maturity of the legal framework, institutions, and plans or strategies
- Review of institutional capacity and capability in relation to human resource needs and supporting the AMIS and ICT infrastructure
- Implementation level of plans or strategies
- Situation and effectiveness of implemented projects on road geohazard risk management, projects under implementation, and planned projects.

Results of an institutional capacity review reach official consensus on weaknesses, targets for institutional strengthening, and definition of investment priorities and their financing strategy.

2.4.2 PROCEDURE

The country capacity review may be conducted based on ToR 1: Institutional Capacity Review and Target Setting and its checklists, included in Appendix A of this handbook. The general procedure for the review is as follows, requiring access to supporting evidence and interviews to complete the assessment:

1. Understanding and confirmation of review items
2. Collection of necessary data for the review

3. Review of the country capacity using checklists
4. Sharing of review results between the people concerned
5. Discussion, evaluation, and finalization of the country capacity review
6. Definition of challenges for the country.

2.4.3 SCOPE OF THE INSTITUTIONAL CAPACITY REVIEW

The scope of the institutional capacity review is classified into three main categories (Table 2.2):

- ***Review of the institutional framework:*** To review the laws and regulations, plans and strategies, standards and manuals, institutional-technical coordination, and financial mechanism for road geohazard risk management
- ***Review of practice on road geohazard risk management:*** To review the activity for road geohazard risk management by road management authorities or relevant organizations
- ***Review of organizational capacity:*** To review the authority's capacity for road geohazard risk management in terms of human skills, equipment, and related aspects that are required to be in place to deliver on the relevant laws, regulations, and guidelines.

Specific items are shown in the checklists of ToR 1: Institutional Capacity Review and Target Setting (see Appendix A).

2.4.4 TARGET SETTING

This handbook proposes three step-up targets on road geohazard management:

- ***Essential targets*** are the initial requirements for instituting road geohazard risk management and setting up of road geohazard management. They focus on the existence of fundamental laws, regulations, and high-level plans to support institutions to carry out this function. Definition of responsibilities in laws and regulations, along with establishing proactive measures for ad hoc recovery, are important to achieve at this initial target stage.
- ***Intermediate targets*** are the next level of requirements to operationalize road geohazard risk management. They generate more detailed and upgraded inputs required to make specific risk management investments.
- ***Advanced targets*** enhance road geohazard risk management through more rigorous review, elaboration, and enhancement using advanced technologies.

These steps conform to the requirement, and the difficulty level also increases as the steps advance. Each government reviews its institutional capacity and budget constraints and sets a target step as a first step. The items and activities of each target step shown in this section are intended as an outline and are subject to be modified and detailed by each government to meet its situation as shown in Table 2.3 and below.

2.4.5 IMPROVEMENT PLAN

Having completed the capacity review, an improvement plan can be implemented that sets time-based initiatives to close the gap between current and desired levels of capability. The target (essential, intermediate, or advanced) along with the time to achieve the target will naturally vary from road authority to road authority, based on the level of geohazard exposure and other competing demands for funding.

Table 2.2: Institutional Framework for Road Geohazard Risk Management with Stepwise Approach

FRAMEWORK	CATEGORY	RECOMMENDED PRACTICES
INSTITUTIONAL FRAMEWORK	Laws and regulations	Laws for disaster risk management, geohazard risk management, and road geohazard risk management exist and are consistent and comprehensive. The responsibilities of government authorities and the regulations regarding disaster risk and hazard management—including the penalties for illegal geohazard-inducing activities (such as burning agriculture, irrigation watering on roadside slopes, litter on road drainage, dumping or throwing away of soils, and excavation or filling without authority approval)—are defined.
	National and subnational high-level plans or strategies	National and subnational government development plans and strategies include disaster risk management, geohazard risk management, and road geohazard risk management. Such plans and strategies exist at all government levels.
	Technical standards, guide-lines, and manuals	Elaborated technical standards include disaster risk management, road geohazard risk management, risk assessment, structural measures for road geohazard risk management, and road operations and maintenance for road geohazard risk management (nonstructural measures).
	Institutional and technical coordination mechanisms	Institutional and technological coordination mechanisms include consultation from meteorological and hydrological organizations; coordination between national and subnational governments; and participation of road users, residents, and private sectors.
	Funding mechanisms	Funding mechanisms include budgets for risk assessment, planning on road geohazard risk management, proactive measures, and contingencies for postdisaster response and recovery.
ROAD GEOHAZARD RISK MANAGEMENT PRACTICE	Risk evaluation	Road geohazard risk management activities are conducted and deliver outputs of sufficient quality to drive the geohazard risk management process as outlined within this guideline.
	Geohazard risk management planning of roads	
	Structural and nonstructural measures for road geohazards	
	Postdisaster response and recovery	
ORGANIZATIONAL CAPACITY	Human resources	The necessary human resources (both capability and capacity) are in place to deliver on all required aspects of geohazard risk management, including road authority staff, wider government staff, and relevant private sector participants.
	Equipment	Is the equipment available in the right quantity and in the right locations to address geohazards? Considering that, in many cases, geohazard events may occur at multiple locations across the network at the same time, equipment needs to be appropriately dispersed to enable an efficient response.
	Facilities	Are the facilities of an appropriate size and in appropriate locations to enable responses? Do they have the necessary emergency power and communication systems to be of use in emergencies?

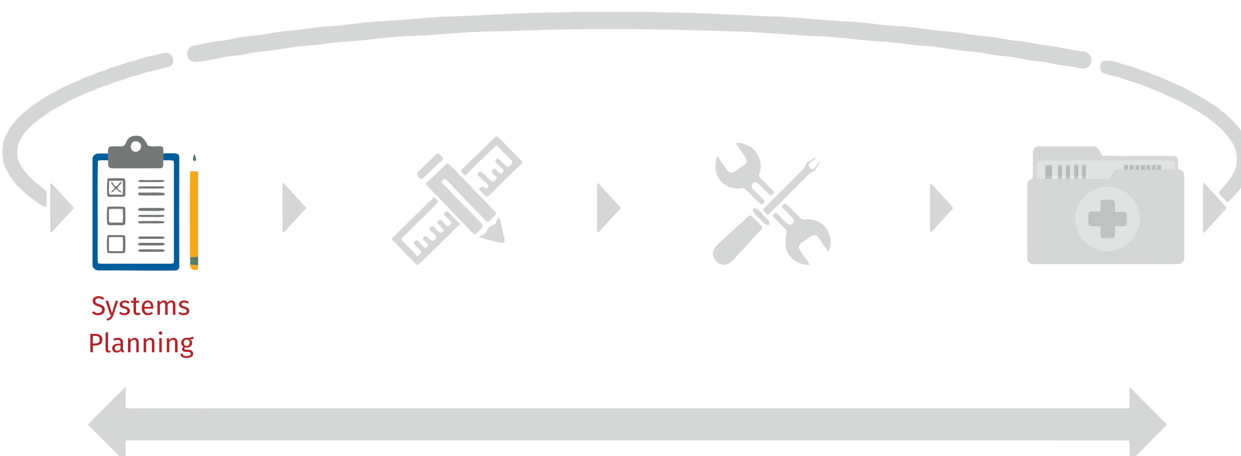
Table 2.3: Step-Up Targets for Strengthening Road Geohazard Risk Management

GEOHAZARD LIFE-CYCLE PHASE	ASPECT OF ROAD GEOHAZARD RISK MANAGEMENT	STEP-UP TARGET		
		ESSENTIAL	INTERMEDIATE	ADVANCED
Institutional Setup	Laws, regulations, and technical standards	Formulation of key laws and regulations pertaining to responsibilities for road geohazard management and response (note that these are likely to be part of larger civil defense-type laws and regulations and not specific to geohazards)	Review and updating of laws and regulations Formulation of technical standards and guidelines	Further review and updating of laws and regulations, including the contribution of the road function subnational geohazard management (for example, extreme-emergency management laws)
	National or subnational plans and strategies	Formulation of national or subnational plans	Review and updating of plans or strategies Formulation of detailed plans or strategies (for example, comprehensive investment schemes)	Further review and updating of plans or strategies (for example, business continuity plan for road operations)
	Mechanisms for implementation	Formulation of fundamental mechanisms of funding and of institutional and technical coordination	Review and upgrading of mechanisms (for example, formulation of operational procedure of subsidy or coordination committee)	Further review and upgrading of mechanisms (for example, standby contracts for emergencies)
	Risk evaluation	Starting with basic method of risk evaluation (such as simple risk qualitative evaluation, using multiple criteria)	Review and upgrading to intermediate method of risk evaluation (for example, risk-level rating)	Further review and upgrading to advanced method of risk evaluation (for example, economic risk evaluation as potential annual loss)
	Risk management planning	Setting up of the framework and starting	Review and upgrading of the framework and practices	Further review and upgrading of the framework and practices (for example, road risk management, which contributes to local geohazard risk management)
Engineering and Design	Structural measures	Construction of fundamental structural measures (for example, earthworks, surface drainage, and vegetation and bioengineering)	Construction of common structural measures (for example, standard retaining walls)	Adaptation of advanced structural measures for higher-magnitude geohazards (for example, high-energy rockfall protection)
Operations and Maintenance	Nonstructural measures	Establishment of fundamental measures (for example, routine patrol and monitoring, and an abnormality information system)	Enhancement of nonstructural measures (for example, precautional road closure arrangements)	Further enhancement (for example, a road geohazard early warning system using advanced ICT)
Contingency Programming	Postdisaster response and recovery	Preparation and fundamental practice for postdisaster response, including preidentification of responsibilities and budgets to address geohazard events	Enhancement of postdisaster response, including formalized plans to address specific geohazard events, such as communication of road closures	Further enhancement of postdisaster response and recovery (for example, formation and training of special task force for wide-area severe geohazard event)

Note: ICT = information and communication technology.

3

SYSTEMS PLANNING


Systems
Planning

3.1 WHAT IS SYSTEMS PLANNING?

The systems planning stage of the life cycle covers those activities that are often referred to as the institutional arrangements that are necessary to support the overall geohazard risk management process. This handbook addresses three main aspects of systems planning:

- Risk identification and assessment
- Risk evaluation
- Risk management planning.

For more detailed information on risk management practices, see ISO 31000.[7]

The achievements after using Part III are

- To understand road geohazard risk identification, assessment, and evaluation; and
- To understand the practice of disaster awareness.

Reference documents for Part III of the handbook include the following:

- Terms of Reference 2 (ToR 2), Risk Evaluation and Risk Management Planning (in Appendix A) is a standard ToR to either evaluate geohazard risks on an existing road alignment (or whole road network) or to identify geohazards on a potential new-road alignment. It includes a ToR template for consultancy service for risk evaluation and risk management planning of road geohazards.
- Terms of Reference 3 (ToR 3), Development of Manual for Promotion of Road Disaster Awareness and Partnership (in Appendix A)
- Operations Manual 1 (OM 1), Economic Risk Estimation and Cost-Benefit Analysis (in Appendix B) presents the procedures of risk estimation as a potential annual economic loss and provides model spreadsheets for analysis.
- Case Study of Japan's Road Geohazard Risk Management (in Appendix C) presents in detail the risk evaluation procedure in Japan.

3.2 ROAD CRITICALITY

As is covered later (Section 3.6.3.1, under "DMDU Methodology"), it is critical to all aspects of road geohazard risk management to understand the fundamental importance (or criticality) of a road link within the overall road network. Regardless of the funds available to investigate, monitor, or repair (proactive or reactive) geohazards, it makes sense that the focus should be on the most critical road links first. Criticality in this context extends beyond geohazard risk management because a single criticality should apply to a road—regardless of the different risks that would affect that road.

Road criticality should be based on national or regional standards and may include items such as high-priority designation being given to routes that are key to trade; access to social and political services; emergency evacuation and access routes, and so on. Without this, any response (be it predisaster or postdisaster) runs the risk of being uninformed and not focused on the identified priority access needs. It is important to note that the criticality of a road may have little to do with the road from a transport perspective and more to do with the other services that the road serves. For example, a low-trafficked road may lead to a city's water treatment plant, making it a high priority to be protected from risks. Similarly, there may be minor roads that have key gas, power, telecommunication, or similar utilities buried within the embankment.

[7] See ISO 31000:2018, "Risk Management—Guidelines": https://www.iso.org/standard/65694.html.

The determination of a road criticality is therefore best done by a cross-government working group, which can examine a road from all points of view and assign a criticality index. Such a working group is the New Zealand Lifelines Council (NZLC) (box 3.1).

Box 3.1 Purpose and Functions of the New Zealand Lifelines Council (NZLC)

The NZLC was established in 1999 and focuses on "enhancing the connectivity of lifeline utility organizations across agency and sector boundaries in order to improve infrastructure resilience."

The NZLC specifies three needs for framing its work on infrastructure resilience:

- Robust assets or satisfactory alternative service continuity arrangements
- Effective coordination, pre- and post-event, at the national and local levels
- Realistic end-user expectations, so that users are risk-aware and better able to consider options.

The principal functions of the NZLC are as follows:

- Advising Lifelines Groups on best practices across a range of activities, including encouraging new projects and supporting them by offering information on methodology and other learnings from projects in other regions
- Providing a link between Lifelines activities and the government, including relevant government programs such as Lifelines work within the Ministry of Civil Defense & Emergency Management (MCDEM) and national infrastructure planning within Treasury
- Promoting and promulgating resilience-related research
- Organizing the annual National Lifelines Forum, which updates representatives from Lifelines Groups and national utilities on the latest developments and provides an opportunity to develop positions on common resilience-related issues.

The NZLC includes the following:

- Spark NZ Ltd. (communications company)
- Transpower New Zealand Ltd. (national power grid manager)
- New Zealand Transport Agency (state highway road authority and 50 percent funder of local road authorities)
- Vector Limited (power and gas distributor)
- First Gas Limited (gas transmission and distribution)
- Water New Zealand
- Ministry of Civil Defense & Emergency Management (MCDEM)
- Ministry of Business Innovation and Employment
- Earthquake Commission
- GNS Science (an earth, geoscience, and isotope research entity).

Source: "Overview of the New Zealand Lifelines Council (NZLC)," Lifeline Utilities, Ministry of Civil Defense & Emergency Management, New Zealand Government: https://www.civildefence.govt.nz/cdem-sector/lifeline-utilities/new-zealand-lifelines-council/.

3.3 INTEGRATED INFORMATION DATABASE

One aspect of geohazard management that needs to be considered is how to integrate all the many data sets to enable the analysis to occur. For instance, it may be that hydrological information is collected and held in one government department, land use in another, road information in another, and key social service information (on hospitals, schools, and so on) in their own government department records. Furthermore, there may be central government, regional government, and local (municipal) government levels involved in each of these different areas—meaning that integrating information to enable more efficient and effective management of geohazards to occur is a key enabler of geohazard risk management.

3.4 RISK IDENTIFICATION AND ASSESSMENT

Risk identification and assessment is the first stage in the risk management process and consists of two steps:

- Step 1: Identifying hazards
- Step 2: Identifying the likely consequences should the hazard occur.

These two steps will then enable the selection of those geohazards that warrant a more detailed evaluation process (as further discussed below) and associated mitigation measures (see Part IV).

3.5 RISK EVALUATION

3.5.1 RISK EVALUATION RESPONSIBILITIES

In general, road management authorities are responsible for evaluating related risks to their road systems. Therefore, these authorities are normally the lead agencies for (a) developing technical manuals or guidelines for risk evaluation, and (b) setting rules and time frames for conducting on-demand or periodic risk evaluation inspections on existing roads. The risk evaluation inspections are normally conducted by staff, experts, or engineers contracted by the road management authorities.

3.5.2 INFORMATION RESOURCES FOR RISK EVALUATION

Bureaus, agency, or institutes of international, national, and subnational levels are information resources of risk evaluations. The main information sources for geohazard risk evaluations are geohazard management (or Sabo, sediment control); river management; geology; disaster risk management; and universities and colleges; and other resources such as the following:

- OpenDRI: Open Data for Resilience Initiative, http://opendri.org/
- Open Data for Resilience Initiative Field Guide, https://www.gfdrr.org/sites/gfdrr/files/publication/opendri_fg_web_20140629b_0.pdf
- ThinkHazard! http://thinkhazard.org/.

International online resources are shown under "Web Resources" in Part VII of this handbook.

3.5.3 HOW TO UNDERTAKE GEOHAZARD RISK EVALUATION

Although the geographic scope of any geohazard risk evaluation will inherently be different between studies on existing roads and those on potential new-road alignments, the underlying methods are the same. For existing roads, the approach may be constrained to a single site, a single road, or expanded to the entire network of roads. For new-road alignments, the approach needs to ensure full coverage of all potential road alignments.

For existing roads, the outcome of the geohazard risk evaluation is to develop a prioritized list of sites for subsequent mitigation. For new-road alignments, the risk evaluation process should ensure that there is a basis for proper planning to avoid cost overruns, construction delays, and costly operation and maintenance outcomes. It can also help to manage the local negative social and environmental impacts of new roads and to plan the new road functions in coordination with local geohazard mitigation objectives.

The risk evaluation of geohazards involves mainly detailed hazard mapping, preferably using geographic information system (GIS) tools. The workflow for risk evaluation of geohazards consists of five steps, as further clarified in the following sections:

1. Definition of the study's geographic scope
2. Identification and mapping of geohazards
3. Preliminary assessment of geohazards
4. Detailed assessment of geohazards
5. Evaluation of the wider impacts of geohazards.

In principle, new-road planning aims to ensure that the true long-term costs of the different alignments are appropriately assessed, which typically results in avoidance of high-risk hazardous locations. By contrast, for existing roads, the intent of risk evaluation and planning is to ensure that funds to mitigate risks are appropriately prioritized and that contingency plans can be put in place should the risk arise.

3.5.4 STEP 1: DEFINITION OF THE STUDY'S GEOGRAPHIC SCOPE

Although it may appear obvious, it is important that the scope of the study extend sufficiently beyond the road corridor (existing or proposed) to ensure full coverage of any large-scale geohazards. The extent of this may be from a few tens of meters in areas of relatively flat terrain to kilometers where the road is located in a steep mountain valley and risks may be located well off the road alignment.

Following the definition of the road corridor (existing or new) that is the focus of the study, a quick scan of the area by an appropriately qualified geotechnical engineer will enable the selection of an appropriate study area. At this stage, it is important to remember that the focus is on the risks that the defined road corridor is exposed to—and not on all the risks that may exist within the study area. Significant risks may remain in the study area, but if they do not have an impact on the road corridor under investigation, then they will not necessarily be reported or managed (but ideally they would be passed along to the appropriate agency).

3.5.5 STEP 2: IDENTIFICATION AND MAPPING OF GEOHAZARDS

Geohazard identification typically involves a combination of field-based observations and desktop analyses. For geohazards that have a high frequency of occurrence (less than 10 years between events), there is likely to be significant institutional knowledge on the presence (and potentially the magnitude) of geohazard risk sites. However, for geohazards that may fail much less frequently, it is quite possible that there is no awareness that the hazard exists—let alone the potential magnitude of any failure event.

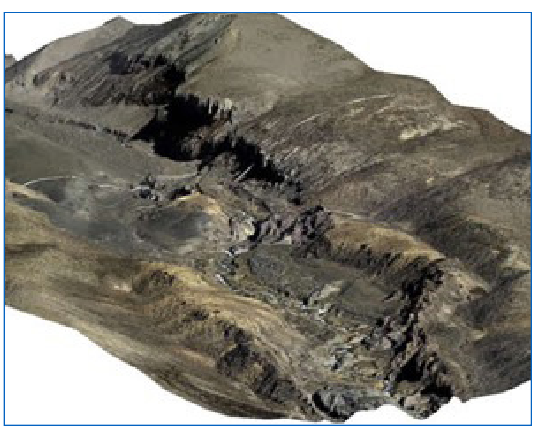
It is recommended that all identified geohazards be coded into the road authorities' GIS system, such that the resulting information can be readily integrated with other map layer data (terrain, rainfall, road alignments, population data, and so on). Basic information such as location, notional size, type of geohazard, and the like should be collected to enable prioritization of resources for subsequent, more-detailed studies.

The first initiative should be to capture the location of all known geohazards. Interviews of experienced road authority staff, consultants, contractors, and adjacent landowners are good sources of base information for such data. A search of newspaper records and similar sources may also provide information on both the occurrence and magnitude of previous events, potentially providing an estimate as to the frequency of failure. By default, these known hazards tend to be very localized in scale—with dimensions typically in the sub-100-meter range—and they can often be managed through routine maintenance of either removal of the material deposited onto the shoulder of the road (regular material being deposited on the road traffic lanes would warrant further investigation because the safety impacts are much higher), through top-up of small slump sites, and so on. Although localized, these hazards still have the ability to cause significant disruption to traffic and pose safety risks to road users and those tasked with removing the materials.

Upon completion of the initial capture of known geohazards, the next stage will necessitate the use of technical specialists (see Part II, Section 2.3.3 on "Human Capacity") to examine a range of data sources to identify and classify unknown geohazards. In this context, geohazards can be man-made, such as cut slopes that are too steep to meet the required factor of safety. It is also necessary to consider how climate change (in particular, any trend of increasing intensity of rainfall) may result in previously low-risk geohazards becoming higher-risk over time. These geohazards tend to also be much larger in scale than those that are observed to fail on a regular basis—with dimensions greater than 100 meters not uncommon. Furthermore, if they did fail, the result is often beyond the routine maintenance contract to address and may result in road (or lane) closures for a moderate period of time (in days or weeks, rather than hours).

Aerial photography is particularly useful for identifying geohazards, especially where a time-series of photographs is available covering many years (or decades). In more recent times, the use of Light Detection and Ranging (LiDAR) data in conjunction with aerial photography is providing even further information for the specialists to examine in identifying geohazards such as faults (either currently active or dormant); landslides; changes in river patterns; and coastal erosion (Photo 3.1). Much of this data is made more valuable through having a time series of it, such that a regular program (say, every five years) of aerial photography should be considered as part of the data collection process of the road authority.

Photo 3.1: Example of Combining Aerial Photography with LiDAR Data



The photograph shows the path of the 2007 lahar down Whangaehu River valley at the Round the Mountain Track (Tongariro National Park), North Island, New Zealand. It is an example of a digitally enhanced map from a LiDAR survey draped with a vertical orthophoto (an aerial photo with distortion removed and related to specific points on the ground).

Source: QP 2013. ©Quality Planning (QP). Reproduced, with permission, from QP; further permission required for reuse.
Note: LiDAR = Light Detection and Ranging. A lahar is a violent, highly destructive type of mudflow or debris flow from a volcano, typically along a river valley.

The required detailed hazard map (preferably in GIS) for the planning of new roads is provided on a small scale (1:10,000 to 1: 50,000); it displays all old and susceptible hazard areas in the study area.

The purpose of detailed hazard mapping is to show what types of geohazards are present throughout the study area. The mapping is conducted by experts in geotechnical engineering, hydrology, or hydraulic engineering—depending upon the nature of hazards in the study area. A detailed hazard map shows all types of hazard-prone locations, including historical event information as well as potential geohazards. The mapping is mostly formulated by interpretation of contour maps, aerial photographs, and satellite images, augmented by available information of historical geohazard events. Field reconnaissance and field interviews (data collection of historical geohazard events and current abnormalities due to geohazards) are conducted collaterally.

Hazard-prone road locations are identified to initialize the geohazard risk management planning process. This process is conducted based on the perceived level of geohazard risk, using the methods outlined in the remainder of Part III and summarized in Table 3.1. Using higher-level identification methods may identify additional potentially hazard-prone locations. However, these higher-level methods may not be practical for budget-deficient countries. Therefore, for these countries, the basic method is recommended other than for selected highly critical road sections. Detailed hazard mapping (advanced method) may be used by countries that can afford such an investment or be limited to areas where the basic method identifies issues that warrant further investigation.

Table 3.1: Methods for Identification of Geohazard-Prone Road Locations, by Risk Level

Budget capacity	**Perceived geohazard risk**	
	Low	Medium to High
Low	Basic method	
Medium to High	Intermediate method	Advanced method

The identification of hazard-prone road locations becomes more accurate but also costlier as one moves from basic to advanced risk identification methods. The following text describes each method level in further detail.

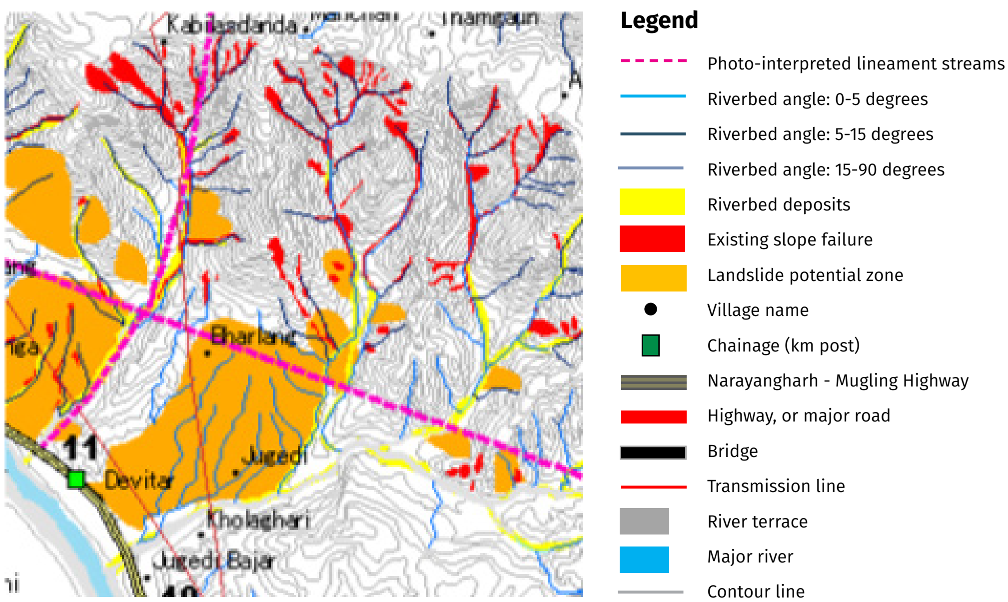
Basic method: On-site visual inspections and information from road users. The road maintenance staff identifies any abnormality or deformation of the road by using their maintenance experience, on-site visual inspections, and information provided by road users.

Intermediate method: Identification survey. Geotechnical engineering experts conduct an identification survey of hazard-prone road locations by collecting data of historical geohazard damage events, screening hazard-prone road locations via on-site observations, and filling out inventory sheets for each hazard-prone road location. Inventory sheets include (a) location type (such as mountainside slide slope, valley-side slope, or site with crossing river or stream); (b) simple observation results such as landscape, ground surface condition, abnormalities or deformations, and existing structural measures; and (c) sketches and photographs. Because hazard-prone road subsections are usually 1–10 kilometers long and road locations are less than 1 kilometer long, the inventory sheets also include a space to describe the road section's strategic importance within the hazard-prone road location. (Strategic importance may include, for example, its designation as an evacuation and emergency transport route for serious disasters, its importance as a logistic corridor from a main port to metropolitan areas, or its vital importance to populated areas without alternative detour roads.)

Advanced method: Detailed hazard mapping. Engineering geology experts conduct the detailed hazard mapping along with the intermediate method (geohazard identification survey). The detailed hazard map to identify hazard-prone locations is prepared through the analysis of contour maps, and interpretation is conducted using either aerial photographs or satellite images. LiDAR data (from planes, drones, or other techniques) is becoming increasingly affordable at either a project or network level and can provide a highly detailed data set that can be used to identify land changes in and around the road network over a period of time. In the sample, a detailed hazard map for an existing road (Map 3.1), the mapping data contribute to the accuracy of the risk evaluation.

Map 3.1: Sample Detailed Hazard Map for an Existing Road in Nepal

a. Sample map indicating relevant geological features



b. Satellite image used to construct sample map

Source: JICA 2009. ©Japan International Cooperation Agency (JICA). Reproduced with permission from JICA; further permission required for reuse.

Note: For this map—prepared for a disaster risk management study of the Narayangharh-Mugling Highway in Nepal (JICA 2009)—an engineering geologist group identified unstable slopes and slides where supply sources of debris flows are deposited. The mapping was done by field reconnaissance and interpreting satellite images from the riverside to the mountainside landscape ecosystems (including the road).

3.5.6 STEP 3: PRELIMINARY ASSESSMENT OF GEOHAZARDS

Before a detailed evaluation, an initial assessment should be undertaken to identify where the limited investigatory and mitigation resources should best be placed.

For the initial assessment, rather than undertaking a quantitative evaluation of both the likelihood and consequence of a risk event occurring, a simpler qualitative evaluation may be used. If a road authority guideline defines likelihood and consequence, then this should be used as the basis for the geohazard ratings also. If no guidance document exists, the definitions below may be used based on the documented case studies and author experience.

Likelihood may be defined in terms of occurrence probability (also called the "return period"), as follows:

- ***Low:*** more than 20 years between failure events
- ***Medium:*** 5–20 years between failure events
- ***High:*** less than 5 years between failure events.

Consequence may be defined in terms of the duration and magnitude of damage, as follows:

- ***Low:*** Would result in the closure of a noncritical road for up to 3 months, or of a critical road for less than 2 days. The event would not be expected to cause a loss of human life or have significant safety issues either during the event or during the postevent rectification period.
- ***Medium:*** Would result in a closure of a noncritical road for up to 12 months, or of a critical road for less than 1 month. The event may have an impact on human life during the event or other significant safety issues.
- ***High:*** Would result in a closure of a noncritical road for more than 12 months, or of a critical road for more than 1 month. Alternatively, the event could reasonably be expected to have a significantly negative impact on human life during the event (for example, a landslide over a busy highway).

When applying the above guidance, the analyst will need to consider the various ways in which a geohazard may fail. For instance, an unstable slope may have many medium-likelihood, low-consequence events as well as the potential for a low-likelihood, high-consequence event. In such a scenario, the combination that yields the highest risk rating (Table 3.2) should be adopted. Furthermore, the assessment needs to consider the nature of the closure: is it a loss of a shoulder (critical for cyclists and pedestrians but not necessarily critical for motorists); the loss of a single lane on a multilane road; the loss of a whole carriageway; or complete closure?

Once the likelihood and consequence of each identified geohazard have been assessed, Table 3.2 may be used to assign a resulting "risk rating." The importance of the initial qualitative assessment is not to get overly caught up in the details, but rather to focus on the purpose of the initial qualitative assessment—which is to identify those risks that warrant the highest priority of a more detailed evaluation.

Table 3.2: Default Risk Matrix

CONSEQUENCE (impact) if risk occurs	**LIKELIHOOD** (probability) of risk occurring		
	LOW	**MEDIUM**	**HIGH**
HIGH	Medium	High	High
MEDIUM	Low	Medium	High
LOW	Low	Low	Medium

The output from this initial risk identification and assessment process should be a register (and associated map) showing the location of all geohazards, along with the assessed likelihood, consequence, and risk rating. The register should also contain a short comment as to how the ratings were arrived at, such that the more detailed evaluation (which may not be undertaken for some years into the future for low-risk hazards) has a basis to work from.

At this stage, the road authority will need to determine whether further examination of the geohazards of each (or any) of the options is warranted. For those risks assessed as being low, and where budgets are limited, then further investigation may not be a good use of funds; these risks may be best dealt with under a specific operations and maintenance plan. Conversely, risks assessed as high would warrant further study—or such options could be eliminated as deal breakers through the selection of the preferred option process (see Section 3.7).

3.5.7 STEP 4: DETAILED ASSESSMENT OF GEOHAZARDS

For those risks that warrant a more detailed assessment, the specialists will typically need to undertake a range of field studies (potentially laboratory testing, drilling bore logs, installing monitoring equipment, land surveys, or similar) as well as some form of modeling to determine the actual level of risk that exists at each geohazard site.

The aim of the detailed risk evaluation is to better understand both the probability of an event (or the likely triggers of the event, such as certain rainfall events) and the consequence of the event (such as the flow path of a landslide outside the road corridor). Once these factors are better understood, the risk rating can be refined as discussed in Section 3.5.6.

In many cases, those undertaking the detailed risk evaluation will also be able to concurrently advise on the range of potential options to mitigate the geohazard risk. Therefore, there is a strong connection between this detailed risk evaluation phase and the option development task in Section 3.7.1.

The risk evaluation must prioritize the identified hazard-prone road locations to generate the maximum effect from limited budgets. The text below describes basic, intermediate, and advanced methods for the risk evaluation of hazard-prone road locations. The technical difficulty, the cost, and the accuracy of the evaluation all increase with the method level. Should the budget not permit a Level 3 approach to be applied at a network level, then either a Level 1 or Level 2 approach should be applied to identify the highest-risk sites—to which a higher (Level 2 or Level 3) approach can then be focused.

Level 1: Basic method. As described earlier (Section 3.5.6), Level 1 applies a simple matrix approach to the risk evaluation.

Level 2: Intermediate method—Risk rating of an endangered road location is assigned (low-budget, medium-capacity countries). The Level 2 approach builds on the Level 1 approach by evaluating the likelihood and magnitude of damage on a number of subcategories, with a score assigned to each. These scores are then multiplied to generate an overall score of risk level as follows:

Score of risk level = Score of likelihood of road damage x Score of magnitude of road damage impact

The score of the likelihood or the magnitude is just the sum of the scores assigned to each category of items rated (Table 3.3). The "likelihood" rating items include elements such as geohazard activities (existence and progression of minor damage or deformation on the road and roadside slope), historical geohazard impacts, and existing countermeasures. The "magnitude" rating items include elements such as the strategic importance of the road, traffic volumes, and detour distance in case of a road closure. A relatively high rating score is assigned to a category that would increase the likelihood or the magnitude of a geohazard impact considerably.

With reference to the example contained within Table 3.3, the following is noted:

- The example has been designed for the evaluation of land-movement-type geohazards. For other types of geohazards (for example, impact of flooding), the tables will need to be appropriately modified to incorporate suitable factors and scoring ranges.
- Factors in Table 3.3 that have higher positive scores are considered to be indicative of a high risk of a future event, while negative scores indicate factors that would lessen the risk of a future event. For instance, the presence of four or more events in the past 10 years is considered indicative of further events in the future (score of +6), while the presence of deep-rooted vegetation to hold an earth embankment (above or below the road) is considered to be a mitigating factor (score of −1).
- In the case of the mitigation measures, more than one factor may be selected depending on what mitigation is in place, unless such measures do not appear to have been effective at preventing previous events. For instance, if the vegetation has moved with the land movement, then its effectiveness may be neutral (a score of 0).
- When assigning scores for the presence of mitigation measures, smaller negative values (that is, indicative of being less effective) shall be used if appropriate maintenance of the mitigation measures are not in place or where there is evidence that they have not been effective (that is, no change in the frequency of events since the mitigation measure was implemented).
- The challenge with this approach is in assigning the score for each rating category, and for this it is recommended that a technical committee of experts be involved—noting that a range of skill sets will be required.
- For the rating of the magnitude of damage, it is necessary to consider (if at all possible) the presence of foot traffic past the hazard even if vehicle detour routes are much longer. If foot passage is possible and porters could transfer goods (and people) to temporary shuttle buses on each side of the closed portion, the score for the rating "detour distance" or "no detours" shall be decreased accordingly. (That is, the detour is not assessed on the longer length of vehicle access—unless a specific vehicle must get through or the goods cannot be transported short distances by porters—but rather on the additional journey time.)

• In the example, scores of 6, 3, and −1 were assigned for each of the three likelihood factors, resulting in an overall likelihood score of 8; while scores of 6, 2, and 1 were assigned for the damage, yielding a score of 9. These two values then are multiplied to yield an overall risk score of 72.

Table 3.3: Sample Rating of Likelihood and Magnitude of Geohazard Damage to a Road Location

a. Rating items for likelihood of damage from geohazards

RATING CATEGORY	History of damage from geohazards			Minor damages or deformations			Mitigation measures applied since last failure		
	Check/description/score			Check/description/score			Check/description/score		
	x	Geohazards have caused road closures more than four times in the past 10 years.	6		Minor damages or deformations are clearly and evidently progressing on road.	6	x	Vegetation (bioengineering) works to hold earth are planted on roadside embankment.	−1
		Geohazards have caused road closures one to three times in the past 10 years.	3	x	Minor damages or deformations are slightly progressing on road.	3		Drainage works are installed to lower moisture in soil.	−2
		Geohazards have not caused any historical road closure, just reduced traffic speeds, in the past 10 years.	1		Minor damages or deformations are recognized but dormant on the road.	1		Structural measures are designed to prevent or protect from geohazard during road service time.	
Score of selected rating category			6			3			−1
Total score: summing up of scores of selected rating categories			8						

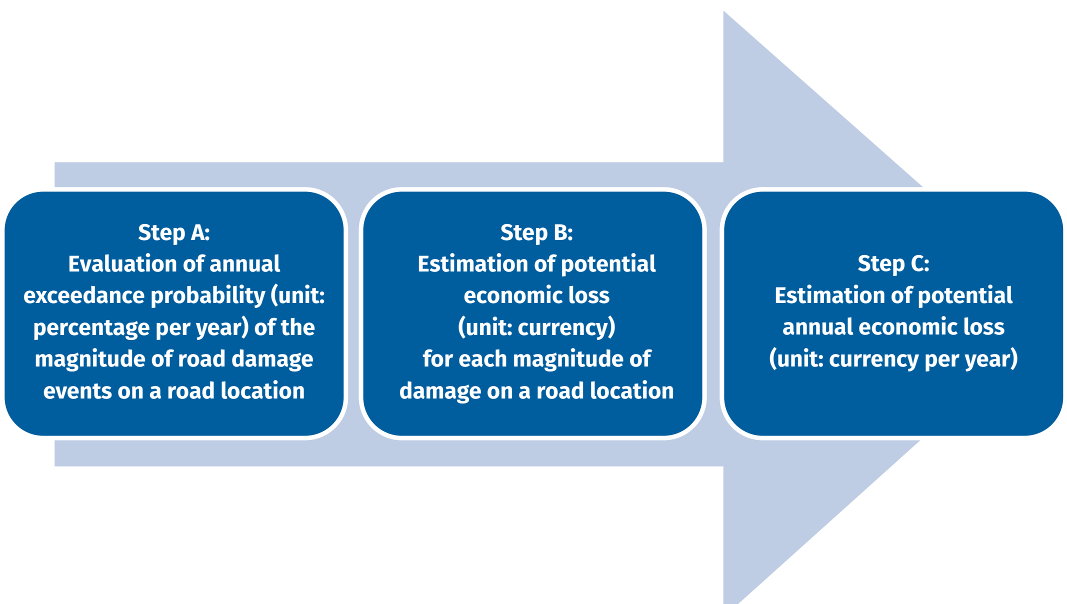
b. Rating items for magnitude of damage from geohazards

RATING CATEGORY	Road strategic importance			Road traffic volume			Distance of potential detour		
	Check/description/score			Check/description/score			Check/description/score		
	x	All-weather roads are designated for emergency transport or evacuation during disaster.	6		High traffic volume	3		Long-distance detour (more than 30 percent of average total journey length for those traveling past the geohazard)	9
		All-weather roads are not designated for emergency transport or evacuation during disaster.	3	x	Moderate traffic volume	2		Moderate-distance detour (10–30 percent of average total journey length for those traveling past the geohazard)	3
		No all-weather roads exist.	1		Low traffic volume	1	X	Short-distance detour (less than 10 percent of average total journey length for those traveling past the geohazard)	1
Score of selected rating category			6			2			1
Total score: summing up of scores of selected rating categories			9						

The setting of the relevant factors and score for use in tables such as those in Table 3.3 need to be developed on a case-by-case basis. For instance, the relevance of vegetation or drainage as mitigation measures in a country where the geohazards are related to mass rockfall from earthquakes will be minimal compared with the same mitigating factors in an area with high rainfall and soil that suffers from slips. Similarly, the determination of the damage (or impact) encompasses many types: social, economic, environmental, political, safety-related, access-related, and connectivity-related. Determining which factors are important enough to be considered in terms of impacts is part of the risk evaluation. For example, various road alignment options may be vulnerable to embankment slips that may crush a car, wipe out a sensitive fauna or flora species, prevent access to an important agricultural area, or restrict access to a politician's house. In setting the values in the tables, the road authority needs to determine the relative importance of each of those factors and use that information to identify a preferred alignment or treatment.

Level 3: Advanced method—Risk estimate is calculated as potential annual economic loss. For a Level 3 analysis, the focus moves on to assess the spectrum of potential risk events and, for each magnitude of a risk event, to evaluate the likelihood (probability) and economic consequence (impact). It is then the summation of the spectrum of risk events that yields the resulting overall risk evaluation. The potential annual economic loss is a risk evaluation index of high accountability—shown as the monetary loss expected annually—and can be prioritized for endangered road locations (Figure 3.1). The potential annual economic losses calculated can be used to estimate the benefits of implementing risk mitigation measures when completing the cost-benefit analysis during the conceptual and design stages.[8]

Figure 3.1: Workflow for Potential Economic Loss Estimation of a Road Location



3.5.8 STEP 5: EVALUATION OF WIDER IMPACTS OF GEOHAZARDS

This aspect of the geohazard risk management process is one where the geohazard process produces outputs for other specialists (notably environmental and social safeguard specialists and economists) to then use in their work. It is not the expectation that the engineers and hydrologists—who are specialists in their own right—would undertake these other assessments.

[8] For the detailed estimation procedure, see "Operations Manual 1: Economic Risk Estimation and Cost-Benefit Analysis of Investments for Road Geohazard Risk Reduction" in Appendix B.

Depending upon the approach to selecting the preferred option (see Section 3.7), other specialists who may require outputs from the geohazard analysis would include road safety personnel, cost-estimation experts, structural designers, and economists.

3.6 NETWORK-LEVEL ANALYSIS, OR DECISION MAKING UNDER DEEP UNCERTAINTY (DMDU)

3.6.1 WHAT IS DMDU?

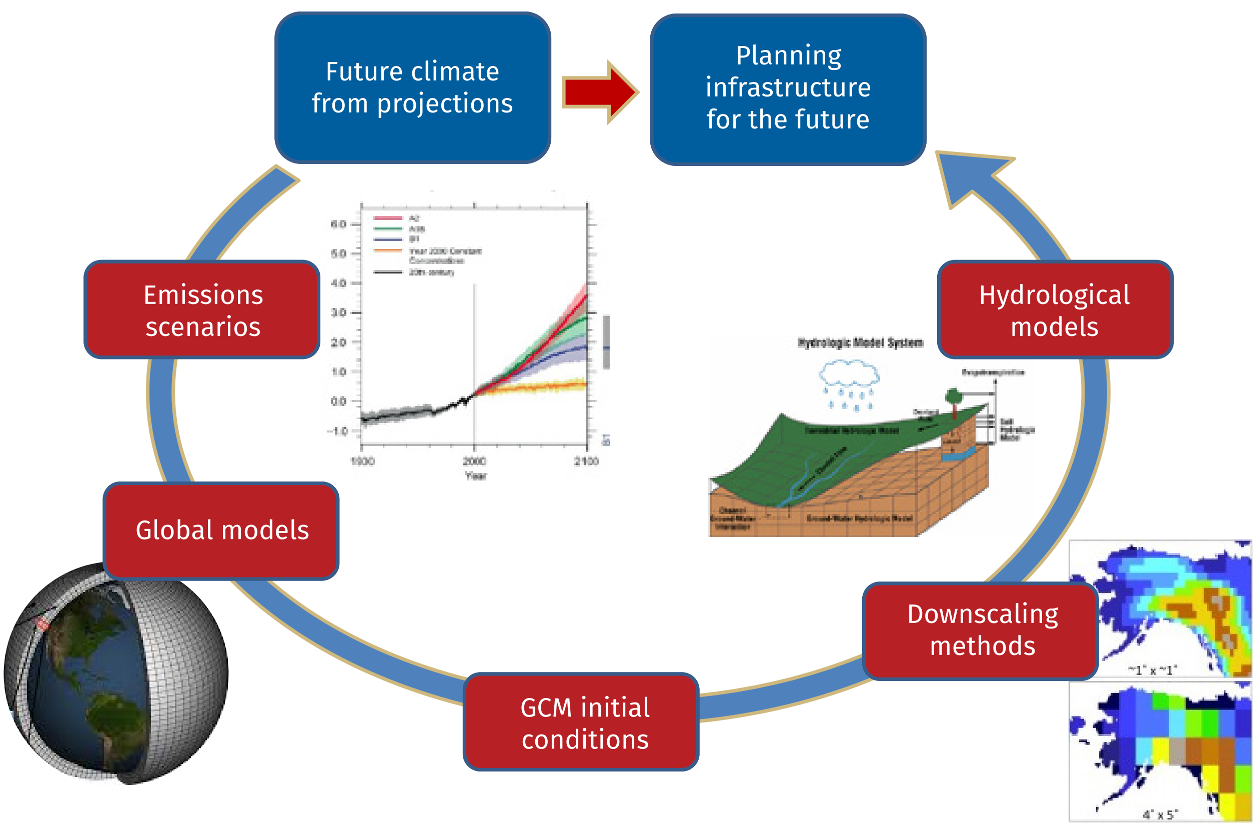
Decision making under deep uncertainty (DMDU) is a relatively recent analytical approach that provides an analysis framework for making decisions when there is a high level of uncertainty. Such decisions are described by Espinet (2018) as entailing the following difficulties for decision makers:

- Difficulty in understanding the true nature of the problem
- Difficulty in defining future standards to adapt infrastructure to the changing climate
- Difficulty in choosing the best strategy to withstand future weather events.

Espinet (2018) goes on to illustrate the many uncertainties associated with planning infrastructure with regard to climate impacts (Figure 3.2). Although geohazards are not singularly climate-related, the nature of geohazard risks and associated decision making is closely aligned with the above DMDU description.

He further explains that, under DMDU, the decision-making process is reversed from a normal "predict, then act" methodology (identify a scenario, develop solutions, sensitivity-test the solutions) to one that must develop a range of strategies, identify the vulnerabilities of each strategy, and finally identify strategy adaptations to reduce the vulnerabilities.

Figure 3.2: Potential Uncertainties in Infrastructure Planning Regarding Climate Impacts



Source: Espinet 2018. ©World Bank. Further permission required for reuse.
Note: GCM = global climate model.

3.6.2 APPLICATION OF DMDU TO GEOHAZARD RISK MANAGEMENT

For either a new road where the range of risks may be limited or an existing road network that is relatively short, the traditional '"predict, then act" methodology—with associated option selection based on cost-benefit analysis (either on road authority costs or incorporating economic loss considerations, as discussed earlier in Section 3.5.7)—is relatively simple and effective. However, for longer road sections or road networks that are often tens to hundreds of kilometers in length, for the purpose of geohazard risk assessment, the cost-benefit approach is much more difficult to apply.

As with the example in Figure 3.2, geohazard risk management at the network level consists of a range of uncertainties that make it practically impossible to precisely define a future scenario to design for. A range of factors (climatic, tectonic, man-made, and so on) all have a distribution of probabilities of occurrence and magnitude of events. These events can then trigger a range of geohazards in terms of location and magnitude, which in turn will have a distribution of impacts on road users and adjacent landowners. Such a range of unknowns is ideally suited to the DMDU approach.

3.6.3 DMDU METHODOLOGY

The application of DMDU involves a five-step process (Espinet et al. 2018):

1. Determine the criticality of a road link
2. Determine the exposure of the road link to geohazard events
3. Determine the vulnerability of the road link to geohazard events
4. Determine the risk to the infrastructure (expected annual damage to the infrastructure)
5. Calculate the resultant priority of the road link.

3.6.3.1 STEP 1: DETERMINE THE CRITICALITY OF A ROAD LINK

The first aspect of determining the criticality is to define what the measure of criticality will be. This could include aspects such as

- Change in the total road user costs, calculated from analysis tools such as Highway Development and Management version 4 (HDM-4);[9]
- Total kilometers traveled;
- Total travel time;
- Total journey time to the nearest school or hospital;
- Any other network-level metric (or combination of metrics) that the road authority wishes to use to define criticality.

The approach to determining the criticality is to analyze the network, first with the assumption that all road links are fully functional, and then one-by-one remove a road link from the analysis and recalculate the metric assuming that road users will divert to their next best route. In this analysis, a "road link" is any length of road that the analyst wishes to consider. The criticality being determined could be that of a single road, a subnetwork of roads, or some other combination such as a key route between cities.

For each road link, the resulting difference in the metric between the "fully functional" and "without link" results is used to define whether the impact is very low, low, medium, high, or very high. The exact definition of these ratings is not that important, because it is more about the relativity than the absolute value. However, a road authority may have in place an existing definition for criticality, and this should be used if available.

[9] For more information about HDM-4, see http://www.hdmglobal.com.

Alternatively to the above analytical methods to assign criticality, a scoring system may be employed based on predefined criteria. This may be more applicable to low-volume rural roads or to countries with limited funds to expend on the traffic modeling-based approaches suggested above. For instance, the New Zealand Transport Agency has had research completed into the development of a criticality assessment of roads that it controls (AECOM 2016), with the outcome being a recommendation to adopt a criticality framework that incorporates three elements:

- One Network Road Classification (ONRC)
- Access to lifeline utilities or a lifeline evacuation route
- Access to essential services.

A scoring system was proposed by AECOM (2016), with each criterion to be equally weighted (Table 3.4).

Table 3.4: Proposed Road Criticality Components, New Zealand Transport Agency

CRITERION	COMMENT OR RATIONALE	SCORING	POTENTIAL DATA SOURCE
One Network Road Classification (ONRC)	The ONRC provides an established functional classification covering traffic volumes, economic criteria, accessibility, connectivity, and so on.	4 – National or high volume 3 – Regional or arterial 2 – Primary or secondary collector 1 – Local or access	ONRC assessment
Access to lifeline utilities, or a lifeline evacuation route	For a region to recover from any natural hazard event, it is important for the various key utilities such as water, wastewater, power, and telecoms to be able to access their assets to inspect and undertake repairs. This category includes physical utility assets such as substations that require access to maintain continuity of service to the public and also access to critical transport hubs such as ports and airports. This also includes any routes that are considered themselves as essential for evacuation.	Based on the total number of utilities on a route, and by the criticality of utility, as follows: 4 – More than five locally significant utility assets, more than three regionally significant assets, or one or more nationally significant assets 3 – Three or four locally significant utility assets, one or more regionally significant assets, or an essential evacuation route 2 – One or two locally significant utility assets 1 – No access for utilities	Utility asset information
Access to essential services	These are essential services that would be required for response and recovery during a natural hazard event. Seven priority areas are proposed: • Hospitals and large age-care facilities • Ambulance, fire, police, and emergency ops centers • Major utility control centers • Welfare centers • Key retail outlets (hardware stores, construction resources, and supermarkets) • Schools and sector posts • Major industry.	Based on the total "priority score" calculated based on all the priority services accessed by a given route *(refer to body of the main report for details):* 4 – Score of more than 5 3 – Score of 3–4 2 – Score of 1–2 1 – Score of less than 1	Essential service asset information

Source: AECOM 2016.

3.6.3.2 STEP 2: DETERMINE THE EXPOSURE OF THE ROAD LINK

The next stage is to assess the impact of a range of different-magnitude events on the road network. Exposure could be related to rainfall, earthquakes, or any other trigger of a geohazard event. A typical analysis should consider 5–10 different exposure levels for each geohazard risk category under consideration (such as rainfall, earthquake, and so on). The more exposure levels analyzed, the more reliable the results will be when subsequently determining the risk rating of a road link.

Ideally, the lowest exposure level should yield little, if any, damage to the road network. If the calculation of the vulnerability (Step 3 in the DMDU process) for the lowest exposure levels indicates otherwise, then a new lower level of exposure should be considered until such a scenario is found. Alternatively, it may be possible to assume that a high-exposure event such as a 1-in-1-year rainfall will have zero impact (low vulnerability) on infrastructure for the purpose of this analysis.

For instance, it may be that the exposure is being assessed on the impact of a range of return-period rainfall events—from 1-in-5-year events to 1-in-1,000-year events. Under each exposure scenario, each road link is assessed as to what impact such an event would have on that particular road link, measured in terms of water depth across the road. As with the criticality analysis, the water depths are then grouped into bands ranging from very low, low, medium, high, or very high levels of exposure.

3.6.3.3 STEP 3: DETERMINE THE VULNERABILITY OF THE ROAD LINK

Having identified the range of exposure levels that each road link could be exposed to, the vulnerability is then assessed on the basis of the assumed financial cost to the road authority to repair the damage. As with the exposure analysis, there will be a vulnerability for each return period being analyzed. For practical application, it may be necessary to make assumptions about the likely impact of different exposure levels that can be readily applied across the road network.

For instance, a rainfall exposure event of “very low” impact may be assumed to cause only minimal damage to the unpaved portions of a road, while a “very high” exposure may also result in the loss of paved surfacing, among other things.

Because the analysis is on the basis of a road link, and because roads will be affected differently at different locations along the road, the vulnerability assessment is the arithmetic sum of the vulnerabilities along each road link. For instance, using the aforementioned rainfall example, the vulnerability of a road link can be estimated based on the length of road with “very low” impact multiplied by the unit rate to undertake minor repairs, plus the length of road with “low” impact multiplied by its unit rate, and so on.

3.6.3.4 STEP 4: DETERMINE THE RISK TO THE INFRASTRUCTURE

The risk to any given road link is then the expected annual loss (EAL) based on the combination of the exposure level and the vulnerability costing (Espenit et al. 2018). This is calculated using the trapezoidal rule, where the probability of an event is the inverse of its return period. The formula for EAL for each road link is therefore as follows:

$$EAL = \frac{1}{2} \sum_{i=1}^{n} \left(\frac{1}{T_i} - \frac{1}{T_{i+1}} \right) (D_i + D_{i+1}),$$

Where ***n*** is the number of exposure events under analysis;

i is an integer between 1 and n–1, corresponding to the exposure event analyzed;

Ti is the *i*th return period; and

Di is the damage to the infrastructure corresponding to *Ti*.

Based on the resultant EAL, the risk of the road link is categorized as very low, low, medium, high or very high. Again, the exact definitions of these categories are not so important, because it is more about determining the relative risk levels between road links.

3.6.3.5 STEP 5: CALCULATE THE PRIORITY OF THE ROAD LINK

The final step is to combine the criticality with the risk ratings to calculate the priority of each road link. This is undertaken using a matrix (Table 3.5).

Table 3.5: Determining Priority Rating under DMDU Approach

		RISK RATING				
		VERY LOW	**LOW**	**MEDIUM**	**HIGH**	**VERY HIGH**
CRITICALITY	**VERY LOW**	Very Low	Very Low	Very Low	Very Low	Low
	LOW	Very Low	Low	Low	Low	Medium
	MEDIUM	Low	Low	Medium	Medium	High
	HIGH	Medium	Medium	High	High	Very High
	VERY HIGH	Medium	High	High	Very High	Very High

Note: DMDU = decision making under deep uncertainty.

Once the priority rating of each road link is determined, the highest-rated links are then subjected to further detailed analysis. If the initial definition of a road link was a relatively long length of road (or even a subnetwork of roads), it may be appropriate to rerun the DMDU analysis on the high-priority road links, with each road link split into a number of small links. This will then provide further guidance as to the best portion of the network on which to focus subsequent efforts.

At some stage, the DMDU approach will lead to the need to examine specific solutions at specific locations—as addressed in Section 3.7.

3.7 PROJECT-LEVEL OPTION SELECTION

Although a road in poor condition can be readily repaired, a road in a poor location cannot be so readily modified. Most of the investment in a road in poor condition can be salvaged, but excessive maintenance costs follow when it is in a poor location and can even lead to the abandonment of such a road. Hence, there is a need for proper investment of time and money in finalization of road alignment.

3.7.1 OPTION DEVELOPMENT

Road geohazard risk management sometimes has negative effects or causes trade-off impacts to road users and local stakeholders, as in the following typical cases:

- Roadside river erosion measures sometimes increase the flooding risk on the opposite side of a riverbank because of the change in river flow; they can also increase a flow rate caused by a narrowed river watercourse because of the erosion protection structures installed on the roadside.
- Precautionary road closures have the trade-off between saving road users' lives and generating traffic-related losses (detour, waiting, and trip cancellation) and can cause inconvenience or even isolation in local areas.

A balance must be struck between (a) road safety and reliability, and (b) the cost of improving road safety and reliability. Such issues and other important items should be decided while accommodating stakeholders' opinions—recognizing that geohazards are but one input to an overall road project evaluation process. Even relatively high geohazard risks may well be acceptable where the alternative routes are significantly costlier or are otherwise undesirable relative to a less reliable route through the hazardous area.

The geohazard risk management policy should consider the road type, as noted in Part I, Section 1.5. The basic idea is that for low traffic volumes, the investment in road geohazard risk management may be relatively low, considering a balance between the investment level and the expected level of safety and reliability of the road against geohazards. Conversely, for high-traffic-volume roads or roads serving key strategic destinations, a high degree of road resilience is desired with an associated higher level of investment in risk mitigation measures. In Part IV, Photo 4.4 provides a comparison of river-crossing solutions that illustrate different levels of resilience to geohazard events.

A road geohazard risk management approach for non-all-weather rural and low-traffic-volume roads is practical but should allow for temporary road closure under abnormal weather conditions. An example is to build a low-cost ford river crossing that is designed to allow water with soil to pass over the road carriageway during floods. The road is submerged and may not be used during flooding; however, this loss in accessibility for the infrequent nature of the geohazard and the low number of users affected can save significant construction costs compared with a bridge. Further details on the design of fords are covered in Part IV, Section 4.4.4. The strategies are determined by cost-benefit analysis of bridge construction cost, potential annual economic loss, and maintenance cost considering temporary road closure and sand and debris removable after flooding.

An adequate operations and maintenance system and a flooding system to alert users and prevent loss of life are required, the complexity of which will vary from country to country. It is important to have in place standby machinery and staff during heavy rains to clear the debris accumulated on the fords just after the flooding.

Geohazard risk management strategies for low-volume roads in low-budget countries also should consider a low initial investment to allow geohazard damage control to be completed in several years. For example, a mountainside slope can be intervened by making a small cutting operation, instead of a full cut operation, and waiting for several years for it to become stable with a gentle gradient by natural collapsing.

For low-capacity countries, geohazard identification and evaluation is difficult and may lead to either underevaluation or overevaluation of different endangered road locations. Misevaluation can result in cost-consuming geohazard risk management. It is a practical strategy to keep initial investments small for structural measures. For several years after the new road construction, endangered road locations can be identified by visual inspection, and earlier remedial measures (such as works for minor damage portions conducted without the need for designs, such as sealing of cracks) can be applied to prevent the development of more serious damages.

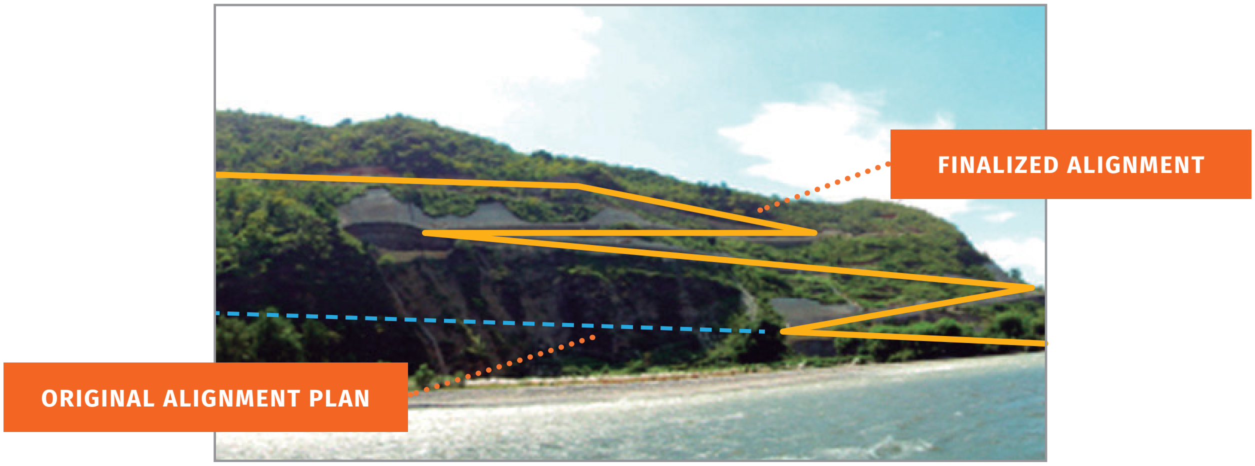
Proper new-road alignment planning by avoidance of moderate and high geohazard risk locations can save significant life-cycle costs, avoiding cost overruns, costly delays of construction, and subsequent maintenance costs (as illustrated in Photo 3.2). Planning of alternative alignment for the geohazards should consider the terrain present on both sides of the road (that is, slopes above and below the road). It is important to pay attention to inundation risks, especially when the route passes through flat areas.

Figure 3.3 shows a detailed hazard map prepared for a new-road alignment, with the preferred alignment (orange line) being selected to avoid the sliding slope and the slope susceptible to river erosion. This example is significant because it illustrates that, in many cases, the selection of a new route can be made so as to reduce the geohazard risk, but often it is not possible to eliminate all geohazard risks. In such a situation, the evaluation of options can be thought of as picking the "least bad" outcome.

Figure 3.3: Sample Detailed Hazard Map for a New Road

Source: ©World Bank. Further permission required for reuse.
Note: Map is a hypothetical example.

Photo 3.2: Example of Road Alignment Plan Avoiding Geohazards



The Sindhuli road alignment in Nepal was shifted up the mountain to avoid an area of unstable collapse-type geohazard and the undercut slope susceptible to river erosion. Although the total length of the road is longer, significant life-cycle costs can be saved.

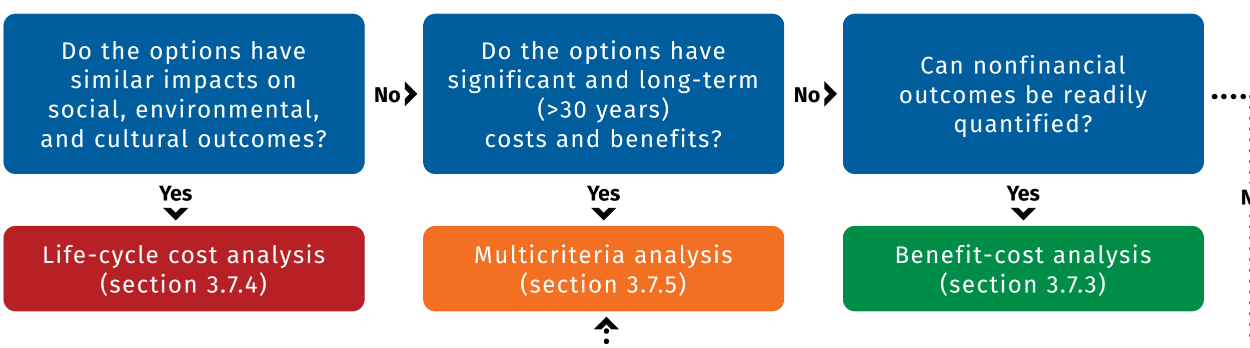
Source: ©Department of Roads (DOR), Ministry of Physical Infrastructure & Transport, Government of Nepal. Reproduced, with permission, from DOR; further permission required for reuse.

3.7.2 EVALUATION APPROACH

The first stage in selecting the preferred option is to define the evaluation approach, with Figure 3.4 providing an overview of how to determine the appropriate methodology to apply. Typically, for existing roads, the different options can be compared using life-cycle cost analysis on the presumption that each option will broadly offer the same benefits to road users, and the decision is primarily a technical one as to which solution can be delivered for the lowest cost.

For new-road alignments, the decision will typically involve multiple factors, including many nongeohazard factors such as cost (initial construction and ongoing maintenance); safety, social and environmental impacts; property impacts; cultural issues; vehicle operating costs; and so on. For such scenarios, road authorities will often revert to the use of multicriteria analyses (MCAs) or similar techniques.[10] Then, having decided the basis upon which the preferred option will be selected, a three-step evaluation process can be implemented (Figure 3.5).

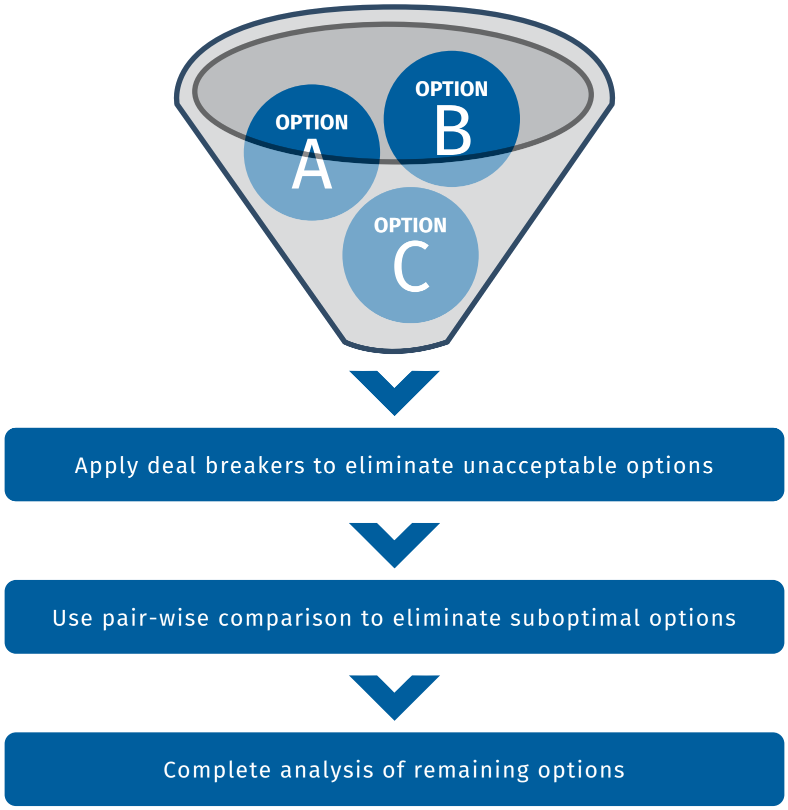
Figure 3.4: Determining the Appropriate Evaluation Approach to Option Selection



Source: NAMS 2004. ©National Asset Management (NAMS) Steering Group. Reproduced, with permission, from NAMS Steering Group; further permission required for reuse.

[10] For further guidance on making decisions involving infrastructure, see NAMS (2004).

Figure 3.5: Process for Selecting Preferred Option



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Initial screening of the options with the assessed risks, costs, benefits, and other factors will often identify solutions that are unacceptable in one or more category (often referred to as deal breakers). This will involve a multidisciplinary team because, often, avoiding one negative factor—such as avoiding a moderate geohazard risk adjacent to a river—will result in higher social disbenefits through the location of a road on, say, valuable farmland.

In applying deal breakers, it is important to not eliminate an option just because it is undesirable from one specialist's viewpoint, and it is also important to use only absolute deal breakers. For instance, an alignment that goes through a United Nations Educational, Scientific, and Cultural Organization (UNESCO)-protected area could well be considered a deal breaker, whereas an alignment that has a slightly higher geohazard risk could still be acceptable if the other factors are strongly in favor of it.

In general, the analysis will compare the existing situation of "no new road" with each of the proposed alignments. For each component of the project, the specialists should undertake sufficient analysis to enable them to justify why a given option should not be considered further. These nonacceptable options can then be eliminated from further consideration. This deal-breaker stage may eliminate options for any factor under consideration, including those of a non-geohazard-risk nature.

Subsequent pair-wise comparison of any two acceptable options may reveal further options that can be eliminated because an existing alternative is better across all factors under consideration. For instance, if alignment A is cheaper to construct and maintain and has a lower geohazard risk along with lower social and environmental impacts, yet also delivers better economic outcomes than alignment B—then alignment B can be eliminated from further analysis, regardless of whether alignment B has yet been compared with alignments C, D, and E.

The remaining alignments will then need to be developed, consulted upon, and otherwise subjected to option evaluation according to the country's normal decision-making practice. Geohazard considerations are then considered as part of the overall costs, reliability of routes (and associated benefits), and wider social and environmental impacts.

3.7.3 BENEFIT-COST ANALYSIS (BCA)

The BCA approach converts both benefits and costs over the analysis period into monetary terms, providing the ability to calculate the following indicators:

- ***Net present value (NPV) =*** present value of the benefits – present value of the costs
  - If the NPV is greater than $0, then the investment is worthwhile, with larger positive values indicating a greater return on the investment. The NPV tends to favor large-scale investments, where large benefits can be realized.
- ***Benefit-to-cost ratio (BCR) =*** present value of the benefits / present value of the costs
  - If the BCR is greater than 1, then the investment is worthwhile. The BCR is better suited to comparing investments of significantly different costs.
- ***Internal rate of return (IRR):*** The discount rate at which the present value of the benefits equals the present value of the costs. A higher IRR indicates a better project, because it will "pay itself off" in a shorter period of time.

To determine the benefits, it is necessary to consider the wider economic benefits of the options. Because the calculation of economic loss from geohazards is a relatively complex analysis, it is addressed separately in Operations Manual 1 (in Appendix B).

Although these approaches can be used at a network level, they are more appropriately applied to discrete project-level analyses where the different investment options provide different benefit streams. For many geohazard solutions, the benefit streams are very similar and it is only the costs of the solutions that vary significantly—thereby enabling the use of a simplified life-cycle cost (LCC) assessment comparison, as discussed below.

3.7.4 LIFE-CYCLE COST (LCC) ASSESSMENT

At a minimum, all options should be compared on an LCC basis (NAMS 2004). The LCCs include the initial investment costs of each option, along with the corresponding annual maintenance cost. The evaluation period for determining the LCC should align with established practices within the road authority, which typically range between 15 and 50 years. Where no guidance is provided within a country on the period to analyze, a good approach is to consider the life expectancy of the longest-life option.

To determine the LCC assessments, the following input data are required:

- Investment cost for the option
- Annual maintenance cost for the option
- Periodic renewal cost for the option if that is required within the evaluation period
- Discount rate for cost-benefit analysis.

The LCC of each option is then the sum of the discounted costs, and it is this value that is used when comparing option costs. The LCC is calculated using the following formula (assuming that investment costs occur in the first year)[11] (NAMS 2004):

$$LCC = InvCost + \sum_{n=1}^{P}(AMC_n + PRC_n) \times \frac{1}{(1+DR)^n},$$

Where ***LCC*** is the present value (or discounted) life-cycle cost for the option;

InvCost is the initial investment cost of the option;

n is the analysis year;

P is the analysis period;

AMC is the annual maintenance cost in year *n*;

PRC is the periodic renewal cost in year *n*; and

DR is the discount rate as a decimal (for example, 6 percent = 0.06).

Having calculated the LCC for each option, then under the assumption that the benefits are largely similar, the option with the lowest LCC is the preferable solution for implementation. The purpose of the LCC approach is to enable the trade-off between different solutions that may have substantially different initial investment costs and ongoing maintenance costs.

Sensitivity analysis should also be conducted by varying each input parameter within an appropriate range and noting any change in the determination of the least-cost option. Projects are considered robust if, after each factor change, the same option remains preferable. If the impact of the sensitivity analysis results in a change to the option that is the least cost, then further analysis may be warranted to enable a lowering of the sensitivity test ranges of the variables.

3.7.5 MULTICRITERIA ANALYSIS (MCA)

Where the benefits or disbenefits between solutions are not broadly similar, then comparison on a basis other than just costs will be required. MCA enables such a comparison to be made, wherein the options are ranked across a range of user-defined factors, in much the same way that the decision on how to define the criticality of a road is undertaken (see Section 3.6.3.1).

The challenge in applying MCA is to determine the relative weighting between the different factors being assessed (NAMS 2004). Once the rating criteria have been set, each option is then scored across the criteria and the sum (often weighted) of the criteria added up. The LCC will typically be included as a criterion, although this may be separated into the discrete components noted earlier in Section 3.7.4: investment, annual maintenance, and periodic costs.

Because MCA is not expected to be used often for the evaluation of project-level geohazard risks, it is not discussed further in this handbook.

3.8

3.8 OUTCOME OF THE RISK EVALUATION PROCESS

Whether it be a network-level analysis or a project-level analysis, the purpose of the risk evaluation process is to prioritize hazard-prone road locations for the subsequent application of risk mitigation measures (refer to Parts IV, V, and VI). The evaluation results are used in the initial decision-making process for optional next steps such as

[11] Where different options have vastly different construction periods or construction is likely to span more than one year, then discounting of the investment costs as per the periodic renewal costs should be undertaken, with the investment cost split across the different years based on expected expenditure of funds.

- Remedial measures (works for minor damage portions conducted without the need for design, such as sealing of cracks);
- Engineering studies for proactive risk management measures;[12]
- Routine visual inspections only; or
- No further action, in the case of low-priority risks.

3.9 SELECTED RESOURCES

The following annotated list provides resources pertaining specifically to the topics covered in Part III.

AECOM. 2016. "Review of Methods to Determine Criticality of Roading Networks." Report prepared for the New Zealand Transport Agency by AECOM New Zealand Ltd., Tauranga, New Zealand.

Deoja, B., M. Dhital, B. Thapa, and A. Wagner, eds. 1991. *Mountain Risk Engineering Handbook*. Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD). Provides the procedure of road geohazard risk evaluation, including rating procedures for geohazard risk in chapters 20, 22, and 23.

Espinet, X. 2018. "Prioritization of Road Interventions in Nampula and Zambezia, Mozambique under Changing Flood Risk and Other Deep Uncertainties." PowerPoint presentation, World Bank, Washington, DC.

Espinet, X., J. Rozenberg, K. S. Rao, and S. Ogita. 2018. "Piloting the Use of Network Analysis and Decision-Making under Uncertainty in Transport Operations: Preparation and Appraisal of a Rural Roads Project in Mozambique under Changing Flood Risk and Other Deep Uncertainties." Policy Research Working Paper 8490, World Bank, Washington, DC.

GESU-DOR (Geo-Environment and Social Unit, Ministry of Physical Planning and Works, Government of Nepal). 2007. "Roadside Geotechnical Problems: A Practical Guide to Their Solution." Guidelines document, GESU-DOR, Kathmandu, Nepal. Provides simple multicriteria risk evaluation procedures for roads.

Highland, Lynn M., and Peter Bobrowsky. 2008. "The Landslide Handbook—A Guide to Understanding Landslides." Circular 1325, U.S. Geological Survey, Reston, VA. Provides landslide evaluation tools including mapping in its Appendix B.

Hughes, J. F., and K. Healy. 2014. "Measuring the Resilience of Transport Infrastructure." Research Report 546, AECOM New Zealand Ltd. Report prepared for the New Zealand Transport Agency by AECOM New Zealand Ltd., Tauranga, New Zealand.

NAMS (National Asset Management Support). 2009. *Optimised Decision Making Guidelines*. Thames, New Zealand: National Asset Management Steering Group.

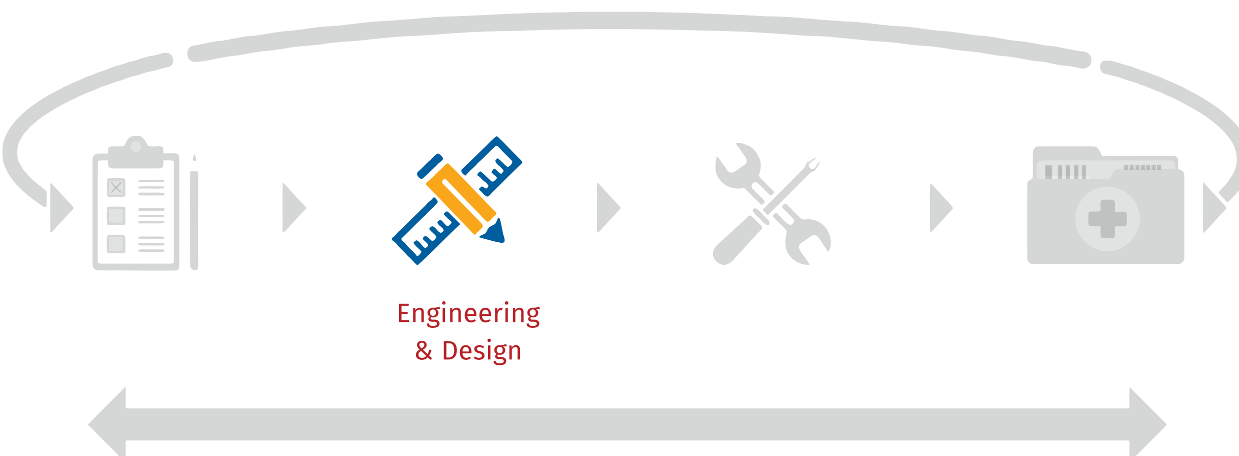
OAS (Organization of American States). 1991. "Primer on Natural Hazard Management in Integrated Regional Development Planning." Reference document, Department of Regional Development and Environment Executive Secretariat for Economic and Social Affairs, OAS, Washington, DC. Provides a general explanation of risk assessment.

Winter, M. G., F. Macgregor, and L. Shackman, eds. 2005. *Scottish Road Network Landslides Study*. Edinburgh: Scottish Executive. Provides detailed risk assessment procedures, especially for debris flow.

[12] Proactive risk management measures include structural and nonstructural measures for geohazard-prone road locations. In contrast, reactive measures are introduced after the road damage due to geohazard has already occurred and are intended to prevent future damage.

4

ENGINEERING AND DESIGN


Engineering
& Design

4.1 OVERVIEW OF ENGINEERING AND DESIGN SOLUTIONS

Part IV describes the process of road geohazard risk management using engineered (or structural) measures. It presents their definition, the general flow of road construction and structural measures, the engineering investigation of structural measures, the structural measures to consider based on geohazard types, and the construction management process. It explains the following aspects of engineered or structural measures:

- Engineered measures, implementation stage, and engineering investigation and study;
- Types of structural measures and design consideration, by geohazard type.

The achievements after using Part IV are

- To understand the implementation stage of investigation and study for structural measures; and
- To understand basic and common structural measures and their design considerations, by geohazard type, and the application of geosynthetics as recently developed materials for structural measures.

Reference documents for Part IV of the handbook include the following:

- Terms of Reference 4 (ToR 4), Design of Structural Measures (in Appendix A) is a standard terms of reference of structural measures design of engineering investigation and study, preliminary design, and detailed design.
- Case Study of Japan's Road Geohazard Management (in Appendix C) shows examples of structural measures in Japan.

4.2 DEFINITION OF ENGINEERED MEASURES

Engineered (or structural) measures are engineering solutions to prevent or protect road damage due to geohazards. They include measures implemented as

- Preventive (proactive) measures implemented to lower the risk of geohazard failure;
- Emergency works, in highly susceptible areas or during geohazard events, that are subject to engineering design; and
- Recovery conducted as secondary damage protection or recovery works in a postdisaster stage that are subject to engineering design.

Although the trigger to implement an engineered measure may vary—and the budget and time constraints might also vary significantly—the fundamental approach is often similar, particularly when the solution to be implemented is a long-lived one, such as a concrete retaining wall. A well-engineered road with a functionally efficient geohazard-proof system will have more or less negligible vulnerability. The same road, if badly designed and constructed, may be 100 percent vulnerable. In other words, vulnerability depends on level of exposure, susceptibility, and degree of preparedness.

In this handbook, structural measures include structures made of concrete or mortar, steel, wood, asphalt, geosynthetics, earth, and vegetation or bioengineering as well as their composites. "Geosynthetics" refers to any synthetic material—typically polymeric products used to reinforce earth against collapse or erosion, such as geotextiles (permeable material) and geomembranes (impermeable material). Earth structures include engineered slopes (cutting slope or embankment slope)—or just a cutting process undertaken as a weight removal of a sliding slope head—and embankments used as a counterweight of a sliding slope toe.

Engineered measures can increase the robustness of roads. They are usually implemented during the stages of road construction and operations and maintenance, based on the priority of the countermeasures required on road hazard-prone locations. They are measures for geohazard risk management, but they can also be implemented as postdisaster recovery measures. An environmental and social impact assessment (ESIA) is typically required (and should be undertaken even if not required) during the concept design phase of new road construction or for the planning of engineered measures for existing roads.

4.3 ENGINEERING INVESTIGATION AND STUDY FOR ENGINEERED MEASURES

The design of structural measures requires investigation and analysis of the relevant geographical, geological, geotechnical, hydrological, and hydraulic conditions of a particular location. The investigation methods depend on the geohazard types and the planned structural measures. Several types of studies or investigation methods are usually conducted to support the design of structural measures (Table 4.1).

Table 4.1: Studies or Investigation Methods to Support the Design of Structural Measures

TYPE OF STUDY OR INVESTIGATION	PROCEDURES AND OUTPUT
Topographic or contour mapping	A base map is created at a scale of 1:100 to 1:5,000 depending on the scale of the hazard area.
Detailed engineering mapping or section profiling	The map or section profile (scale of 1:100 to 1:5,000) shows the outlines of geohazards, soil and rock types, geological structures, springs and seepages, drainages, structures, historical flood area and elevation, and slope brake (changing line of slope gradient).
Engineering evaluation of soil and rock mass	Field reconnaissance, subsurface drilling with core samples, trial pits and trenches, geophysics surveys, in situ tests, and laboratory tests are used. Evaluation is conducted using classifications of soil types and rock crack density and weathering. The engineering properties of strength and durability for seepage are evaluated. The density and directionality pattern of the plane of discontinuities (such as joints) of a rock mass are evaluated.
Slope stability calculation for slide-type geohazards	Limit equilibrium methods are predominantly applied in the world for road slopes because of their simplicity compared with more realistic, yet more complex, analytical procedures. The safety factor is the result of dividing the resistance force against instability by the instability-causing force. A safety factor greater than 1.0 indicates that the slope is stable.
Hydrological calculations	The outputs of hydrological calculations are the volume of floods or debris or earth flow at the road-crossing points of rivers or streams—or the depth of submergence on a road location—obtained by inputting several return periods (occurrence probability in years) of rainfall and thawing water.
Flow rate calculation	The flow rate of a riverside road bank, bridge abutments, or piers are calculated by inputting several return periods (occurrence probability in years) of rainfall and thawing water.
Scouring prediction calculation	Scouring prediction depths of a road riverside bank foot, bridge abutments, or piers are calculated by inputting several return periods (occurrence probability in years) of rainfall and thawing water.

A good reference for studies or investigation methods to support the design study of engineering measures is the *Mountain Risk Engineering Handbook* (Deoja et al. 1991), specifically concerning (a) engineering evaluation of soil and rock mass in Chapter 9 ("Soil Mechanics"), Chapter 10 ("Rock Mechanics"), and Chapter 11 ("Geophysics"); and (b) slope stability calculation for slide-type geohazards in Chapter 13 ("Stability Analysis of Slopes").

From both a geohazard risk and a climate change adaptation perspective, understanding hydrology is important for the design of drainage and structural measures. For example, Table 4.1 presents the types of hydrological and hydraulic rate calculations that should be conducted as part of engineering investigation, such as depth of submergence on a road location with different return periods. A simple hydrological calculation can be done by many engineers to size drainage and culverts based on standard return-period rainfall events and simple formulae. Under some circumstances, however, detailed hydrological and hydraulic calculations have to be conducted using modeling software that requires calibration and validation using past data. Such circumstances may include road crossing of flood-prone streams and rivers; major structural investments (bridges, large culverts, river bank protection, or retaining walls where water is a concern); or cases where the consequence of failure would be significant to either road users or adjacent land users. Such detailed analysis should be undertaken by relevant trained professionals.[13]

4.4

4.4 TYPES OF STRUCTURAL MEASURES AND DESIGN CONSIDERATIONS

The types of structural measures are selected depending on the type of geohazards on the road. Earthwork with surface drainage and vegetation (bioengineering) is always the basic countermeasure to consider for each type of geohazard.

Depending on the method of construction and materials, it is necessary to account for economic efficiency, availability of construction materials and machines, social or environmental negative impacts, and the difficulty of maintenance.

Fundamental structural measures for essential targets are mainly earthworks, surface drainage, and vegetation. Common structural measures for intermediate targets are all shown in this section. Advanced structural measures are high-specification measures that can manage larger-magnitude geohazards (for example, high-energy rockfall protection).

4.4.1 STRUCTURAL MEASURES FOR MOUNTAINSIDE FALL OR COLLAPSE

Structural measures for a fall or collapse are classified into slope stabilization measures and protection measures (Table 4.2). In the case of mountainside falls or collapses, the cutting process or removal process of unstable rock and soil is essential (Figure 4.1). The slope drainage should prevent rivers or streams from causing slope instability on the road or nearby properties.

The slope cutting gradient (vertical to horizontal) ranges from 1:0.3 to 1:1.5 depending upon the geotechnical properties of the material. The design guidelines for road construction or slope engineering of each country or organization of local countries (such as those in Central America) or of high-income countries are used as references. These guidelines—which define recommended cutting gradients depending on the soil rock types and their characteristics—should be used as the basis for any works.

Vegetation has considerable effectiveness for slope stability because it mitigates slope surface erosion and water infiltration into the slope ground. Drainage and vegetation are most effective on slopes with a gentle gradient because rainfall effects are diminished relative to those on a steep slope. Intermediate slope benches (a "berm" on a cutting slope, as shown in Figure 4.1 , panel a)[14] also

[13] Good references for hydrological, flow rate, and scouring prediction calculations include AASHTO (2007) and FHWA (2012).

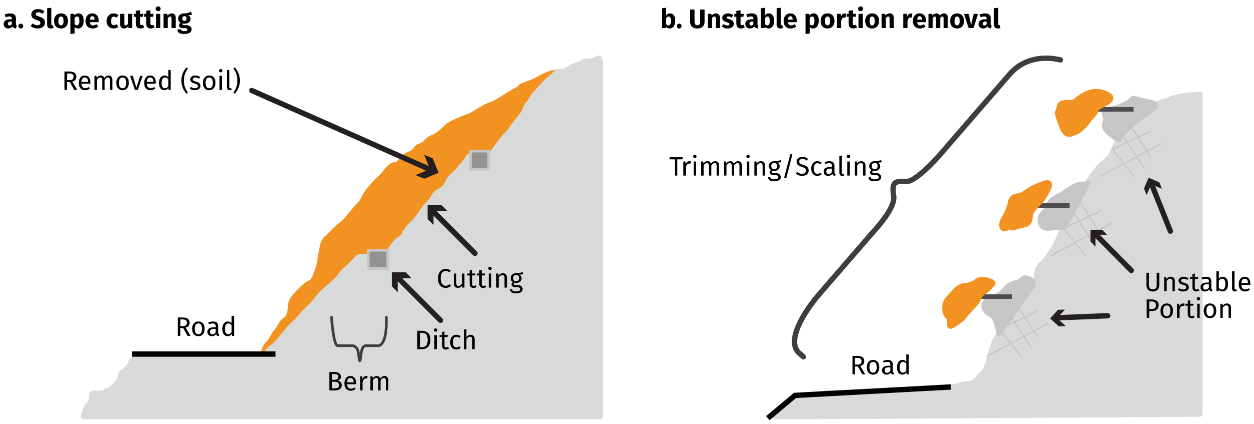
contribute to slope stability, serve as rockfall collectors or to absorb falling energy, and provide a working space for the installation of ditches or a passage for inspection or maintenance of the slope.

Table 4.2: Typical Structural Measures for Mountainside Fall or Collapse

PRIMARY CATEGORY	SECONDARY CATEGORY	TERTIARY CATEGORY	PROCEDURE FOR CONCEPT DESIGN LAYOUT
Slope stabilization measures	Cutting or removal of unstable rock and soil (Figure 4.1)	Slope cutting (Figure 4.1, panel a)	Unstable rock or soil on the slope is identified through visual inspection and shown in the plan and profile. Estimate the volume for cutting or removal as well as the land acquisition requirement of the mountainside slope. Note that the action of cutting, trimming, or scaling a slope may in itself trigger a geohazard event and should be undertaken under the guidance of an appropriately qualified geotechnical engineer.
		Trimming (Figure 4.1, panel b)	
		Scaling (Figure 4.1, panel b)	
	Prevention of erosion or slope surface instabilities	Slope drainage	Lay out slope drainage and vegetation for soil slope. For the spring portion or identified erosion phenomena, drainage shall be laid out to drain such spring or surface water safely during heavy rain.
		Vegetation or bioengineering	
	Slope reinforcement	Rock bolting (Figure 4.2, panel a) or soil nailing Shotcrete (Figure 4.2, panel b)	Area of unstable soil or rock on the slope is identified through visual inspection and shown in the plan and profile. Estimate the volume of the slope reinforcement area.
		Pitching work	
		Slope framework (grid beam) (Figure 4.3)	
		Buttress walls (cavity filling)	
Protection measures for endangered road	Resistance or absorption against the shock	Retaining and breast walls	Determine the possibility of hitting the road directly or by several bounces by simple distance from slope to toe experimentation. Determine the possible maximum rockfall size and calculate the energy of hitting. The protection measures are planned to be durable from the shock energy through energy absorption or by guiding the fall or collapse to the direction outside of the endangered road.
		Catch ditches	
		Barrier (catch fence, wall) (Figure 4.4, panel a)	
		Slope intermediate bench (berm) as rock or soil collector (Figure 4.1, panel a)	
		Wire netting (rockfall net) (Figure 4.4, panel b)	
	Guide fall or collapse direction to the outside of the endangered road	Guide wall	
		Shelters (Figure 4.5)	
		Tunnels	

[14] While many of the figures in this manual illustrate instability or vulnerability above the road (in the cut batter), often instability occurs below the formation level (that is, in earth mass that is supporting the road formation). Potential slips below the road formation can sometimes be harder to identify because they are less visible from the road surface but also can be harder to address owing to challenging access conditions, although the same techniques are equally applicable both above and below the road.

Figure 4.1: Slope Cutting or Removal for Mountainside Fall or Collapse



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Vegetation and vegetation foundation works (bioengineering) are effective in (a) reducing surface erosion caused by water and rainfall impact; (b) reducing infiltration of rainwater; (c) binding subsurface soil with its root systems (Photo 4.1); and (d) improving the landscape of the cut slope. Vegetation is often adopted as a method of slope stabilization in conjunction with structural solutions. In selecting the type of vegetation to be planted or seeded, factors such as rainfall, temperature, slope gradient, and soil properties should be given full consideration. If the slope is prone to erosion, foundation works for vegetation are provided to support the fertilized soil. Then the vegetation foundation is finalized when the soil's supporting role results in the young plant or seedling plant having grown up, the root system having bound the subsurface soil, and the vegetation supporting materials (either natural materials or geosynthetics) having decayed.

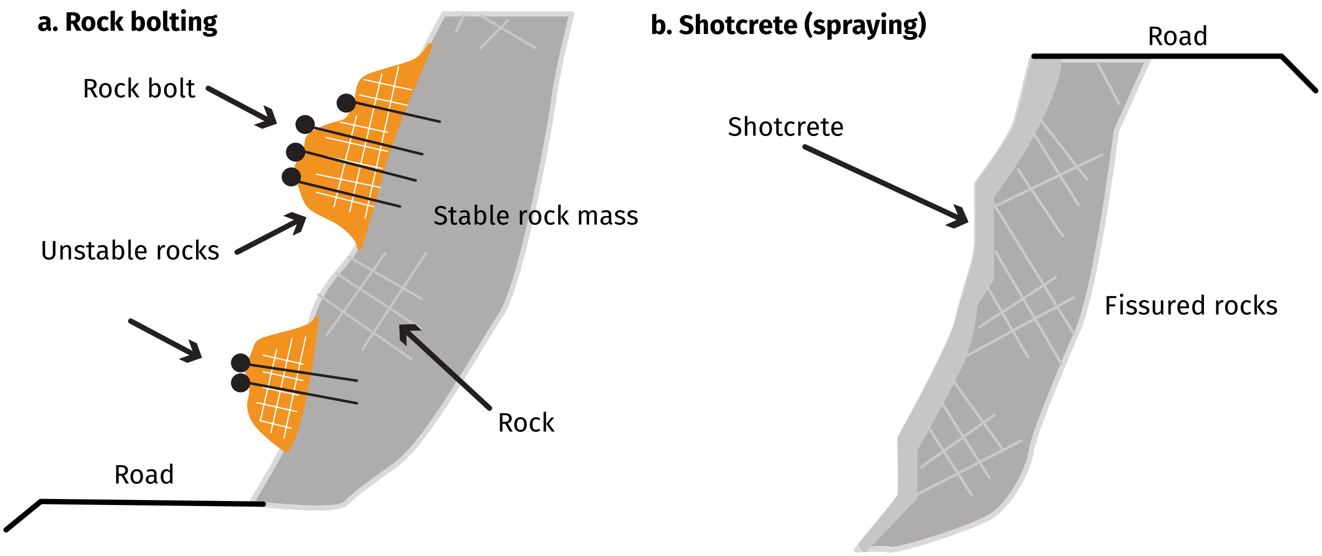
Photo 4.1: Vegetation at a Road Mountainside Slope

A road mountainside slope in El Salvador, August 2016, displays vetiver glass after 11 months of planting. Its long roots have a well-known soil-binding effect.

Source: © World Bank. Permission required for reuse.

For rock slopes, rock bolting and shotcrete are typical procedures used (Figure 4.2)—solutions that are equally applicable both above and below the road. Rock bolting is applied to unstable boulders detaching from stable rock mass. Shotcrete or framing work (grid beam) is applied to the fractured rock slope. Shotcrete is less durable than framing works and difficult to apply to a slope with water seeping from the rock face. Weep holes for drainage from behind the shotcrete area are required so as not to destroy the shotcrete from the generated water pressure.

Figure 4.2: Rock Bolting and Shotcrete for Slope Reinforcement for Mountainside Fall or Collapse



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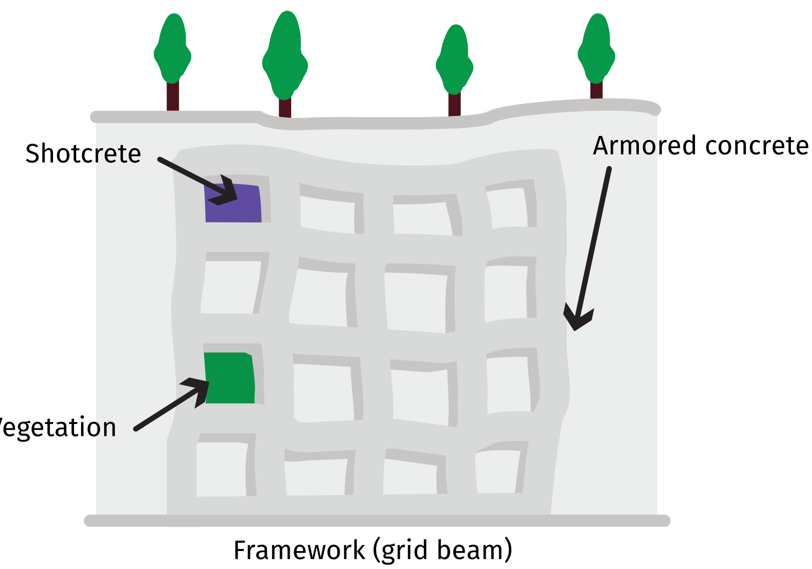
A slope framework (grid beam) or the construction of a grid beam of mortar or concrete on a slope is a method to reinforce the stability of the slope. It can be installed on weak rock or a highly fractured rock with some water springs, where shotcrete cannot be used. Its objective is to prevent a surface collapse, and it can be used as a counterforce structure for the anchor lock bolts; the open spaces of the grid can be covered with vegetation (Figure 4.3).

Figure 4.3: Slope Framework (Grid Beam) for Slope Reinforcement for Mountainside Fall or Collapse



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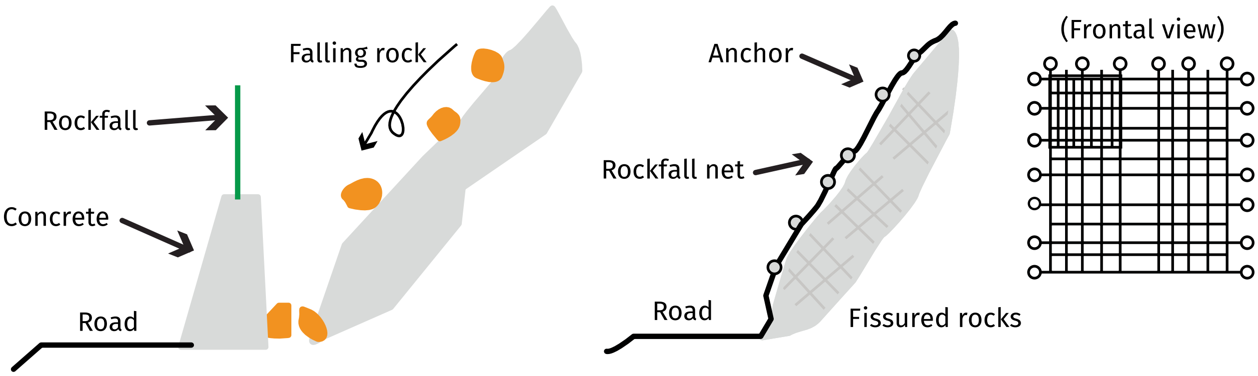
There are several protection measures for roads endangered by mountainside falls or collapses. They are subdivided into "resistance or absorption against shock" and "guide fall or collapse direction toward the outside of the endangered road." Barriers are resistance measures against impact, describing walls, fences, or a combination of walls and fences (Figure 4.4, panel a). Wire netting (rockfall net) alternatives are installed to absorb the rockfall shock and are divided into covering types (Figure 4.4, panel b) and catching types that work like a pocket.

Figure 4.4: Examples of Resistance or Absorption against Shock from Mountainside Fall or Collapse



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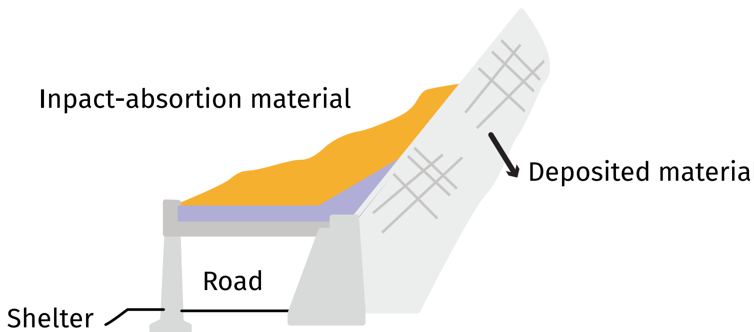
The typical practice of guiding the fall or collapse direction toward the outside of the endangered road consists of using shelters (Figure 4.5). The fall or collapse from the mountainside is captured by the shelter roof and directed into the valley-side slope of the road. This approach is commonly used for very loose material and in mountain passes where avalanches may be a hazard.

Figure 4.5: Sample Shelter for Roads Endangered by Mountainside Fall or Collapse



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4.4.2 STRUCTURAL MEASURES FOR VALLEY-SIDE COLLAPSE OR RIVER EROSION

A valley-side collapse or river erosion can cause a collapse of the road foundation, with the recovery time for full restoration of functionality often taking many days or even months to recover. Slope stabilization measures for a collapse are usually the same as those for a mountainside fall or collapse. In many cases, the entry or infiltration of stormwater or snow-melting water into the valley-side slope of the road induces the road foundation collapse. Therefore, a designer should design a proper drainage system based on hydrological calculations using a formula or curve for rainfall intensity-duration-frequency (IDF).

Road riverside erosion also induces valley-side collapses and road foundation collapses. Countermeasures for river erosion require not only protection from roadside erosion at the riverbank side but also the consideration of the negative impact on the opposite side of the road. Flooding or erosion risks increase because of flow direction change, flow rate increase owing to the narrowing of channels, or higher flood levels from the roadside erosion protection works at the riverbank side—all of which can be unintended consequences of riverside protection works. Riverbed degradation and aggradation may increase the risk of road riverside collapse, which requires measures to prevent these phenomena (Table 4.3).

Table 4.3: Typical Structural Measures for Road Riverside Erosion

PRIMARY CATEGORY	SECONDARY CATEGORY	TERTIARY CATEGORY	PROCEDURE FOR LAYOUT OF CONCEPT DESIGN
Riverbank protection		Revetment (Figure 4.6)	Determine the protection range for minor damaged portions. The structure type is determined by considering the estimated flow rate.
		Revetment foot protection (apron) (Figure 4.7)	
		Spurs or groins (Figure 4.7)	
		Guide wall for river flow (Figure 4.7)	
Catchment-based sediment management facilities	Measures for riverbed degradation, which induces road riverside erosion (groundsill)	Riverbed girdle (Figure 4.8)	Lay out for protection from scoring and riverbed degradation, which may induce roadside river erosion.
		Falling works (Figure 4.8)	Lay out for protection from scoring and riverbed degradation, which may induce roadside river erosion, or lay out the portion where the river current collides with the road valley-side slope at the river bend.
	Measures for riverbed aggradation, which induces road riverside erosion	Slope stabilization works of upstream water in a landscape ecosystem or reforestation (vegetation, foundation works for vegetation) (Figure 4.8)	Lay out the slope stabilization works in the landscape ecosystem, where riverbed degradation may induce road riverside erosion.

When designing structural solutions for valleys or to address river erosion, there is often the need to use large volumes of river shingle and boulders, fallen rocks, slope wastes, and landslide debris in pavement layers, embankment construction, and protection works instead of simply dumping the excavated material on the valley side. Such approaches both prevent damage to the valley side and road embankment and minimize the change in the normal flow of the river, which can adversely affect the riverbanks.

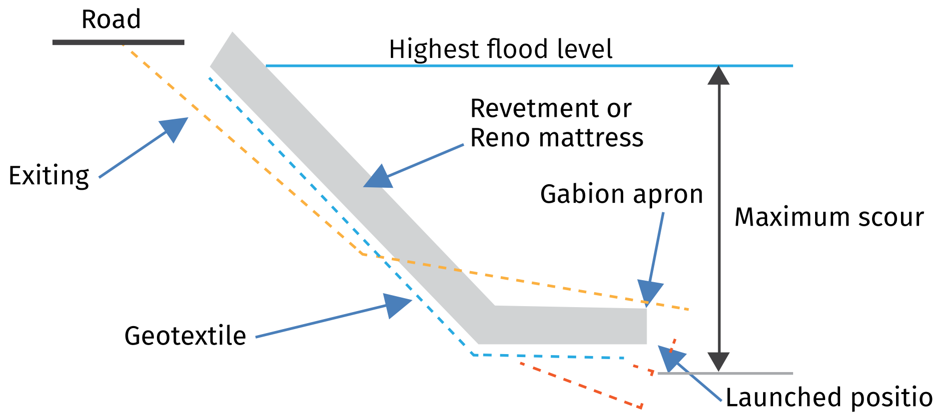
River revetments are the most common riverbank protection measures against riverside road erosion (Figure 4.6).[15] Although Figure 4.6 illustrates the use of gabion baskets to hold the rocks in place, in many situations a rock revetment without the gabion baskets may be practical—especially where river flow rates are not sufficient to dislodge the rocks. Check dams in gullies to dissipate the energy of water, as well as scour checks in ditches in areas of steep grade, are often companion measures to those riverbank protection measures.

Alternative solutions that may be used instead of, or with, revetments include installation of

- Reno mattresses, consisting of small rocks bound in a wire mattress, with a thickness of about 200 millimeters, more commonly used as aprons at culvert outlets or in table or side drains;
- Rock gabion walls (small rocks placed in wire gabion baskets, generally measuring 1 meter x 1 meter x 2 meters) as a form of retaining wall at the riverbank; and
- Gabion aprons, which are flexible (can be inclined downward toward the river center) and serve as footing for the revetment without destroying or making a scouring hole underneath it.

[15] A revetment is a facing of stone, concrete, fascines, or other material to sustain an embankment.

Figure 4.6: Example of Riverbank Protection for Road Riverside Erosion (Revetment)



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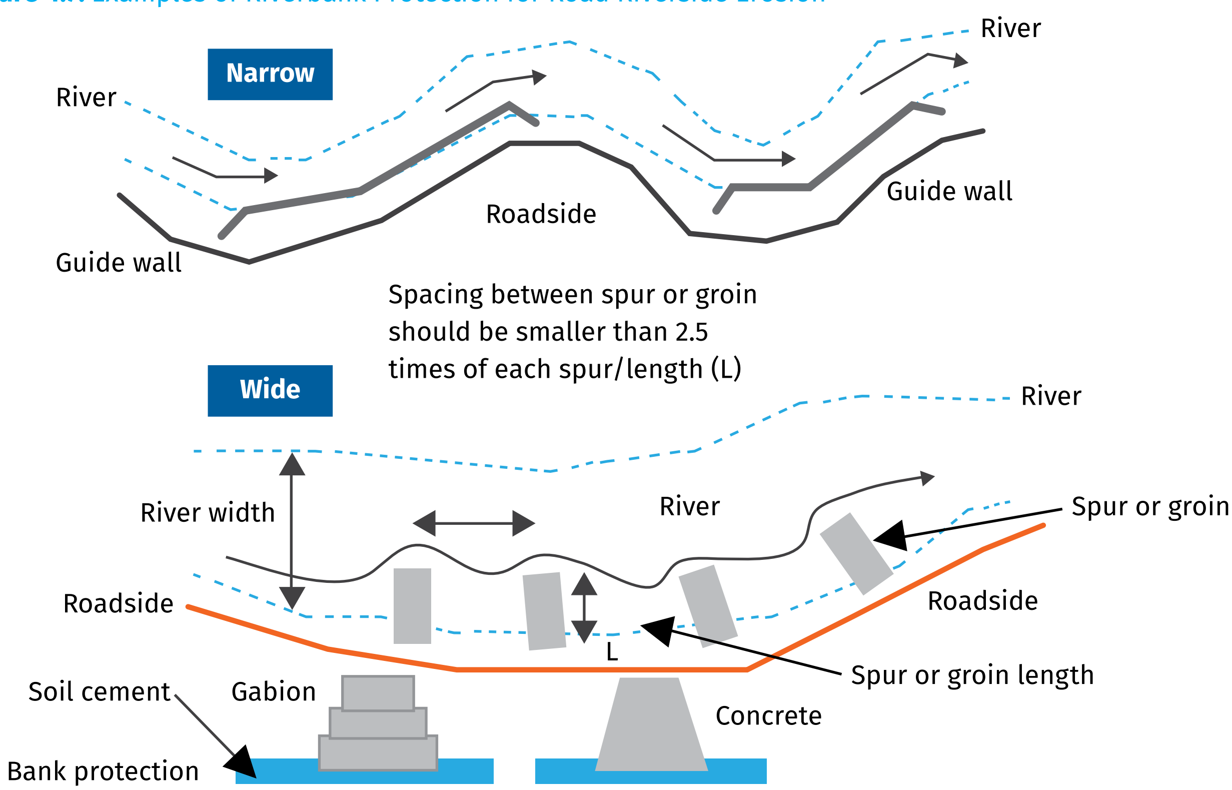
If an active flow is attacking a riverbank portion, a river flow guide wall and spurs or groins may be installed to guide or absorb the energy from the water flow (Figure 4.7). Most examples use the gabion because it is a low-cost engineering measure for areas where stone materials are easily available, and its workability and construction efficiency are good.[16] However, gabions are less durable and not ideally suitable for water-flow protection because of the scouring of their structural bottom. Gabion foundations for riverbanks should consolidate the foundation and their apron using methods such as soil cementing.

Figure 4.7: Examples of Riverbank Protection for Road Riverside Erosion



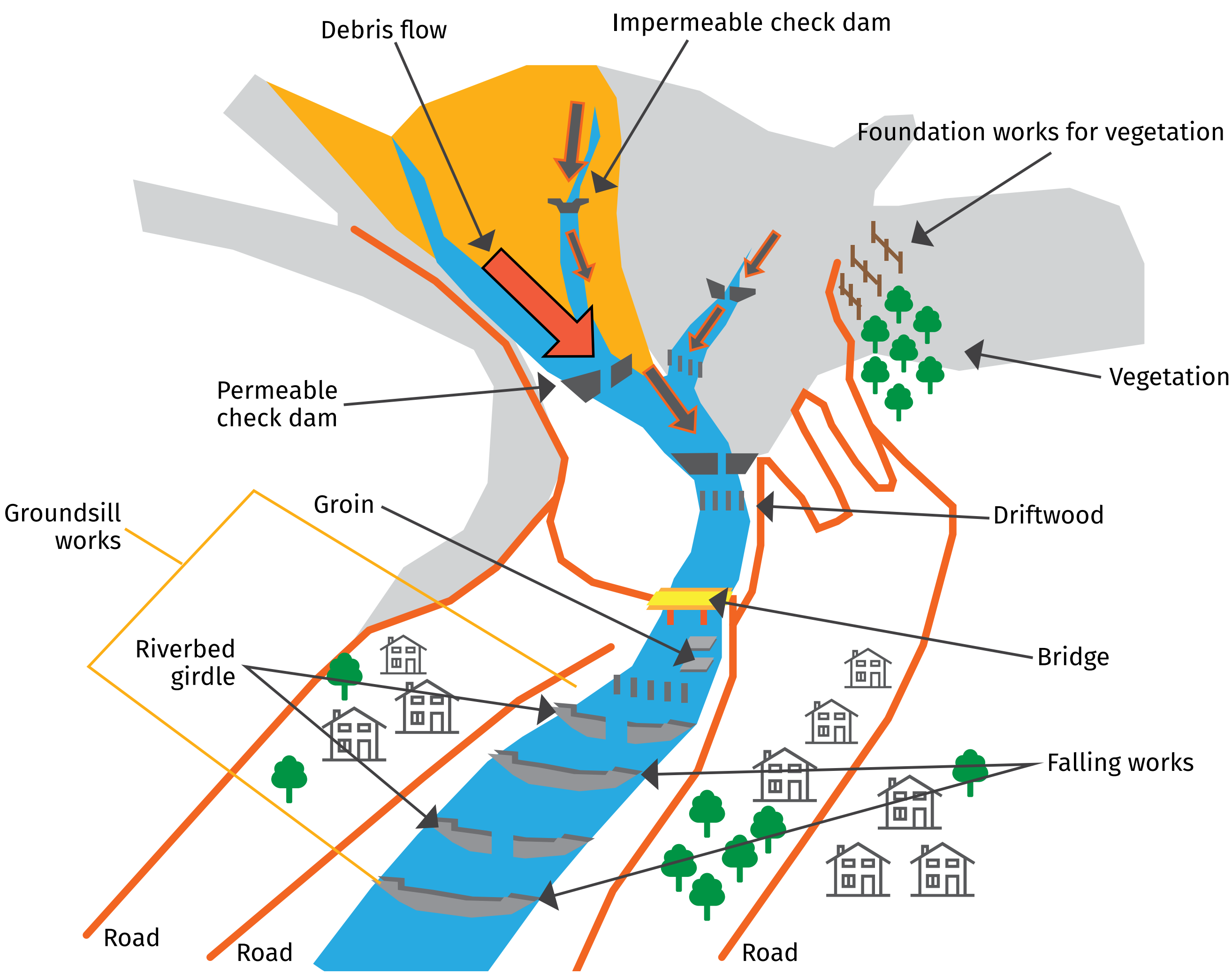
Source: Adapted from GESU-DOR 2007. ©Department of Roads (DOR), Ministry of Physical Planning and Works, Government of Nepal. Adapted, with permission, from DOR; further permission required for reuse.

[16] A gabion is (a) a hollow cylinder of wickerwork or strap iron, like a basket, that is filled with stones or earth and used in building fieldworks as revetments; or (b) a gabion-like contrivance filled with stones, to assist in forming an earth retaining wall, dike, or similar structure.

Catchment-based sediment management facilities are also adequate to mitigate riverside road erosion in mild erosion situations. Landscape ecosystem management not only affects the road section itself but also mitigates river erosion risk for other nearby properties through the slowing of water flows.

Catchment-based sediment management is subdivided into measures for riverbed degradation or aggradation. The riverbed degradation measures include groundsill works, which are divided into riverbed girdles and falling works (Figure 4.8). A riverbed girdle is a structure whose crown (the highest surface of the structure) is at the same level as the riverbed; it is the least expensive way to protect the riverbed. In contrast, falling works have the crown higher than the riverbed to reduce flow speed. The measures for riverbed aggradation aim to mitigate flow-type geohazards such as debris flows and flooding by maintaining the flow capacity of the waterway. Bioengineering in the landscape ecosystem comprises vegetation and foundation works, which decrease rainfall runoffs. These decrease flow-type geohazard or erosion volumes (sediment yields) and riverbed aggradation.

Figure 4.8: Catchment-Based Sediment Management Facilities to Mitigate Road Riverside Erosion and Flow-Type Geohazards



4.4.3 STRUCTURAL MEASURES FOR SLIDE-TYPE GEOHAZARDS

The countermeasures for slide-type geohazards are subdivided into three main types of risk mitigation (Table 4.4):

- Avoidance of the area
- Reduction of the slide's driving force
- Increase of the resisting force against the slide.

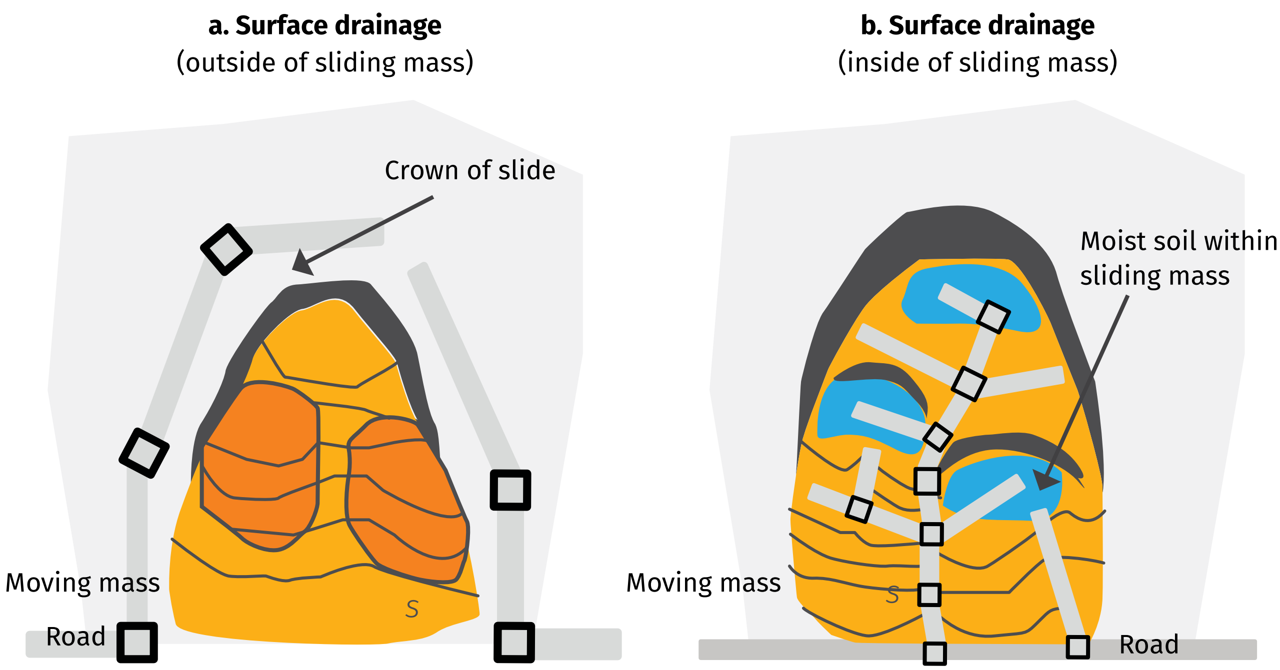
The slide's driving force can be reduced by removing the head top portion of the slide-prone terrain (earthworks). Strengthening of the resisting force against slides can be done using counterweight fills (earthworks), along with ensuring that water drainage or infiltration prevention is in place to increase internal friction strength.

Table 4.4: Typical Structural Measures for Slide-Type Geohazards

PRIMARY CATEGORY	SECONDARY CATEGORY	TERTIARY CATEGORY	PROCEDURE OF CONCEPT DESIGN LAYOUT
Sliding area avoidance	Road alignment selection or realignment to avoid endangerment by slides		Lay out the alignment if land acquisition is realistic.
Reduction of slide's driving force	Earthworks	Removal of rock or soil of slide head to reduce weight	Planning the layout of the earthworks in the available land use is a priority.
Strengthening of resisting force against slides	Earthworks	Counterweight fills on sliding foot	Planning the layout of the earthworks in the available land use is a priority.
	Water drainage or infiltration prevention to increase internal friction strength	Ground surface drainage (Figure 4.9)	Lay out to drain the surface water and/or surface groundwater so as not to infiltrate deeper ground or increase water pressure on the sliding surface.
		Surface-groundwater collecting conduit with ground surface drainage (French drain) (Figure 4.10 and Photo 4.2)	
		Subsurface drainage (drainage drilling) (Figure 4.11 and Photo 4.3)	Reduce the water pressure affecting the sliding surface to increase the resident force of the slide. The drilling layout covers all sliding mass horizontally (generally 5–10 degrees upward) with the length of drilling at generally 20–50 meters.
		Vegetation or bioengineering (Figure 4.9)	Reducing the infiltration of rainfall is supplementary work.
	Installment of external resisting force	Ground anchors (Figure 4.12)	Ground anchors and piles are planned additionally if the other works cannot meet the slope stability requirement sufficiently.
		Piles	
		Retaining structures such as crib walls or reinforced earth	
		Installation of geosynthetic protection or slope mesh	

Ground surface drainage is illustrated in Figure 4.9. The left-side figure (panel a) shows ground surface drainage to prevent surface water inflow from the outside to the inside of the sliding area. The right-side figure (panel b) shows how to drain surface water from inside of the sliding area to the outside. The practicality of subsurface drainage needs to be examined by a skilled specialist because there is a risk that further land movement could result in a blockage of the drains, requiring further drilling.

Figure 4.9: Ground Surface Drainage for Slide-Type Geohazard



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Although not affecting transport infrastructure, the Cairnmuir Landslide in New Zealand—50 meters above the surface of Lake Dunstan and held back by the Clyde Dam—provides an excellent example of both of these surface drainage approaches. The Cairnmuir Landslide is a slow-moving (less than 300 millimeters per year) landslide that was considered a risk of giving way into the lake and overtopping the Clyde Dam (a 100-meter-high concrete hydroelectric dam). To reduce the risk, the ground surface of the landslide was covered with a waterproof coating and surface drainage over an area of some 14,000 square meters. Within the landslide itself, some 18 kilometers of drainage tunnels were bored to lower the water table and further stabilize the slope. The total cost of stabilizing the landslide would be close to US$1 billion in today's terms (in 2019).

A surface-groundwater collecting conduit with ground surface drainage also called a French drain is standard practice to control the sensitive groundwater level rising in response to rainfall and activation of sliding by intense rainfall (Figure 4.10).[17] Surface groundwater is collected into a conduit section made of crushed stone through a perforated drainage pipe, which is a perforated pipe covered with permeable textile (geotextile). The bottom and sides of the conduit portion are enclosed by an impervious sheet (geomembrane) to avoid the leakage into lower ground. The collected surface groundwater is flowed down the drainage pipe for several tens of meters and flows out into open space at the catch pit, where it is drained into an open ditch (Photo 4.2).

[17] A French drain or weeping tile (also blind drain, rubble drain, rock drain, drain tile, perimeter drain, land drain, French ditch, subsurface drain, subsoil drain, or agricultural drain) is a trench filled with gravel or rock or containing a perforated pipe that redirects surface water and groundwater away from an area. A French drain can have perforated hollow pipes along the bottom to quickly vent water that seeps down through the upper gravel or rock.

Figure 4.10: Surface-Groundwater Collecting Conduit with Ground Surface Drainage

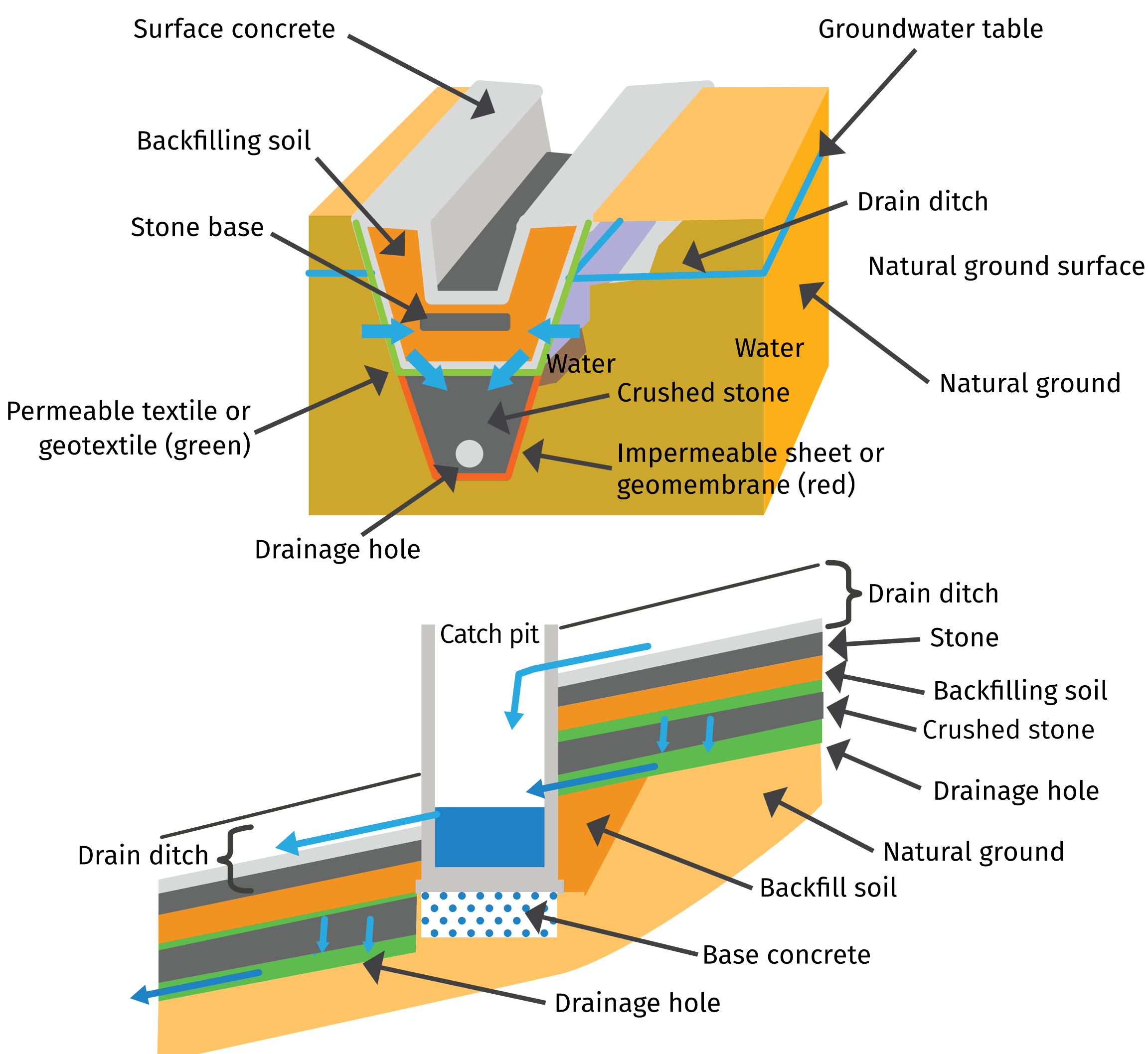

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Photo 4.2: Surface-Groundwater Collecting Conduit with Ground Surface Drainage at Catch Pit

The site is a section of the Sindhuli-Bardiabas Road in Nepal, August 2014.

The image displays drained, collected surface groundwater from a conduit drainage pipe.

Source: Mikihiro Mori / Japan International Cooperation Agency (JICA). ©JICA. Reproduced, with permission, from JICA; further permission required for reuse.

Subsurface drainage drilling is also a common practice to lower the groundwater surface more drastically, decrease pore water pressure at the sliding surface, and increase the internal friction strength at the sliding surface on the subsurface. The most common practice is horizontal drilling drainage from roadside to mountainside with a 5- to 10-degree elevation angle (Figure 4.11). The longest practical length is 100 meters in most situations. It is important that the drainage of collected groundwater from the outlet of the pipe extends to the outside of the sliding mass or to an area not affected by geohazards. The installation of the drainage requires specialized skills and equipment to determine the correct spacing and length of each drilled hole, both to ensure its effectiveness and to avoid exacerbating the risk of a landslide. Once the hole is drilled, a perforated pipe (wrapped in geotextile fabric) is typically installed to collect water and transport it to the surface. As noted earlier, in the Cairnmuir Landside in New Zealand, more than 18 kilometers of subsurface drainage was installed. A further example is shown in Photo 4.3.

Figure 4.11: Subsurface Drainage Drilling

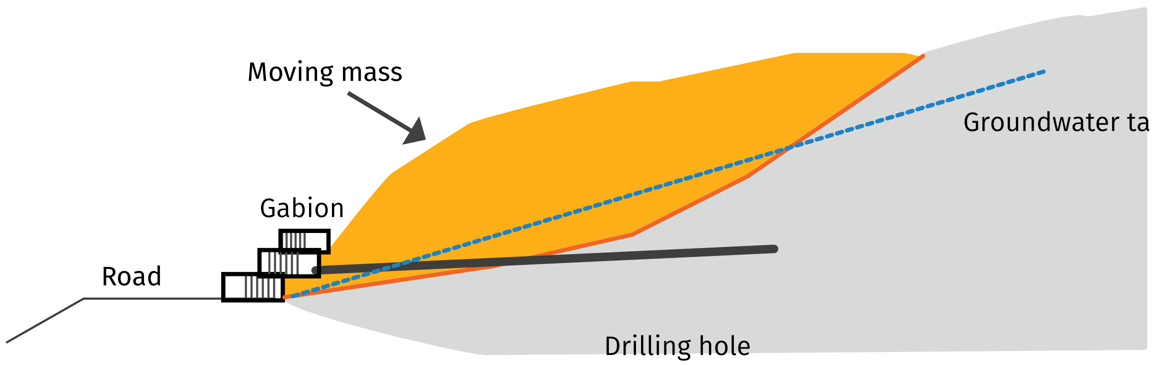

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Photo 4.3: Drained Subsurface Water at a Sliding Road Mountainside Slope

This drilling operation, in El Salvador, was managed by the JICA Technical Cooperation Project team, April 2013.

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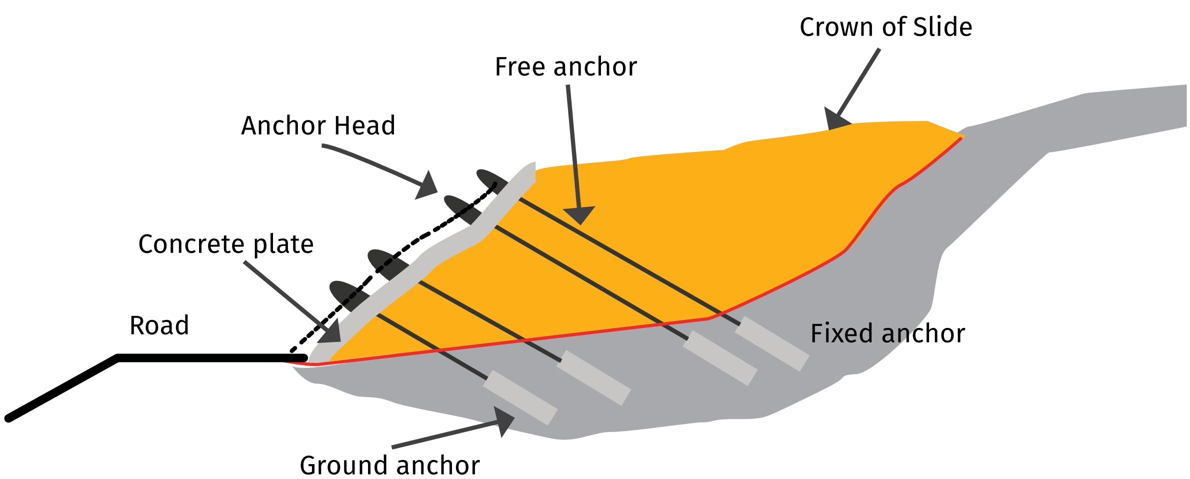
Use of ground anchors is another popular practice on road slopes to apply external resistance force against slide-type geohazards. Such external resistance force works are called "restraining works," and their implementation depends on the requirements defined after "control works" (earthworks and drainage works) are completed.

A ground anchor (as shown in Figure 4.12) is a device designed to apply external resistance force to the sliding surface. It is divided into three parts: a fixed anchor (fixed using grouting to the stable ground), a free anchor (to transmit the tensile force), and an anchor head with a concrete plate (which takes the reaction at the surface part).

Figure 4.12: Ground Anchors as External Resisting Force for Slide-Type Geohazard



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For many years, geosynthetics have been applied to enhance the performance of structural measures. Geosynthetics have been used to support geohazard measures as follows:

- Reinforcement of embankment slope soils with reticulated geogrid
- Prevention of soil draw-out for the sand and fine-grained soil from cut slopes and for drainage of water-permeable ground with nonpermeable, cloth-like geotextile
- Prevention of infiltration of surface water and rainwater under the ground with nonpermeable, cloth-formed geomembrane
- Drainage of materials in the back of the vegetation foundation of cut slopes with the geocomposite drain
- Coverage of perforated pipe with geotextile.

Given the diverse range of geosynthetics available in the marketplace and their diverse range of uses, installation requirements, and functionality, further details on these are not contained within this manual.

4.4.4 STRUCTURAL MEASURES FOR FLOW-TYPE GEOHAZARDS

The planner or designer shall conduct the hydrological and hydraulic calculation using the intensity-duration-frequency (IDF) of rainfall for the selection of countermeasure types and design for flow-type geohazards (debris flows, earth flows, and flash floods). Properties of the flow, such as the component ratio of the flow (contents of stone, soil, and water) are also important to consider when designing the structural measures to ensure that flow paths are not readily blocked, resulting in the overtopping of drainage structures and subsequent erosion of the road or diversion of floodwaters into adjacent land.

The countermeasures for flow-type geohazards are subdivided into three main types: adequate flow structures for road-crossing waterways, retarding or protection structures, and landscape ecosystem conservation (Table 4.5).

Table 4.5: Typical Structural Measures for Flow-Type Geohazards

<table>
<tr><th>PRIMARY CATEGORY</th><th>SECONDARY CATEGORY</th><th>PROCEDURE OF CONCEPT DESIGN LAYOUT</th></tr>
<tr><td rowspan="3">Adequate flow structure of road-crossing waterways</td><td>Road bridge</td><td rowspan="3">Lay out waterway structure with adequate capacity against flow-type geohazards.</td></tr>
<tr><td>Road-crossing culvert</td></tr>
<tr><td>Ford river crossing: (a kind of bridge or culvert that allows flood and soil or rock flows to cross, passing over the road surface (Figure 4.13)</td></tr>
<tr><td rowspan="2">Retarding structure</td><td>Sand pockets</td><td rowspan="6">Regarding the protection structure for landscape ecosystem conservation, it is conceptually designed so that, to reduce the peak flow rate, land for temporary water retardation upstream of the stream or river crossing is available. This is normally planned for regional flow-type geohazard control (not only for a specific road location).</td></tr>
<tr><td>Stormwater storage, retarding basin</td></tr>
<tr><td rowspan="2">Protection structure</td><td>Debris flow check dam (Figure 4.14)</td></tr>
<tr><td>Flood control dam</td></tr>
<tr><td rowspan="2">Landscape ecosystem conservation</td><td>Hillside works or reforestation to reduce stormwater runoff (Figure 4.8)</td></tr>
<tr><td>Groundsill (Figure 4.8)</td></tr>
</table>

Structures for waterway crossings should be designed using appropriate target return periods of floods, with appropriate consideration of the impact of soil, rocks, and other debris in the water. As a low-cost measure for low-volume roads or roads that are not required to deliver all-weather access, ford river crossings are designed. A ford river crossing is a kind of bridge or culvert that allows flow-type geohazard elements (flooding and soil or rock flows) to cross and pass over a road surface. An adequate flow structure for fords will not overflow into the neighboring carriageway outside of the ford structure or waterway and will not be destroyed by the flow-type geohazard crossing over the ford. Floods and soil or rock will flow transversally to the concrete road surface, and the road is closed during periods of flooding.

A ford river-crossing structure (Photo 4.4 and Figure 4.13) is made of reinforced concrete to be robust against the shock of colliding stones and to prevent erosion during periods of high flow. Protection walls are placed on the upstream side of the ordinary road sections to prevent water with soil or stones from reaching the road pavement (outside of the ford structure). Depending on the volume of water in the river, ford crossing culvert pipes may be installed with sufficient capacity to handle the river flow under normal weather conditions, with the alternative being a permanent flow of water of less than 200 millimeters in depth[18] across the ford at all times.

[18] Above this level, crossing on foot, bicycle, or motorcycle becomes difficult, and water can enter the footwell of motor vehicles with low ground clearance.

Photo 4.4: Examples of Ford River-Crossing Solutions

a. Ford river crossing without culvert

This type of crossing is for a river whose water level presents a problem only during flooding. The ford river crossing is a type of bridge that allows the flow of flooding water to cross over the carriageway. It is used on rivers whose riverbeds have a gentle gradient.

b. Ford river crossing with culvert

This type of ford river crossing is for a river where water flows not just during flooding but also during normal times.

c. Ford river crossing of continuous box type

Although not technically a ford, this type of crossing is applied to large-flow-rate rivers. It is designed to allow flooding water over the carriageway.

Source: ©Department of Roads (DOR), Ministry of Physical Infrastructure & Transport, Government of Nepal. Reproduced, with permission, from DOR; further permission required for reuse.

Figure 4.13: Sample Ford River Crossing

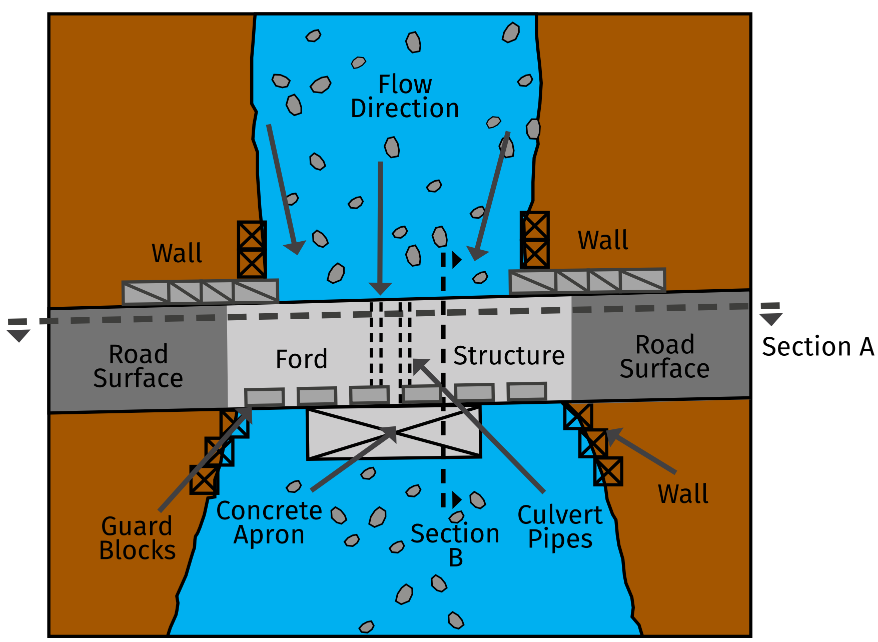
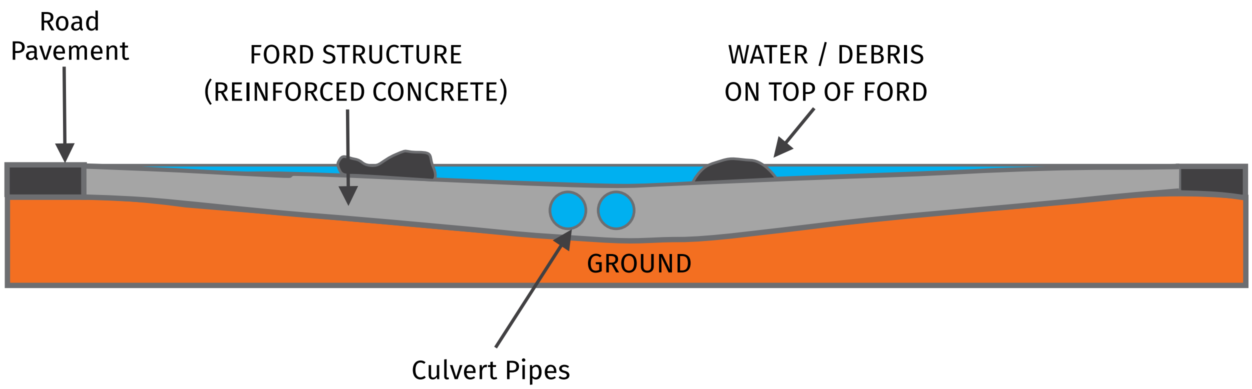
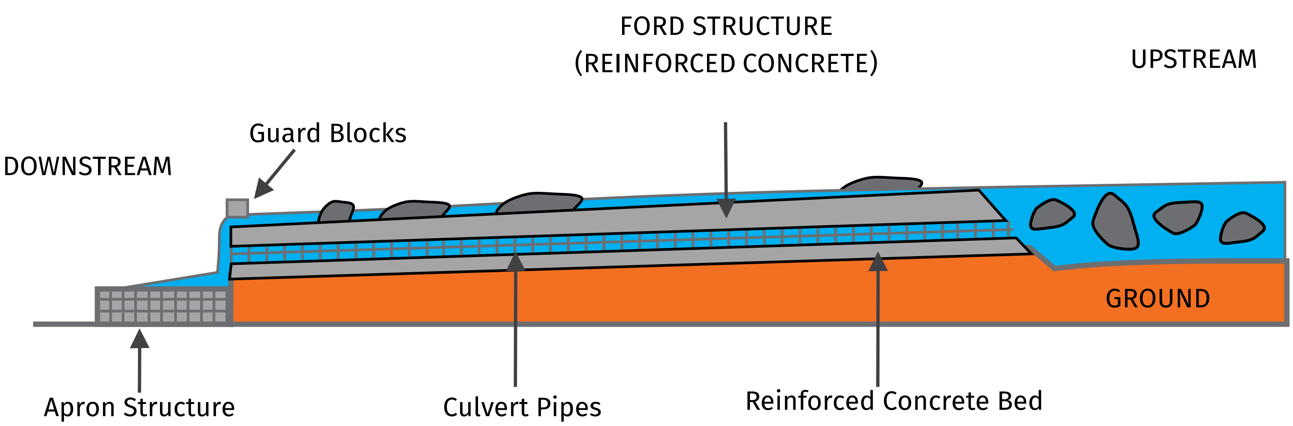


Figure 4.13: Sample Ford River Crossing (cont.)

SECTION A



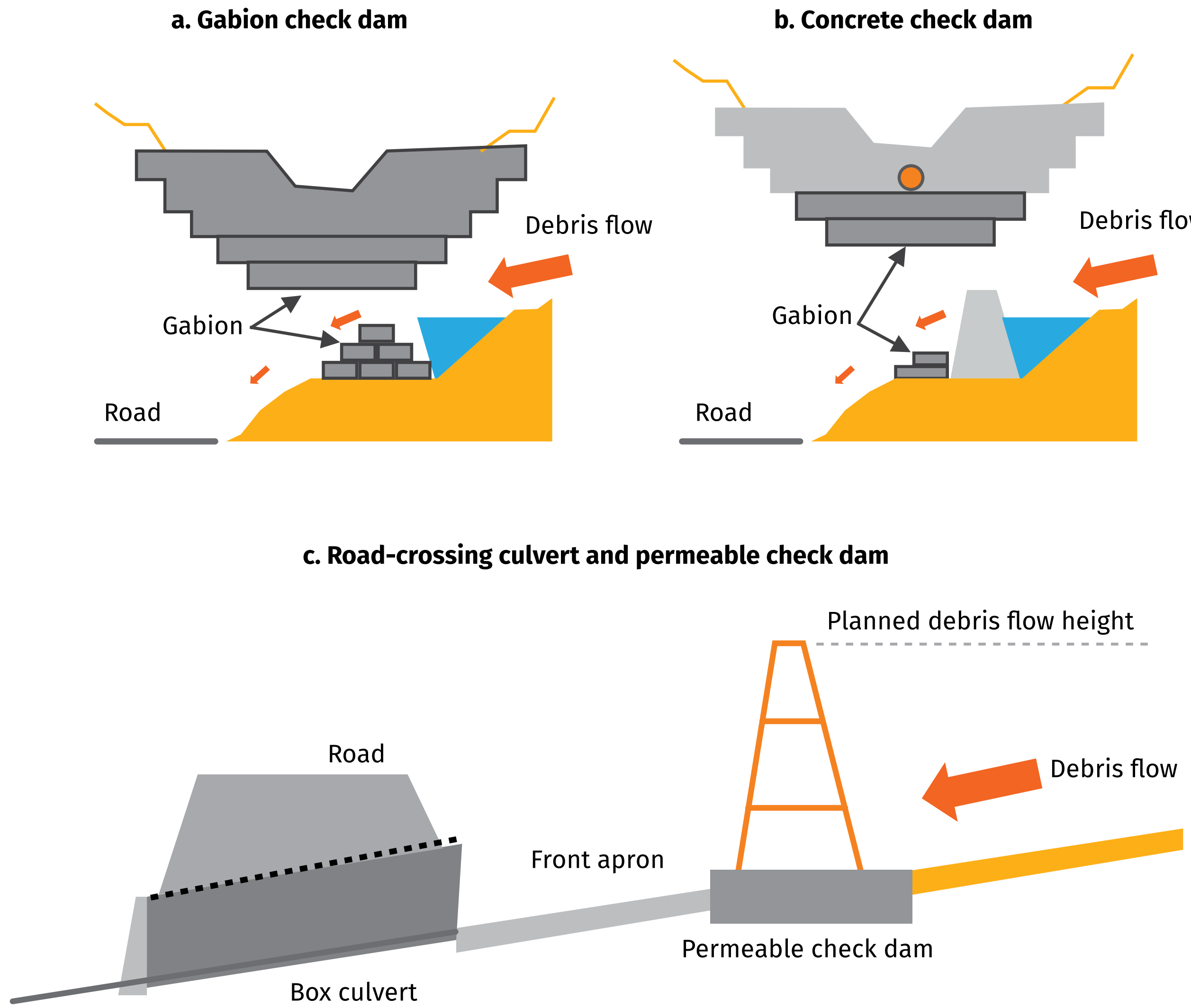
SECTION B



Source: © World Bank. Permission required for reuse.
Note: A "ford river crossing" refers to a kind of bridge that allows flow-type geohazard elements to pass over the road surface.

Check dams (Figure 4.14) provide protection to roads and other infrastructure against flow-type geohazards. Concrete-type check dams with outlet conduits are typically used for flood control (Figure 4.14, panel b). Gabion-type check dams are a lower-cost option to the concrete solution and require a foundation treatment such as soil cementing to protect the foundation against scouring (Figure 4.14, panel a). Permeable check dams, such as those made from gabions, have the advantage of not disturbing the natural water and sediment flow; they protect only against large boulder stones or driftwoods during a flooding event (Figure 4.14, panel c). Check dams are commonly used to control erosion and sedimentation in roadside drains. They slow down water flow (reduce erosion of the drain) and allow for sediments to fall out into the dam area behind each check wall. It is important that the system be kept well maintained or it loses its effectiveness.

Figure 4.14: Protection Structures against Flow-Type Geohazards



Source: © World Bank. Permission required for reuse.

4.5 SELECTED RESOURCES

The following annotated list provides resources pertaining specifically to the topics covered in Part IV.

AASHTO (American Association of State Highway and Transportation Officials). 2007. *Highway Drainage Guidelines*, 4th ed. Washington, DC: AASHTO. Provides hydrologic and hydraulic calculation procedure and road drainage design.

Cruden, D. M., and D. J. Varnes. 1996. "Landslide Types and Processes." In *Landslides: Investigation and Mitigation*, edited by A. Keith Turner and Robert L. Schuster, 20–47. Washington, DC: Transportation Research Board. Provides investigation and mitigation procedures.

Deoja, B., M. Dhital, B. Thapa, and A. Wagner, eds. 1991. *Mountain Risk Engineering Handbook*. Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD). Provides the stability analysis of slope (chapter 13), construction materials (chapter 15), retaining walls (chapter 17), drainage (chapter 19), detailed survey and design (chapter 24), and construction (chapter 25).

FHWA (Federal Highway Administration). 2012. "Hydraulic Design of Highway Culverts, Third Edition." Publication No. FHWA-HIF-12-026, FHWA, U.S. Department of Transportation, Washington, DC. Provides hydrologic and hydraulic calculation procedures and road-crossing culverts design.

GESU-DOR (Geo-Environment and Social Unit, Ministry of Physical Planning and Works, Government of Nepal). 2007. "Roadside Geotechnical Problems: A Practical Guide to Their Solution." Guidelines document, GESU-DOR, Kathmandu, Nepal. Appendix provides examples of different structural measures.

Highland, Lynn M., and Peter Bobrowsky. 2008. "The Landslide Handbook: A Guide to Understanding Landslides." Circular 1325, U.S. Geological Survey, Reston, VA. Provides landslide mitigation concepts and approaches in its Section III.

Howell, J. 1999. *Roadside Bio-Engineering: Site Handbook*. Kathmandu, Nepal: Department of Roads, His Majesty's Government of Nepal. Provides details on roadside vegetation works.

IGS (International Geosynthetics Society) website, http://www.geosyntheticssociety.org/, provides instruction for the use of geosynthetics in geohazard risk management measures.

JLS (Japan Landslide Society). 2012. "Landslides in Japan (The Seventh Revision)." Periodic report, JLS, Tokyo. Provides investigation procedures and examples of structural measures.

Keller, Gordon, and James Sherar. 2003. "Low-Volume Roads Engineering: Best Management Practices Field Guide." Report prepared for the U.S. Agency for International Development, Washington, DC. Provides many low-cost structural measure techniques.

Winter, M. G., F. Macgregor, and L. Shackman, eds. 2005. *Scottish Road Network Landslides Study*. Edinburgh: Scottish Executive. Provides structural measure techniques for debris flow in section 8.4 ("Mitigation Techniques").

World Bank. 2012. "Field Guide on Soil Bioengineering for Slope Stabilization in Timor-Leste." Working Paper No. 73666, World Bank, Dili, Timor-Leste. Provides vegetation technique for slope protection.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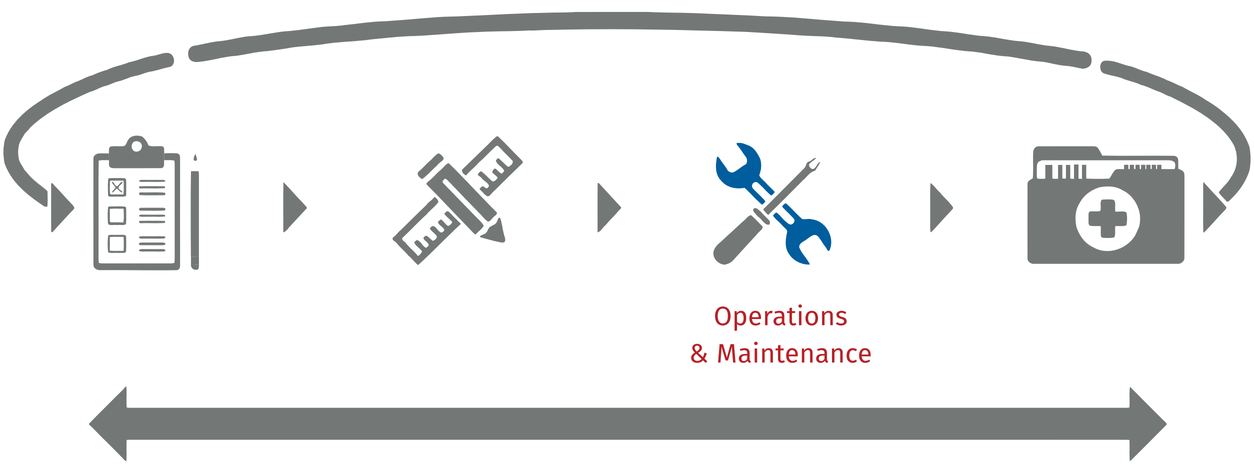
5

OPERATIONS AND MAINTENANCE


Operations
& Maintenance

5.1 OVERVIEW OF OPERATIONS AND MAINTENANCE MEASURES FOR GEOHAZARDS

Part V provides procedures to enhance road geohazard risk management through preparedness or other nonstructural measures in the operations and maintenance stage.

Part V of the handbook

- Defines and explains the activities of nonstructural measures and important practices to increase positive effects; and
- Explains the procedures and operational considerations regarding the nonstructural measures.

The reader is also advised to see the following reference documents pertaining to Part V:

- Terms of Reference 5 (ToR 5), Development of Manual for Operation and Maintenance for Road Geotechnical Assets (in Appendix A), is a standard terms of reference (ToR) to formulate manuals in the maintenance of structural measures, early anomaly detection and emergency information collection, and emergency preparedness and response.
- Terms of Reference 6 (ToR 6), Development of Emergency Information System (in Appendix A) is a standard ToR to develop a road emergency information system, including early warning or precautional road closure.
- Road Geohazard Risk Management: Case Study of Japan (in Appendix C) shows examples of nonstructural measures in Japan.

The achievements after using Part V are

- To understand the purpose and procedures of nonstructural measures;
- To understand the planning and operational consideration of nonstructural measures; and
- To understand the importance of good communication with key stakeholders and their participation for effective nonstructural measures.

5.2 DEFINITION OF NONSTRUCTURAL MEASURES

In contrast to structural measures, nonstructural measures for road geohazards are any measures not involving physical construction. They are less expensive than structural measures and include

- Routine maintenance of previously constructed measures;
- Monitoring of geohazards (potentially using automatic measuring devices, linked to automated warning systems); and
- Road closures to prevent injury before (or during) a geohazard event.

Nonstructural measures include risk avoidance methods (such as advanced warning or closing roads) to prevent vehicle damage and loss of human life even if a geohazard event occurs, and they seek to ensure efficient maintenance of the structural measures for geohazard risk management.

5.3 ROAD DISASTER AWARENESS

5.3.1 CONTROL OF ROAD DISASTERS CAUSED BY HUMAN ACTIVITIES

Human activities often trigger road geohazard disasters. For example, garbage and accumulated sediment (including the deliberate infilling of side drains for property access) in roadside drainage makes the drainage less effective and could activate a road geohazard. Water use, such as irrigation or deforestation, and banking of the potential sliding slope head or cutting the slope foot may cause geohazard activities as well.

Raising public awareness is a first step toward stopping harmful human activities that could induce geohazards on roads. Laws and regulations that control land use are also necessary to prohibit harmful human activities that may cause geohazards.

5.3.2 TRAFFIC SIGNS TO RAISE AWARENESS

The road management authority installs traffic signs and uses intelligent transport systems (ITS), mobile phone warnings, social media, websites, or other channels to inform road users of endangered road locations, hazard-prone road subsections, and road subsections selected for the precautionary road closure to protect road users from disasters and accidents.

5.3.3 AWARENESS RAISING AND TRAINING FOR ROAD STAKEHOLDER ENGAGEMENT

Engagement of the primary road stakeholders (road users and residents near the road) requires that they receive information on any abnormality (as described below in section 5.5.3) as well as on the control of road disasters caused by human activities (as noted above). Toward those ends, an awareness-raising campaign or training is preferably conducted.

Holding a campaign or training along with a road safety campaign or a community disaster evacuation drill (if in an urban area or if the geohazard event would isolate a community) are practical steps. It is also practical that any such awareness campaign, training, or drill involve the various and institutional partnerships as described in section 5.6.

5.4

5.4 MAINTENANCE OF STRUCTURAL MEASURES

Appropriate maintenance of structural measures guarantees the measures' proper effect. This handbook includes the maintenance of structural measures among the nonstructural measures because such maintenance is work conducted without the need for a specific design. Proper maintenance requires preparation of an inspection schedule, maintenance procedures, materials, and machinery.

Maintenance includes the removal of sediments in debris flow protection dams or sand traps and the preservation of slope vegetation. Maintenance costs and their availability are considered during the planning stage. A feasibility assessment of the structural measures is commonly included in the maintenance costs.

The maintenance of structural-measure methods established in roads or adjacent to them is unified with the maintenance of roads such as pavements and carried out by road management offices, branch offices, and commissioned private companies and workers. The road management authorities develop the maintenance plans (such as yearly maintenance plans) of structural-measure methods (systems, schedules of patrol or checking, materials, and preparations of machine parts), and they measure the budget as a part of the maintenance plans of roads.

The maintenance and management of structural-measure methods are often not limited to the operation of roads maintenance entities. Such methods (for example, removal of earth and debris from a dam or a sedimentary sand place and maintenance of seeding and planting works in a basin) are established in road crossings outside the road management sites or valley streams and rivers to the side against flow-type disasters such as earth and debris flows, floods, and flash floods. Therefore, the road management authorities adjust their plans and budgets with disaster management authorities as well as with the organizations, local governments, communities, and other entities that manage maintenance entities such as water utilization and conservation of mountains, river improvement, erosion control, and irrigation.

5.5 EARLY ANOMALY DETECTION AND EMERGENCY INFORMATION COLLECTION

5.5.1 VISUAL INSPECTION AND HAZARD MONITORING FOR EARLY ANOMALY DETECTION

The early detection of anomalies is important to prevent disasters and avoid damages for road users. Both visual inspections and specific geohazard monitoring have their place in this effort.

The visual inspections are conducted using a range of tools and techniques and are carried out either by vehicle or on foot. Based on their frequency, they are subdivided into the following:

- ***Routine patrol:*** Visual observation conducted from vehicles daily, weekly, or at some other time interval. These are typically undertaken by staff with limited geohazard technical expertise but who often have significant experience on the road network and are aware of how the network performs and where high-risk locations are.
- ***Inspection patrol:*** Inspection of endangered road locations before and after the rainy season, earthquakes, or other potentially hazardous events. It is performed with the aid of the hazard inspection record format and past records including photos or sketches.
- ***Emergency patrol:*** Inspections during highly disaster-susceptible situations or in response to complaints of abnormalities from road users or other observers. The initial emergency patrol may then generate the need for a specialist's inspection.
- ***Automated geohazard monitoring:*** Monitoring of failing (falling, collapsing, or sliding) slope ground movement and geohazard triggers such as heavy rainfall or the rise of groundwater tables (Table 5.1). The monitoring is conducted at prioritized endangered road locations where structural measures have not been implemented owing to budgetary or technical difficulties. The monitoring results are used as criteria for early warning and precautionary traffic closures to avoid damages to road users.

Table 5.1: Geohazard Monitoring Types and Equipment Used

GEOHAZARD PHENOMENA	HARDWARE SUPPORT
Surface movement	Monitoring CCTV camera Rockfall detector Extensometers Crack gauge Surface tilt meter GPS devices LiDAR
Subsurface movement	Borehole inclinometers Pipe strain gauge meters
Groundwater fluctuation	Groundwater meter Piezometer
Rainfall	Rain gauge Automatic weather station

Note: CCTV = closed-circuit television. GPS = global positioning system. LiDAR = Light Detection and Ranging. For useful references about information and communication technology (ICT) for geohazard risk management, see the Japan Bosai Platform's Solution Map, https://bosai-jp.org/pc/solutionmap. In addition, Highland and Brobowski (2008) provide landslide monitoring procedures (in appendix B) and sample safety information for landslides or debris flows (in appendix D). JLS (2012) provides examples of slope movement measurement.

Routine geohazard patrols can be combined with other functions such as road operation maintenance. Trained patrol staff should be assigned to the geohazard-prone road subsections to look for geohazard abnormalities. The ideal solution uses the monitoring equipment shown in Table 5.1; however, should funding not permit, there are simple equivalent monitoring techniques that don't require expensive machinery and materials. Instead of a fully automated weather station, for example, a manual rain gauge will also provide key inputs to the monitoring of geohazard risk profiles.

Light Detection and Ranging (LiDAR) systems are becoming ever more affordable and are part of many road authorities' standard equipment sets—especially when combined with a drone to capture video and photographic data. For high-risk sites, drones can be flown at regular intervals and the resultant three-dimensional (3-D) land models compared within geographic information systems (GIS) to identify the area and scale of land movement. Not only is this often more affordable than installing sensors into a geohazard; it can also cover many more geohazards for the same cost.

5.5.2 EMERGENCY INFORMATION COLLECTION SYSTEM

Emergency information can be obtained from road users and stakeholders and through geohazard monitoring. Road users and residents near the road can contact road management authorities to inform them of road abnormalities via telephone, the internet, or face-to-face communications. Usually, a specific telephone number is assigned for such emergency communication, although it is seldom confined to a single type of emergency (such as geohazards). To guarantee the stakeholders' engagement, road disaster awareness efforts are also required (see Section 5.3).

When a road management authority receives the information from road users or residents, it checks for abnormalities and takes emergency actions if necessary.

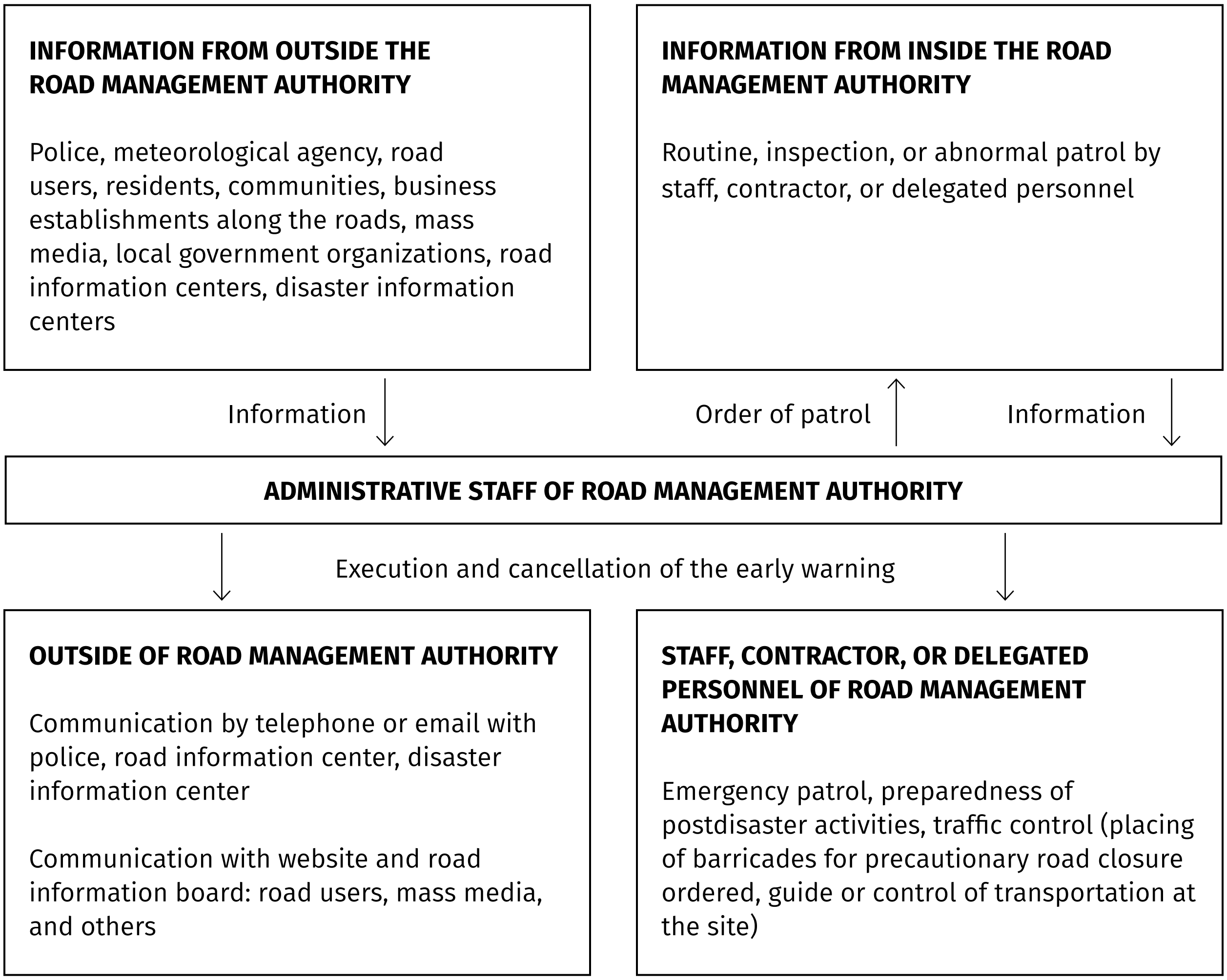
5.5.3 ROAD EMERGENCY INFORMATION SYSTEM INCLUDING EARLY WARNING OR PRECAUTIONARY ROAD CLOSURE

A road condition emergency information system is effective in providing road users with information about geohazard damage occurrences, situations highly susceptible to geohazards, and traffic conditions including road closures. Such early warnings and precautionary information give road users the ability to minimize their losses in adverse conditions by enabling alternative route choices—and, in extreme cases, can avoid loss of life.

Geohazards are often triggered by heavy rainfall. Therefore, a rainfall index often provides an early warning and be used as criteria for a precautionary road closure. The information can be disseminated via road information boards, road operations and maintenance staff, traffic police, mass media, websites, mobile phone alerts, and roadside facilities such as fuel stations. Because the dissemination of information is highly important for geohazard risk reduction, collaboration must be strong between the road management authority, the local or highway police, and the mass media.

The flows of early warning or precautionary road closure information due to geohazards (Figure 5.1) reflect the multifaceted challenges involved in terms of both collecting and dispersing information.

Figure 5.1: Flows of Early Warning or Precautionary Road Closure under Highly Susceptible Road Damage Situation due to Geohazards



The geohazard warning system should be part of the overall road authorities' early warning system that covers any situation that is highly susceptible to disasters and traffic accidents, such as dense fog and strong wind. The early warning is just a warning without any physical measures, but the precautionary road closure is the decisive ordering of a road closure. The decisions to issue warnings and order road closures should be carefully determined based on the level of danger and adherence to established procedures. The road management authority selects the road sections for early warnings or precautionary road closure—the disaster-prone or accident-prone road sections during abnormal weather or other conditions such as river floods or flood tides—and then uses established procedures as follows:

- ***Preparation of criteria for early warning or precautionary road closure.*** The road management authority uses an index of hazard-trigger condition or geohazard activation (for example, the amount of rainfall or thawing, wind speed, increase in the speed of a slow-moving ground mass [measurable using strain gauges or automated survey equipment], volcanic activities, and so on) to set the criteria for early warning or precautionary road closure for each of the selected road sections.

- ***Execution of the early warning or precautionary road closure.*** When the early warning or the precautionary road closure starts, the road management authority announces the possibility of a geohazard damage event or dangerous conditions that could cause traffic accidents, as well as the dangerous road sections, using road information sign boards or other types of notices. During the ordering of precautionary road closure, the road management authority also places barricades to stop traffic at the start and end points of each of the dangerous road sections. A precautionary road closure has difficult operational aspects because it causes losses to road users due to detours, time spent waiting for traffic opening, or trip cancellations. It is thus necessary to minimize the period of road closure. The first practical step should be an early warning that is not accompanied by any road closures. The precautionary road closure needs to be supported by the traffic police using all applicable laws.
- ***Cancellation of the early warning or the precautionary road closure.*** To cancel the early warning or the precautionary road closure, the road management authority sends a patrol to the dangerous road sections and confirms that no abnormalities remain in the aftermath of the abnormal climate situation or other dangerous situations.

5.6 ROLES OF VOLUNTEERS, LOCAL COMMUNITIES, AND INSTITUTIONAL PARTNERSHIPS IN GEOHAZARD RISK MANAGEMENT

The partnership between the road sector, local stakeholders, and the private sector, including residents, can enhance information sharing, help prevent road disasters, and improve road geohazard risk management. The following actions can help to form good partnerships:

- Information sharing (as described earlier in Sections 5.3 and 5.5) and integration of the disaster emergency information systems of the community or municipality with the road emergency information system
- Meetings of subnational governments, bus and taxi transport organizations, and the national road administration
- Volunteer support programs for road disaster management (for example, road drainage maintenance including garbage clearance, snow clearance, and maintenance of roadside trees and road slope vegetation)
- Creation of incentives for volunteer support, such as the installation of roadside billboards to promote the supporting organizations or private companies.

5.7 ASSET MANAGEMENT AS A RESPONSE TO DISASTERS

As noted in Part II, Section 2.2, geohazard management is part of the overall asset management practice within a road authority, with Figure 2.1 providing an example of an overall asset management process. Although climate change is not the same as geohazard management, there are significant overlaps between the two subjects, and it is worth reflecting on the specific actions proposed by Henning, Tighe, and Greenwood (2017), who reviewed the asset management process and proposed specific additional activities that should be incorporated into each stage of the process to ensure climate change was appropriately addressed. Their proposed approach includes a series of specific initiatives that should be implemented to ensure that geohazard management is considered at each stage of the asset management process (Table 5.2).

Table 5.2: Recommendations for Integrating Geohazard Management into Asset Management

PHASE	STEP IN AM PROCESS (REFER TO FIGURE 2.1)	KEY ADDITIONAL ACTIONS
UNDERSTAND AND DEFINE REQUIREMENTS	Develop the AM policy	• Specifically address geohazard risk management within the AM policy statement, including what horizon is to be planned for. • Have agreements in place on how the damage from major events will be funded and who will be entitled to financial support.
	Define levels of service and performance	• Ensure that network resilience measures (for example, restore all major roads within 12 hours of the end of a 1-in-100-year flood) are included into the level-of-service framework. • Revise design guides to take into account the changing frequency of climatic events, and ensure that design standards are in place for geohazards.
	Forecast future demand	• Future demand forecast such as demographic changes and traffic-loading increases should be integrated with geohazard impacts on the expected performance of infrastructure. • Providing for future growth in high-risk areas should be avoided (or at least fully understood ahead of growth being permitted).
	Understand the asset base	• Ensure that data on highway assets and their vulnerabilities or deficiencies are complete and up-to-date. • All data collection processes should be geospatially referenced. • Road data and information should highlight interdependencies with other infrastructure. • Link lifelines and critical interactions between asset groups in the base data.
	Assess asset condition	• Data collection should include measuring and recording of specific geohazard risk effects on road networks.
	Identify asset and business risks	• Ensure that geohazard risks are recognized as risks to the asset and delivery of services. • Risk and vulnerability assessments—already commonly used for geohazard management—should be integrated with risk management from an organizational risk perspective. • The integration with AM risk promises significant efficiency gains.
DEVELOP ASSET LIFE-CYCLE STRATEGIES	Life-cycle decision-making techniques	• Current analytical processes need to incorporate multiobjective capabilities and often need refinement to include risk-based costs. • More emphasis on community involvement in decision making is required when bringing geohazard management into the AM decision making, as often the solution is to reduce the reliability of access.
	Operational strategies and plans	• Operational plans should include specific allowances for identifying and addressing deficient adaptation measures, such as making sure drainage structure are cleaned and without blockages. • Include retrofitting of infrastructure that is found to be significantly deficient. • Trial new designs that may offer better life-cycle solutions to common geohazards. • Operational procedures should include policies and processes identified for responding to disasters.
	Maintenance strategies and plans	• Maintenance strategies and plans should include specific allowance and focus on addressing items that limit the impact from geohazards. • Ensure that there is an accurate record of materials removed from geohazards, as these data are needed for the calibration of many geohazard simulation models.
	Capital works strategies and plans	• Updating of current design criteria is needed to address the full range of geohazards.
	Financial and funding strategies	• Financial and funding strategies should investigate the impacts of different investment scenarios on geohazard mitigation. • Financial and funding strategies should be in place for responding to potential disaster events.
LEVERAGE ASSET MANAGEMENT ENABLERS	Asset management team	• Effective integration of geohazard management and AM must be driven from executive management levels within organizations. • Appoint someone as the geohazard management champion to drive all these actions through the organization.
	Asset management plans	• Ensure that the AM plan specifically addresses geohazards.
	Information management systems and tools	• Information management systems should include the recording of specific geohazard data for planning purposes. • A data residence plan should be in place to respond to disaster planning needs.
	AM service delivery and procurement	• Legislation and procurement processes should allow for the response to shock events.
	Quality management	• Quality management of geohazard measures needs to ensure their sufficient functioning.
	Continuous improvement	• Identify improvements necessary for geohazard management, and integrate these into the overall improvement plan for the road authority.

Source: Base table from Henning, Tighe, and Greenwood 2017.
Note: Table adapts the asset management (AM) process from NAMS 2011 (shown in Part II, Figure 2.1, of this handbook) to focus on geohazard management.

Experience has shown that it is extremely difficult to develop good emergency response policies during an emergency. It is, therefore, necessary to have policies in place before the risk event, addressing issues such as the following:

- Priority of roads to be reopened
  - Prioritization includes the concept of "lifeline" routes that recognize that traffic volume alone does not represent the importance of a road. Low- to medium-trafficked roads may lead to key nonroad infrastructure such as water treatment plants, hospitals, or civil defense sites—and should be appropriately prioritized for maintenance and restoration.
- Pre-event maintenance
  - If the geohazard is caused by a climatic event such as predicted heavy rainfall, predetermined sites should be checked before the rainfall event to ensure that the drainage infrastructure will function as designed during the event.
- Communication
  - Who is going to communicate what, and to whom?
  - Who has what authority to talk to the media?
- Emergency repairs that can be undertaken without design
  - The road often contains many other services, some of which may be private utilities. There is a need to ensure that policies don't result in overinvestment in temporary repairs.
- Mix of public and private sector response to a geohazard event
  - The private sector may be equally as capable as public works of responding in emergencies.
  - Ensure that contracts are in place that cover all roads if using the private sector.
  - Contracts can require the private sector to supply equipment and labor that will be directed as part of a public works response.

Although the natural process is toward the elimination of any significant geohazard risks, a review of approaches applied to climate change risks shows that the need for investment in physical works can often be offset through non-asset solutions. For example, parts of the northern motorway in Auckland, New Zealand, are submerged during king tides and storm surges (Photo 5.1). Although an investment of many hundreds of millions of dollars would raise the road, currently an approach of communication, operational lane closures, and maintenance to remove debris enables the network to be operated without such investment.

Photo 5.1: Management of Auckland Motorway Flooding

Location: Auckland northern motorway, New Zealand

Traffic volume: circa 150,000 vehicles per day

Issue: Combination of king tides and storm surges result in southbound traffic lanes (including dedicated bus lane) going underwater for a period of one to two hours at high tide.

Response: Processes in place to monitor predicted tide levels. Advance warning in media and signage. Traffic management plan enacted. Maintenance crew ready to sweep road as water recedes.

Result: Most drivers alter their travel time to avoid peak tides and are generally unimpacted. A potential major investment in raising the road is mitigated through non-asset solutions, with only a minimal impact on traffic.

Source: Top image source www.stuff.co.nz, Bottom image source www.greaterauckland.org.nz ©Reproduced, with permission, from Greater Auckland; further permission required for reuse.

5.8 SELECTED RESOURCES

The following annotated list provides additional resources pertaining specifically to the topics covered in Part V.

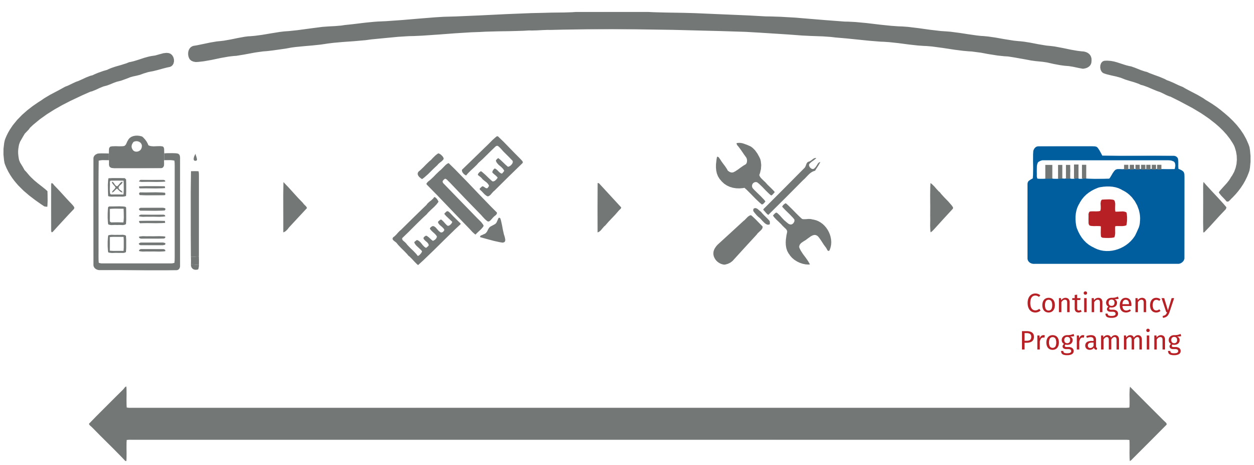
Deoja, B., M. Dhital, B. Thapa, and A. Wagner, eds. 1991. *Mountain Risk Engineering Handbook*. Kathmandu, Nepal: International Centre for Integrated Mountain Development (ICIMOD). Discusses the maintenance procedures (chapter 26) and detailed guidance for nonstructural measures for geohazard risk management

Highland, Lynn M., and Peter Bobrowsky. 2008. "The Landslide Handbook: A Guide to Understanding Landslides." Circular 1325, U.S. Geological Survey, Reston, VA. Provides landslide monitoring procedures (appendix B) and sample safety information for landslide and debris flows (appendix D).

JLS (Japan Landslide Society). 2012. "Landslide in Japan (The Seventh Revision)." Periodic report, JLS, Tokyo. Provides examples of slope movement measurement.

6

CONTINGENCY PROGRAMMING


Contingency
Programming

6.1 INTRODUCTION

Contingency programming consists of three distinct phases:

- ***Emergency preparedness:*** what happens before a geohazard event
- ***Emergency response:*** what happens during and in the immediate aftermath of an event
- ***Recovery:*** what happens following the emergency to restore full functionality to the road network.

The achievements after using Part VI are

- To understand forms of emergency preparedness—an overlooked aspect of geohazard risk management;
- To understand the items and procedures needed for emergency inspection or postdisaster needs assessment;
- To understand procedures of emergency traffic regulation and public notice; and
- To understand contingency programming activities by type of recovery.

Reference documents for Part VI of the handbook include the following:

- Terms of Reference (ToR 7), Development of Manual for Postdisaster Response and Recovery (in Appendix A) is a standard terms of reference (ToR) to formulate manuals in emergency inspection or postdisaster needs assessment, emergency traffic regulation, and recovery.
- Road Geohazard Risk Management: Case Study of Japan (in Appendix C) discusses the practices of postdisaster response and recovery in Japan.

6.2 EMERGENCY PREPAREDNESS

A key outcome from all the prior phases of geohazard risk management described in this handbook is that of understanding the nature of existing risks across the network. From this information, it is necessary to develop an emergency response plan covering what actions would be taken, and by whom, if various risks were to occur. Two key activities underpin the successful completion of emergency preparedness:

- Having in place an emergency preparedness and response plan; and
- Undertaking preparedness training to ensure that the plan can be deployed.

6.2.1 DEVELOPMENT OF AN EMERGENCY PREPAREDNESS AND RESPONSE PLAN

A well-designed, well-executed emergency preparedness and response plan is a key element of road geohazard risk management. The following items are essential to the planning process:

- Definition of organizational roles, responsibilities, and responsible authorities
- Identification of required materials and equipment, and where they should be located on the network, to enable an effective and efficient response
- Establishment of an emergency control center and emergency response team
- Determination of criteria for prioritizing response measures
- Development of response procedures based on (a) classification of emergency levels; (b) advance agreements or contracts for information communication; and (c) emergency activities (especially emergency recovery works for damaged roads) with organizations inside and outside of road management authorities, including communities and private companies

- Development of a communication protocol, including the establishment of strong internal and external lines of communication (including with local communities) and coordination mechanisms with other government agencies and private organizations
- Execution of emergency response drills and training.

In the case of highly disaster-susceptible situations, the general emergency response procedure typically proceeds as follows:

- Collection of information on weather, road, and traffic conditions
- Confirmation and recording of information to a road management log and preparation of a summary report to executives of road management authorities
- Call-up of staff for emergency response (after securing the safety of road users and staff, because the protection of human life is always the priority)
- Arrangement of materials (such as temporary barricades, roadblocks around dangerous portions, and sandbags for immediate remedial earthworks)
- Issuance of early warning of a disaster-susceptible situation, or the initiation of traffic control measures, including precautionary road closure
- Initiation of emergency disaster protection measures, such as sandbag placement to protect against temporary soil collapse
- Initiation of general postdisaster response and recovery (recovery from geohazard damage), as described further below.

An often-overlooked aspect of preparation concerns disposal of materials from slips. Geohazards may well involve a significant volume of material to be disposed of when a major risk event occurs. Prior agreement on where the disposal of any removed materials will be placed can make the recovery process more efficient and also avoid creating secondary geohazards through the placement of excavated materials in inappropriate locations. All necessary consents should be in place permanently for such disposal sites.

6.2.2 PREPAREDNESS TRAINING

While it is important to have in place all the necessary laws, regulations, processes, and people in place to deal with geohazard risks when they materialize, it is also necessary to undertake necessary training through drills to train the many parties involved and to identify gaps in the aforementioned documents. There are often large gaps between disaster risk management policies and manuals and the actual needs in emergency response such as equipment mobilization and government preparedness. It may be that the local office staff have never been trained with (or have access to) the advanced equipment that the central head office uses and that are required by the guidelines.

For each of the main geohazard risk types and locations within the domain of a road authority, drills (and follow-up training) should be undertaken annually (or as frequently as deemed relevant given issues such as changing policies, equipment, or key suppliers of services such as maintenance contractors and consultants). These drills shall be designed to test all aspects of the geohazard response and involve all the respective parties to make the drill as “real life” as possible—including when key individuals cannot be contacted.

6.2.3 FUNDING

The funding of postdisaster recovery is an essential element of the risk management process. The approach taken to the funding of disaster recovery should be directly related to the expected magnitude of disaster events (Table 6.1). The option of cutting back on maintenance standards (that is, stopping the maintenance of the rest of the road network to fix up geohazards in one area) is not recommended, because the long-term consequences of doing so can significantly increase the overall cost to the nation of the original hazard.

Table 6.1: Postdisaster Funding Approaches, by Disaster Magnitude

EXPECTED MAGNITUDE OF DISASTER	APPROACH	DESCRIPTION
Small relative to average annual budget of road authority	Contingent projects	Certain capital improvement projects (such as adding capacity to the network) are identified as being contingent on risks not occurring. If the risks do eventuate, then these projects are postponed.
Moderate or limited to specific infrastructure items	Insurance	The road authority takes out insurance against the risk of geohazards occurring. This is often more practical for specific road assets such as bridges or tunnels than for the network in totality. If the risks are high, then the cost of insurance will also be high.
Moderate to large relative to the average annual budget of the road authority	Road authority budget item	A line item is contained within the road authority's budget to cover disaster events. The item may be suitable for dealing with events of, say, up to a 1-in-10-year probability of occurrence.
Large relative to average annual budget of the road authority	Central government disaster fund	This could be a centralized fund just for roads or an overall fund for any assets affected by natural disasters. This approach is one of "self-insurance" and works on the premise that there will be a regular flow of funds into and out of the disaster fund. It is suitable for large events, such as those with a probability of occurrence less frequent than 1 in 10 years.

A special case of "contingent projects" is available through some international development partners such as the World Bank, whereby a zero-dollar Contingency Emergency Response Component (CERC) can be added to a standard loan arrangement. If a disaster does occur, uncommitted funds can be diverted from their original purpose and readily made available for disaster response.

With any funding approach, the question of "how much money will be required?" must be answered. Even countries with a long history of data collection and ongoing exposure to geohazards may not get this right all the time. For instance, in New Zealand the 2011 Christchurch earthquake resulted in damage that exceeded the central government's National Disaster Fund. To determine the likely funding needs, an analysis of the range of magnitude and consequence of different geohazard scenarios will be required.

6.3

6.3 EMERGENCY RESPONSE

Box 6.1 Overview: Transport Sector Recovery and Reconstruction

In the immediate aftermath of a disaster, during the emergency relief and response phase, the highest priority is to carry out life-saving emergency services, including providing medical attention, food, water, and shelter. To do this, vital transport and supply routes, including roads, ports, and airports, need to be cleared of debris so that evacuations can take place and life-sustaining services can be implemented.

Immediate recovery activities occur in parallel with emergency response activities. Transport officials need to be well coordinated with relevant response agencies to maximize public safety, to protect and preserve transport facilities as much as possible, and to reopen the transport system as quickly as possible. Meanwhile, transport sector recovery planners undertake the estimation of postdisaster recovery and reconstruction needs by assessing the value of destroyed assets and of transport production flows.

Source: World Bank 2018.

Immediately after a significant geohazard risk event, it may be necessary to trigger an emergency response procedure. The highest priority during the initial emergency response phase is on life-saving services (Box 6.1). The role of the road network in such life-saving services is critical, whether it be for access to sites by emergency responders or for the transport of the injured from sites to hospitals.

The focus of the emergency response phase is therefore about making rapid decisions in the field, using limited information, to restore key critical routes (see Section 3.2 on road criticality) as quickly as possible before moving on to the remainder of the network.

For large-scale geohazard events (those caused by major climatic events or earthquakes), it is often the role of emergency response crews (those of either the road authority or contractors) to both clear the road and to provide an initial assessment of the scale of works required at sites.

6.3.1 EMERGENCY INSPECTION OR POSTDISASTER NEEDS ASSESSMENT

The emergency inspection or postdisaster needs assessment of a road is conducted to determine the following:

- Damages to and abnormalities of the road
- Phenomena that had caused the disturbance or road closure and secondary damages (for example, surface depression of the road or debris fallen from a road mountainside slope)
- Road access to logistics, supplies, medical care, and so on
- Needs and priorities for the traffic function of the roads.

The postdisaster needs assessment is conducted in connection with the emergency inspection during abnormal weather conditions. In the emergency inspection, necessary urgent measures are performed such as the placement of barricades, roadblocks, or sandbags to catch collapses, and so on.

Postdisaster activities are unified with nonstructural measures for geohazard risk management as follows:

- Observation patrol and hazard monitoring for early anomaly detection
- Emergency information collecting system for disasters and anomalies

- Emergency response for highly disastrous situations
- Emergency information system for road conditions including early warnings or precautionary road closure.

In most cases, the emergency inspection is conducted by the same staff that performs the routine maintenance of roads. It is important that good communication exist with local public and private organizations such as subnational governments, residents along the road, police, and rescue forces. In the emergency inspection, necessary urgent measures are performed such as the placement of barricades, roadblocks, or sandbags to catch collapses, and the covering of the ground with impervious sheets to prevent water infiltration.

6.3.2 EMERGENCY TRAFFIC REGULATION AND PUBLIC NOTICE

If the emergency inspection determines that road traffic circulation is impossible or highly dangerous, the road management authority sets a detour and starts the traffic regulation until road recovery is completed. The emergency information is publicized to road users and residents through either temporary or permanent information boards on roads. A permanent electronic information board is linked with "nonstructural measures."

An information system for road conditions, including early warnings, is ideal. The information system can be linked to various media such as television, radio, and car navigation sets, and it can help road users make decisions related to their trips and transportation activities.

6.3.3 EMERGENCY WORKS

Emergency response consists of simple works aimed at preventing road traffic suspension. If roads are closed at many locations in a large area owing to a massive disaster such as wide-scale flooding, earthquakes, or the like, then a coordinated and prioritized response is needed. Initial activities include removal of debris, clearing of drains and waterway areas, safety inspections at bridges, safety inspections of structures and slopes following active slip situations, and so on.

For the emergency recovery and elimination of road obstacles, it is important to begin the activity of emergency recovery with preliminary nonstructural-measure activities (including visual inspection to contribute to early abnormal discovery, observations such as precipitation and the ground movement, abnormality, and an urgent information system of road traffic conditions). Prior plans and preparations to affect emergency recovery—such as preparations of materials and equipment, contracts pertaining to private contractors that have local construction machinery and prior emergency recovery experience, and an emergency recovery preliminary budget—are all key elements to have in place ahead of the emergency occurring. It becomes possible to speed up emergency recovery by locating a road management district officer close to the center of the disaster response to expedite decision making and shorten lines of communication.

6.4 RECOVERY

Box 6.2 Transport Recovery Plan

During the short-term recovery phase, transport sector recovery planners use the results of the postdisaster needs assessment to develop a recovery plan, begin to prioritize recovery needs against limited resources, and mobilize the required financing to rebuild the transport network and services in a way that better serves community and nationwide needs now and in the future. Transport officials must work with affected communities to integrate their concerns and needs into these plans. Consider that short-term recovery decisions have long-term implications. For instance, decisions about materials and labor procurement affect the local economy, while locations for debris removal sites can limit longer-term options.

During the medium- to long-term recovery phase, transport officials need to continually assess recovery progress against objectives via a monitoring and evaluation framework (established during immediate or short-term recovery) that can incorporate new information and be adapted accordingly. Transport officials need to begin to think about future land use planning and investments in preparedness that will make recovery faster and more effective in future disaster events.

Source: World Bank 2018.

Reactive measures involve recovery of the road asset to reinstate traffic flow, along with the concept of "build back better," which is the concept of "recovery with improvements" such that the geohazard risk is lower after the event than it was beforehand. Reactive measures are subdivided into emergency recovery (covered earlier), repair, rehabilitation, and reconstruction—as expanded on further below.

Although the emergency response phase is, by definition, undertaken rapidly to restore basic functionality, it is important that the subsequent phases be undertaken more holistically considering the long-term costs and benefits of options (Box 6.2). It is quite possible that, under major events, restoring the existing road is not the best solution and that rather than recovering the existing road, the solution may be to make substantial changes to the alignment to lessen the future exposure of the network to risk.

For example, in New Zealand, the State Highway 3 through the Manawatu Gorge was subject to ongoing small landslides since it was first opened in the 1870s. Each of these on its own was cleared up and the road reopened. However, following a major event in 2011, the road was closed for an extended period (opening in August 2012 with parts still one-lane). The road was temporarily closed by further slips in April 2015. In April 2017, a further large slip closed the road. While clearing that slip, a further slip of 10,000 cubic meters of rock occurred. Rather than try and remediate the site, the New Zealand Transport Authority determined to close the route permanently and instead invest the funds in the creation of a new, lower-risk route.[19]

6.4.1 MANAGEMENT OF THE RECOVERY

For routine geohazards, the rectification of damage will likely be managed and delivered through standard business operations. However, for large-scale disasters, a special management structure may be put in place. In Australia, for instance, following the 2010 Queensland Floods that did widespread damage to the road network and other critical infrastructure, the Queensland Reconstruction Authority was formed to coordinate the rebuilding program beyond the initial response and to allocate the

[19] See "Manawatū Tararua Highway," Projects, New Zealand Transport Agency: https://www.nzta.govt.nz/projects/sh3-manawatu.

special relief fund that was created. The authority now also has a role to increase the resilience of critical infrastructure. Furthermore, a separate Commission of Inquiry was established to investigate all matters related to the floods and to ensure that appropriate lessons were identified and put in place.

For large-scale events (especially those triggered by earthquakes), it is entirely possible that the recovery of the road network will be managed as part of a larger recovery effort. This larger effort will consider not just the reinstatement of roads but also the utilities buried within the roads and, at the largest scale, the very nature of land use served by the roads. An example of this occurred following the 2011 Canterbury (Christchurch) earthquakes in New Zealand, wherein the Canterbury Earthquake Recovery Authority (CERA) was formed to deliver the recovery. CERA had wide-ranging powers and could suspend laws and regulations for the purpose of earthquake recovery. The department operated for five years, from 2011 until April 2016. Under CERA, large areas of the city were deemed unsuitable for further use as residential areas, road networks were reconfigured, and key social services were relocated.

Within New Zealand, the 2016 Kaikoura earthquake caused massive damage to the main state highway and adjacent rail line, severing both for a period of almost 12 months. To enable coordination of the response, an alliance was put in place covering both the road and rail authorities, who in turned worked with industry to restore access.[20]

6.4.2 REPAIR

Repair refers to simple works after minor disasters, such as the sealing of cracks on a road to prevent further deformation of the road foundation through water infiltration. It also relates to the reinstatement of minor assets that may have been damaged during the event, for which design and budgetary issues do not apply.

Prior agreement should be in place on the extent or nature of works to be completed as "repairs" versus those to be undertaken as rehabilitation or reconstruction.

6.4.3 REHABILITATION AND RECONSTRUCTION

Rehabilitation consists of construction works that are typically contracted out, divided into temporary rehabilitation and full-scale rehabilitation. Temporary rehabilitation is conducted just to secure traffic reactivation, including partial-width traffic recovery, temporary detour alternatives, and temporary bridges. Such traffic reactivation is important because long-term suspension of traffic will greatly affect the lives of adjacent residents (for example, commuting, attending school, going shopping, and reaching medical facilities). When a secondary disaster is also expected, temporary rehabilitation should include the construction of countermeasures to prevent any secondary consequences.

Full-scale rehabilitation entails the execution of required disaster prevention measures based on detailed survey and design. It is conducted for improvement of the roads, such as road widening. Full-scale rehabilitation should prevent any secondary disasters. It includes remedial work on existing countermeasures based on a detailed survey and the design of new countermeasures. Strengthening existing countermeasures or constructing new countermeasures can be planned to minimize the maintenance cost of the road functionality.

If the road functionality is interrupted in a complex way such that long-term closure will occur to reinstate traffic flow, reconstruction rather than just rehabilitation should be conducted. For large-scale reconstruction, geohazard risk management procedures for new roads can be applied.

[20] See "Kaikōura Earthquake Response," Projects, New Zealand Transport Agency: https://www.nzta.govt.nz/projects/kaikoura-earthquake-response/.

For example, following the closure of the Manawatu Gorge in New Zealand to a significant landslide, the New Zealand Transport Agency took the opportunity to investigate alternative routes and ultimately determined to abandon the existing route in favor of a new route that was deemed a lower geohazard risk. Although such as decision may cause a longer loss of traffic access in the short run, the long-term improved reliability of the new route is considered a worthwhile trade-off.

6.5 RECOVERY

The following annotated list provides additional resources pertaining specifically to the topics covered in Part VI.

FEMA (Federal Emergency Management Agency). 1993. "Emergency Management Guide for Business and Industry: A Step-by-Step Approach to Emergency Planning, Response and Recovery for Companies of All Sizes." FEMA 141/October 1993, FEMA, Washington, DC. A recommended guidance document on the subject of contingency programming.

World Bank. 2018. "Transport Sector Recovery: Opportunities to Build Resilience." Disaster Recovery Guidance Series, Global Facility for Disaster Reduction and Recovery (GFDRR), World Bank, Washington, DC.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7

REFERENCE AND RESOURCE MATERIALS

7.1 REFERENCES

AASHTO (American Association of State Highway and Transportation Officials). 2007. *Highway Drainage Guidelines*. 4th ed. Washington, DC: AASHTO.

AECOM. 2016. "Review of Methods to Determine Criticality of Roading Networks." Report prepared for the New Zealand Transport Agency by AECOM New Zealand Ltd., Tauranga, New Zealand.

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Espinet, X. 2018. "Prioritization of Road Interventions in Nampula and Zambezia, Mozambique under Changing Flood Risk and Other Deep Uncertainties." PowerPoint presentation, World Bank, Washington, DC.

Espinet, X., J. Rozenberg, K. S. Rao, and S. Ogita. 2018. "Piloting the Use of Network Analysis and Decision-Making under Uncertainty in Transport Operations: Preparation and Appraisal of a Rural Roads Project in Mozambique under Changing Flood Risk and Other Deep Uncertainties." Policy Research Working Paper 8490, World Bank, Washington, DC.

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NAMS (National Asset Management Support). 2004. *Optimised Decision Making Guidelines: A Sustainable Approach to Managing Infrastructure*. Thames, New Zealand: National Asset Management Steering Group.

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QP (Quality Planning). 2018. "Plan Topics 2013: Natural Hazards." Guidance note, QP website: http://www.qualityplanning.org.nz/index.php/planning-tools/natural-hazards/risk-based-approach-to-planning-for-natural-hazards.

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World Bank. 2018. "Transport Sector Recovery: Opportunities to Build Resilience." Disaster Recovery Guidance Series, Global Facility for Disaster Reduction and Recovery (GFDRR), World Bank, Washington, DC.

7.2 WEB RESOURCES

American Association of State Highway and Transportation Officials (AASHTO)
http://www.transportation.org/

Centre for Research on the Epidemiology of Disasters (CRED)
http://www.cred.be/

Federal Highway Administration (FHWA), U.S. Department of Transportation
https://www.fhwa.dot.gov/

International Centre for Geohazards (ICG)
https://www.ngi.no/eng

International Centre for Integrated Mountain Development (ICIMOD)
http://www.icimod.org/

International Centre for Water Hazard and Risk Management (ICHARM)
http://www.icharm.pwri.go.jp/index.html

International Geosynthetics Society (IGS)
http://www.geosyntheticssociety.org/

International Organization of Motor Vehicle Manufacturers
http://www.oica.net/

International Sabo Network
http://www.sabo-int.org/

Japan Bosai Platform (JBP)
https://www.bosai-jp.org/en

Japan Landslide Society
https://japan.landslide-soc.org/?lang=en

Japan Road Association
http://www.road.or.jp/english/

Probabilistic Risk Assessment Platform (CAPRA)
http://www.ecapra.org/

OpenDRI: Open Data for Resilience Initiative
http://opendri.org/

Open Data for Resilience Initiative Field Guide
https://www.gfdrr.org/sites/gfdrr/files/publication/opendri_fg_web_20140629b_0.pdf

ThinkHazard!
http://thinkhazard.org/

UNESCO: Disaster Risk Management
http://www.unesco.org/new/en/natural-sciences/special-themes/disaster-risk-reduction/geohazard-risk-reduction/

United Nations Office for Disaster Risk Reduction (UNISDR)
https://www.unisdr.org/

U.S. Geological Survey Geologic Hazards Science Center
https://geohazards.usgs.gov/

World Bank: Global Facility for Disaster Reduction and Recovery (GFDRR)
http://www.gfdrr.org

World Bank: Transport
http://www.worldbank.org/en/topic/transport

World Road Association (PIARC)
http://www.piarc.org/en/

ROAD GEOHAZARD RISK MANAGEMENT

HANDBOOK

CONTACT

The Global Facility for Disaster Reduction and Recovery (GFDRR)

Email: gfdrr@worldbank.org

Website: https://www.gfdrr.org/

GFDRR is a global partnership that helps developing countries better understand and reduce their vulnerabilities to natural hazards and adapt to climate change. Working with over 400 sub-national, national, regional, and international partners, GFDRR provides grant financing, technical assistance, training, and knowledge sharing activities to mainstream disaster and climate risk management in policies and strategies. Managed by the World Bank, GFDRR is supported by 37 countries and 11 international organizations.

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Website: http://www.worldbank.org/drmhubtokyo

The World Bank Tokyo Disaster Risk Management (DRM) Hub supports developing countries to mainstream DRM in national development planning and investment programs. As part of the Global Facility for Disaster Reduction and Recovery, the DRM Hub provides technical assistance grants and connects Japanese and global DRM expertise and solutions with World Bank teams and government officials. The DRM Hub was established in 2014 through the Japan-World Bank Program for Mainstreaming DRM in Developing Countries – a partnership between Japan's Ministry of Finance and the World Bank.