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Geohazard Management in the Transport Sector

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Geohazards can result in significant loss of human life as well as cause extensive damage to infrastructure. *The magnitude and frequency of geohazard events ranges from earthquakes and tsunamis to landslides and flash floods. In the most severe cases involving the low frequency but more intense geohazards like earthquakes or tsunamis, the primary concern, ex ante, is on the minimization of the potential loss of life and property, damage to infrastructure, and ensuring continuity in the functionality of public and private services. In the higher frequency, lower impact, geohazards, such as landslides, flash floods, and rockfall, proper planning remains vital, but is often overlooked in transition and developing economies. In the transport sector, proper planning for this category of geohazards can realize significant savings in construction costs, avoiding cost over-runs, repair costs and costly delays, and subsequent maintenance costs.*

The principal aims in considering geohazards in the transport sector are: (i) to minimize the risk and effect of geohazards on infrastructure and on the general public; (ii) to ensure that the location decisions in respect to transport infrastructure developments are informed about geohazard risks and that appropriate precautions are identified; (iii) to assist in safeguarding public and private investment by a proper appreciation of site conditions and undertaking of necessary precautionary measures; and (iv) to restore the functionality of the transport infrastructure after unmitigated geohazard occurrences, whilst insuring, as far as feasible, that future occurrences will be mitigated. This technical note provides a summary of the typology of geohazards, prospective mitigation measures, and current practices in managing geohazards. It also outlines some key recommendations to facilitate improved management of geohazards in the transport sector.

The findings, interpretations, and conclusions expressed here are those of the authors and do not necessarily reflect the views of the Board of Executive Directors of the World Bank or the governments they represent.

The scope and objectives of the note

This note deals with high frequency geohazards such as landslides, avalanches and floods. The less frequent, more hazardous ones are not considered as the scale and scope of the response is very different. They are a focus of the Global Facility for Disaster Reduction and Recovery (GFDRR).¹ The majority of developing and transitional countries have limited capacities to address, or even explicitly consider geohazards in the transport sector in a systematic manner. Far too frequently, the result is poor alignment choice in hazard prone areas, inadequate consideration at design stage, cost over-runs at construction stage, insufficient funds for maintenance, and a shortage of funds when geohazards occur. This type of approach represents an inefficient use of resources, and jeopardizes both the infrastructure, and user safety.

However, there is an expanding body of experience in the use of approaches specifically

designed to address geohazards in an integrated and systematic manner. The leaders in the development of approaches of this type are countries like Australia, Switzerland, and the United States. Experience from these countries is summarized in this note.

This note has two main objectives: First, it summarizes a typology of geohazards and prospective mitigation measures, and reviews current practices in managing geohazards in the transport sector.² Then, it outlines key recommendations for incorporating geohazards in the preparation, design, and implementation of transport projects in the developing and transition countries. The intended audience of this note is World Bank staff working on transport infrastructure projects in geohazard susceptible locations; and technical staff in client country authorities responsible for vulnerable road networks.

What are geohazards and why is geohazard management important?

Geohazards can be defined as “events caused by geological, geomorphological and

¹ Research work on the approaches to mitigate the larger, less frequent hazards like earthquakes can be accessed from the Global Facility for Disaster Reduction and Recovery (GFDRR) at <http://www.gfdr.org>.

² With the primary focus on road infrastructure.

climatic conditions or processes which represent serious threats to human lives, property, and the natural and built environment.³ They range from large ones like earthquakes and tsunamis, to the smaller but more frequent ones like landslides and flash floods. In the land transport sector, landslides are the most prevalent. Though destructions and number of lives lost are small compared to earthquakes, mass movements account for about 1,000 deaths per year, and cause damage amounting to several billions of dollars.⁴ Moreover, in many transitional and developing countries, lack of preparedness, limited resources, and poor condition of infrastructure all combine to enhance the severity of landslide when it occurs. In addition, some countries and regions are more prone to landslide events than others, for example, countries in South East Europe (Albania, Bosnia and Herzegovina, Montenegro, Serbia) in Central Asia (Kyrgyz Republic, Tajikistan), and a significant number in Latin America and Asia.

Geohazards have the potential to significantly impact the cost of construction, operation and maintenance of infrastructure. Geohazards discovered during project implementation are a major cause of cost overruns and delays. They have the potential to overwhelm contingency provisions, and undermine stated project economic and financial appraisal benefits. Early identification of geohazards ensures that future risks are avoided, often without additional cost. Appropriate geohazard assessment and management is vital to the design, planning and financing of successful projects.

Types of geohazards

There is a wide variety of geohazards, but two key parameters help in differentiation: the intensity and frequency of the hazard.⁵ A simple typology using these two parameters can be established. The intensity can be characterized in terms of high, medium and low, while the frequency can be classified into very seldom, seldom and frequent. This note focuses on the high frequency hazards, which have an event return period of up to a few years. In this group of geohazards, the most relevant for transport are landslides, rockfall, and floods. The first two are the most common, and will therefore feature most prominently in this note. Flooding, and its impact

on infrastructure is considered, but to a lesser extent.

Landslides

A landslide is defined as a downward mass movement of rock or soil controlled by gravity, geology, the presence of water and morphology. The term "landslide" can also be used to describe "a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill or a combination of these."⁶ The materials may move by falling, toppling, sliding, spreading or flowing. Depending on conditions, the movement can be a slow or rapid process, and can vary widely in terms of width, ranging from several meters to up to a kilometer.

Figure 1. Translational landslide, Beatton River Valley, British Columbia, Canada, 2001.



Source: Réjean Couture, in Highland, L.M. & Bobrowsky, P. (2008), "The Landslides Handbook: A guide to understanding landslides", USGS & CGS. Reproduced with the permission of Natural Resources Canada 2010, courtesy of the Geological Survey of Canada (Photo by Réjean Couture).

There are a number of classification systems for landslides.⁷ One simple classification system differentiates landslides by the kinds of material involved and the mode of movement. A classification system based on these parameters is available in the literature,⁸ and an illustration of these types of landslides is shown in Figure 2. Other classification systems incorporate additional variables, such as the rate of movement; the water, air, ice content of the landslide material; the depth of their sliding surface; shape; geometry; speed; consistency; and by the activity. Water plays a critical role in the landslide process. Slope saturation by water from rain,

³ Anders Solheim et al (2004).

⁴ See BRGM (2007), and Highland (2004).

⁵ This is not a systematic treatment of landslide classification. The analysis presented is a selective typology identified as suitable for relevant aspects in the transport sector.

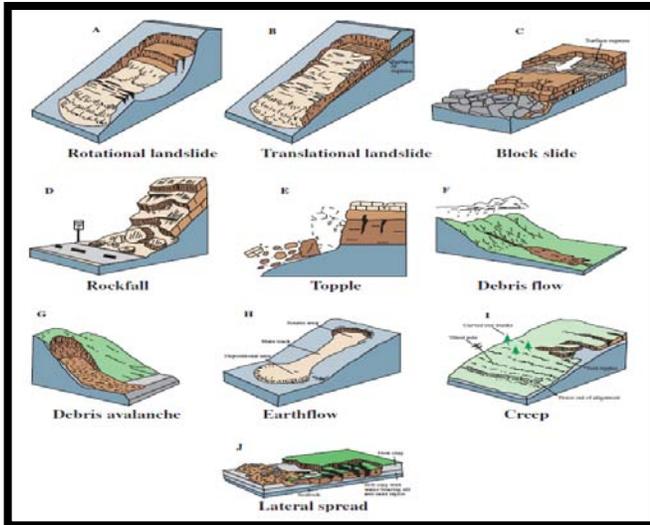
⁶ Highland L. (2004)

⁷ A. Boll (2002).

⁸ See Varnes, (1978)

snowmelt or change in ground water level aids the landslide process.

Figure 2. Different types of landslides



Source: Highland, L. 2004. "Landslide Types and Processes". Factsheet 2004-3072. Dated July 2004. U.S. Geological Survey. US Department of the Interior.

There are three main triggers of landslides: geological, climatic (meteorological), and human causes.⁹ Geological triggers include: weak or sensitive materials, weathered materials, sheared, jointed, or fissured materials, adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth), differences in permeability and/or stiffness of materials, and ground acceleration from seismic events. The most relevant meteorological triggers are precipitation, snowmelt and freeze thaw cycles. It has been documented that landslides and avalanches are often triggered as a function of distinct meteorological conditions, in particular extreme weather events, such as major storms with heavy rain and snowfall.¹⁰ Human causes have been found to include: excavation of slope or its toe, loading of slope or its crest, drawdown (of reservoirs), deforestation, irrigation, mining, artificial vibration, and water leakage from utilities.

Three special types of landslides with relevance for transport are discussed in more detail below: earthflow, rockfall (including rock topples and rock avalanches), and snow avalanches.

⁹Highland, L. (2004).

¹⁰Sandersen, F., Bakkehoi, S., Hestnes, E. and Lied, K (1996), "The influence of meteorological factors on the initiation of debris flows, rockfalls, rockslides and rock mass stability" in Landslides, Proceedings of the 7th symposium on landslides, edited by: Senneset, K.

Earthflow: Earthflow has a characteristic hourglass shape with a source area, main track and depositional area (see H in Figure 2). The slope material liquefies and runs out. This requires the material to have high content of fine grained soil with high water content wet enough to flow. The causes of earthflows and landslides are similar. Like landslides, earthflows appear mainly after heavy rain when the soil surface is saturated. Earthflows often have a density much higher than water, resulting in higher transport energy and destructive potential. Earthflows of this nature have moved up to a few kilometers.

Rockfall: Rock falls, rock topples, and rock avalanches are abrupt and rapid dislocations of rocks and boulders that become detached from steep slopes or cliffs. Separation commonly occurs along discontinuities such as fractures, joints, and fault and bedding planes. Movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of water. They are often triggered after a freezing and thawing cycle, or by filling of cracks with water after rain events. (Micro) seismic events are often the ultimate trigger when a slope or cliff is close to toppling, or in limit equilibrium to use the vernacular. With increasing rock mass, the movement changes from falling and bouncing to a more flowing movement. This transition from rock fall to topple and debris avalanche is fluent and sometimes difficult to distinguish. Limits can be drawn depending on mass volume and velocity.¹¹ Rockfalls can have a significant impact on transport infrastructure causing damage to the infrastructure, and in some cases to passing vehicles or people. They can also engender considerable delay for road users, reflecting partial or complete closure of the road carriageway, or during clearance/mitigation work.

Snow avalanches: There is a variety of types of avalanches reflecting size, type of snow, motion and origin. The fundamental classification is based on the point of origin. A subdivision is made based on snow water content, whether the snow is dry, damp or wet. The sliding mechanism also plays a role. The snow may slide on another snow layer in a block (a slab avalanche) or on the ground. Avalanches are generally caused by loss of cohesion in the snow mass. They often occur after substantial snow fall or by intrusion of water. They can be triggered spontaneously by wind, rock fall or additional snow, or by other disturbances like skiers or vibrations (seismic events, noise, artillery shells). In susceptible

¹¹The interested reader is referred to Lateltin, O. & Bonnard, C. (1999). "Hazard assessment and land use planning in Switzerland for snow avalanches, flooding and landslides".

countries, snow avalanches represent a very dangerous hazard. In Norway, they are noted as being the geohazard that most frequently leads to loss of life and infrastructure damage.¹²

Floods

The primary impacts of flooding are erosion around structures, inundation, damage of unprotected structures, and deposition of debris transported by the floods. The hazard of flooding is also dependent on the topography of the region and the watershed catchment area, climate and vegetation. As the Lynmouth tragedy in 1952 showed, small rivers and streams descending quickly from mountainous areas experiencing unexpectedly heavy rains can be exceptionally dangerous. In this particularly notorious case, nearly 20 cm of rain fell in 24 hours on the uplands in Devon above the village, adding to already swollen rivers. The result was a wall of mud, debris, and water, which swept down through the community, killing thirty four people.¹³

Deforestation is a key contributor to events of this nature, as it removes buffer storage for rain water. A second contributor to flooding, and the resulting damage, is the restriction of river flow, particular in areas of settlements. Also regulation of a river may increase the hazard of floods, with subsequent destructive consequences for adjoining transport infrastructure and facilities. A final factor in the severity of the flood impact is the development of the natural flood basin, often for residential purposes.

Counter measures to geohazards

When describing prevention and mitigation measures against geohazards, a distinction is drawn between proactive and reactive management.

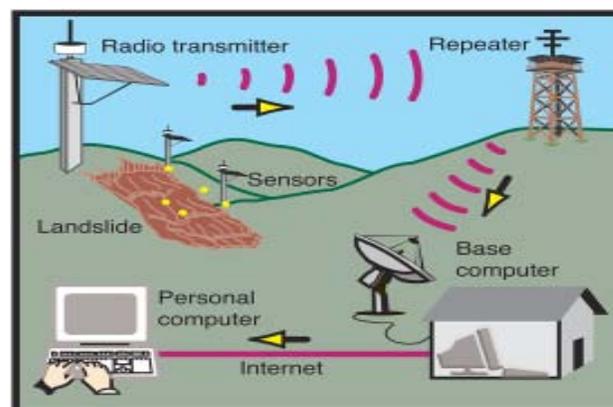
Proactive measures: As the name suggests, proactive measures are applied before an event. They can also be referred to as vulnerability reduction measures. The planning and design of vulnerability reduction measures depends on process studies, hazard assessment and risk analyses. Proactive risk management measures will include guidelines and task lists that guide the planner through the process of consideration and analysis of geohazards in the planning process.

Proactive measures can be divided into passive measures and active measures. Passive measures try to exclude people and vulnerable objects from

dangerous zones.¹⁴ Such measures are mainly initiated by planners and are based on extensive process studies, danger zone mapping and risk analyses. Usually, they do not contain physical or structural measures. With respect to already populated areas and existing traffic routes, they are often difficult or even impossible to realize. By contrast, active measures are meant to influence the dangerous processes and mitigate natural hazards. They consist of structural and/or bio-engineering elements. Depending on the processes and the general protection concept, they can be located at some distance from the endangered objects (for example, check dams, retaining walls and reforestation programs in the catchment area of a torrent), or quite close to them (for example, rock fall barriers, anchors and bolts, retaining walls immediately above a motorway). Depending on the safety requirements, temporary or permanent measures can be installed.

Monitoring and warning systems: These are usually established as a three component system: sensing units installed in the landmass to detect deformation or movement, a transmitting unit to transmit signals that are interpreted by the analysis unit. The analysis unit can be connected to a warning system, for example, a traffic light to block traffic progress when a certain threshold is exceeded.

Figure 3. Network for transmission of real time landslide data



Source: Spiker, E.C. & Gori, P.L. (2003), "National Landslide Hazards Mitigation Strategy: A framework for loss reduction". U.S. Geological Survey Circular 1244.

Drainage: This is a very important proactive measure and the most common type of landslide stabilization. The cost is low but effectiveness is quite high. Improved drainage can be achieved by installing drainage wells, trenches or other draining pipes in the land mass; surface drainage

¹² Jaedicke, C., et al. (2008),

¹³ Similar events occurred in 2004 in the Cornish village of Boscastle, and in 2010 on the island of Madeira.

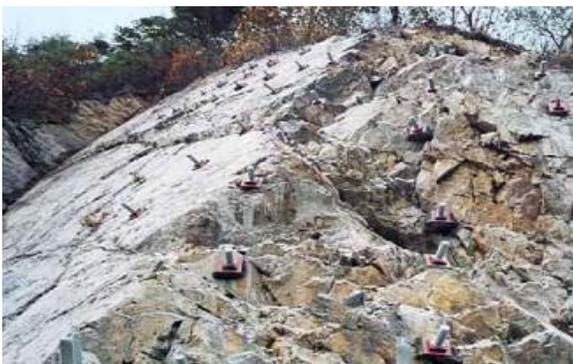
¹⁴A. Boll (2002).

like surface water interception drainage (catch water drains); or use of prefabricated half-shells and other mid or side drains. The key effect of drainage is lowering the ground water table and improving surface water runoff flow. This, in turn, leads to a reduction in pore water pressure in the slope and an increase in the mobilized (effective) shear strength of the soil.

Vegetation: Vegetation of slopes is a cheap but effective measure for slope stabilization. All side slopes of project works (at cuts and on embankments) need to be vegetated, ideally using good topsoil with grass and/or tree/shrub planting. Ideally, the bill of quantities should include a line item for this in the project bid documents, and should be considered a full part of the construction process and supervised accordingly. The objective is to diminish the corrosive action of surface runoff that wears away the side slope materials and leads to easier and faster collapse of the road structure. One study in Sachseln, Switzerland found that besides hydrological, geological and geotechnical parameters, the lack of vegetation is a decisive factor in landslide occurrence.

Dowels, anchors and nails: Dowels and anchors are used when the requirements for slope stabilization are higher, for example, when the slope is loaded by a road. Dowels transfer the load to deeper ground layers and increase the shear strength in the sliding plane. Anchors provide the additional forces to push back against the sliding mass. Soil or rock nailing with sprayed concrete ("shotcrete") cover is suitable for shallow sliding mass and loose surface rock. Bolting, nailing and anchoring may be reasonable options as a protective measure against rock falls, often employed in a very targeted manner to secure single unstable blocks or critical areas of a rock face.

Figure 4. Rock bolts and anchors, Hongchon Street No. 36, Gangwondo Province, South Korea



Source: Dywidag Systems International, "DYWIDAG Geotechnische Systeme"

Retaining Structures: Retaining structures are common means of slope stabilization in dealing with road and railway cuts and fills. The retaining wall can be made of concrete, gabion cages, precast concrete elements like cribs or other type of reinforcement like geo-synthetics. The walls anchor the slope or side mass by acting as a counter-weight.

Protective structures: These include protection nets, for example, against earthflows, and protection dams. Protection nets (wrap around nets) are used for small earthflows where the path is defined. Dam structures are needed when the earthflow path is broad and protection needed is high. Alternatively, protection dams (earth, concrete or other material) can be used to protect against floods. Protection nets and structures can be used against both, rock falls and snow avalanches. In those cases where the rock cannot be stabilized at origin, the use of barrier nets at the side of the road or railway asset is used to protect against falling rock boulders. At the top end of the spectrum of protective structures are rock galleries. These can be very expensive structures but are able to protect against a galaxy of hazards: rock fall, earthflow and snow avalanches. The transition from a gallery to a tunnel is quite smooth since galleries are often covered with several meters of cushion material, mainly soil. For snow avalanches, other protective structures can include structures installed in the starting zone like snow nets, snow bridges, and snow rakes.

Figure 5. Protective wire mesh (net) over rock adjacent to road



Source: Highland, L.M. & Bobrowsky, P. (2008), "The Landslides Handbook: A guide to understanding landslides", USGS & CGS.

Table 1 provides a summary of possible options for proactive counter measures against geohazards. This list is not intended to be exhaustive, and other solutions are possible

including a customized combination or variation of options.

Table 1. Options for proactive measures

Measure	Landslides (including rockfalls and avalanches)	Floods	Cost
Avoid by rerouting round hazard areas	✓	✓	V
Remold landscape and remove mass	✓	×	M-H
Controlled blasting	✓/×	×	L
Monitoring and warning systems to enable route closure	✓	✓	L-M
Protection forest and vegetation	✓	✓	L
Stabilize by dewatering and drainage	✓	✓	L-M
Remove rain and surface water from slope	✓	✓	L-M
Stabilize by anchors, nails, dowels	✓/×	×	M-H
Stabilize with retaining structures (walls, gabions or berms)	✓	✓	M-H
Protective structure: retaining wall or dam	✓	✓	H
Protective nets (wrap-around)	✓	×	M
Protective structure: Catch nets	✓	×	M
Protective structure: gallery	✓	✓	H
Protection of river banks	×	✓	M
Retaining of road bed/ruble	×	✓	V
Protection structure in starting zone (Snow bridge, rake, net)	✓/×	×	M-H

V – Variable; L – Low; M – Medium; H – High

Reactive measures: Reactive measures are applied after an event and are mainly focused on providing resources for rapid intervention and repair as well as maintenance and rehabilitation of transport infrastructure. The resources for intervention can be provided by insurance or other types of funding in order to achieve a quick mobilization. Reactive measures also include guidelines and task lists for the incorporation of measures in maintenance and operation. A further reactive measure is the establishment of preparedness. This includes training for the case of emergency and establishment of emergency plans. Preparation of repair materials and equipment stockpiles, as well as framework contracts with qualified contractors for routine repair works can greatly shorten the response time and period required for repairs. These would

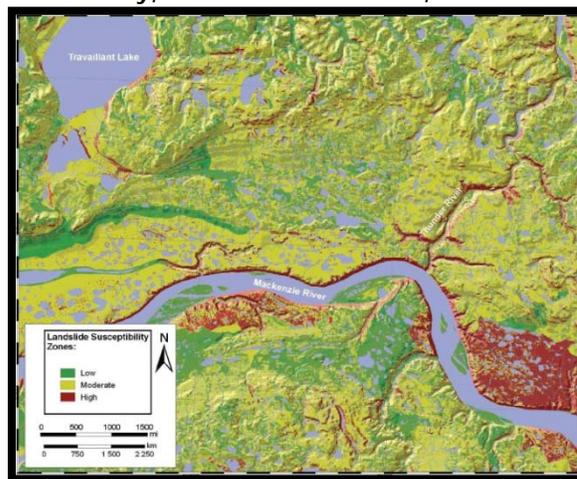
enable the efficient management of the situation after a hazard event in order to clear up and put the system into function as quickly as possible.

Current practice in developed countries

Experience in dealing with geohazards from three countries with the longest history of systemic and integrated responses: Australia, the United States and Switzerland has been synthesized for this note. In all countries, important lessons can be learnt on the strategic framework for management of the hazards, a supportive legal and institutional framework, concrete measures in terms of mitigation strategies and instruments, and the related issues of economic viability and financing. These three countries differ in the approaches and areas of emphasis in managing geohazards, for example, use of network systems approaches or lifeline cultures. Australia has excellent documentation on codes, guidelines and frameworks for dealing with geohazards all promoted by the Australian Geomechanics Society.¹⁵ In the United States, landslides are given substantial focus and attention. Important lessons are available in the country's National Landslide Mitigation Strategy. The main elements of this strategy include:

- *Research:* Developing a predictive understanding of landslide processes and triggering mechanisms.

Figure 6. Landslide susceptibility map, Mackenzie River Valley, Northwest Territories, Canada



Source: Réjean Couture, in Highland, L.M. & Bobrowsky, P. (2008). Reproduced with the permission of Natural Resources Canada 2010, courtesy of the Geological Survey of Canada (Graphic by Réjean Couture)

¹⁵See for example Australian Geomechanics Society extracts on "Practice Note Guidelines for Landslide Risk Management 2007", and "A National Landslide Risk management Framework for Australia" from the Journal and News of the Australian Geomechanics Society Vol. 42 No. 1, March 2007.

- *Hazard Mapping and Assessments:* Delineating susceptible areas and different types of landslide hazards at a scale useful for planning and decision-making.
- *Real-Time Monitoring:* Monitoring active landslides that pose substantial risk.
- *Loss Assessment:* Compiling and evaluating information on the economic impacts of landslide hazards.
- *Information Collection, Interpretation, and Dissemination:* Establishing an effective system for information transfer.
- *Guidelines and Training:* Developing guidelines and training for scientists, engineers, and decision-makers.
- *Public Awareness and Education:* Developing information and education for the user community.
- *Implementation of Loss Reduction Measures:* Encouraging mitigation action.
- *Emergency Preparedness, Response, and Recovery:* Building resilient communities.

Similar endeavors are implemented in Switzerland. However, there is also considerable emphasis on a holistic management approach. A new integrated comprehensive risk management concept is being finalized to include hazard assessment, risk analysis, exposition analysis, consequence analysis, risk calculation, risk assessment and evaluation. A number of guidelines exist to guide the management of geohazards. Hazard mapping is fairly well established with two types of maps: hazard indicating maps and hazard maps. Hazard indicating maps show what types of hazards are present in an area. They are not very detailed and are provided at a large scale (1:10,000 to 1:50,000). Hazard maps display individual hazards. They are very detailed at small scale (1:2,000 to 1:5,000). These maps are color coded to show the frequency and intensity of the hazard. All hazard maps are updated on regular basis and maintained by the authorities. The country also has a robust hazards database and an event register. All regional authorities are obliged to collect data of events and enter it into the database. There is also great awareness in the country of the economic evaluation of hazard mitigation measures to weigh elements at risk against costs of countermeasures.

Current practices in developing and transition countries

Most developing and transition countries do not have coherent frameworks for addressing

geohazards in the transport sector. Most actions with respect to geohazards in these countries are undertaken on an ad-hoc basis, driven by need, on a project by project or road section by road section basis. This lacuna is problematic, particularly in the geohazard prone countries (mountainous terrain, flood prone, heavy rainfall countries). Funds for restoration are hard to come by, and in most cases are diverted from other priorities. At the same time, there are related costs due to damage to the infrastructure, delays to commuters due to blocked roads, with occasional fatal or serious injury, or damage. Many projects implemented in geohazards prone areas are usually heavily disrupted by hazard occurrence leading to costly project overruns, project delays and problematic operation and maintenance. One interesting effort in addressing geohazards in the sector is underway in the Kyrgyz Republic.¹⁶ In these countries, the framework of geohazards risk management can be applied but the main problems are lack of reliable data on geohazards and general lack of awareness and preparedness until hazards occur and reactive measures are sought.

Summary recommendations

Five main recommendations arising with regards to geohazards in the transport sector are:

(i) Create an enabling legal and regulatory framework for geohazards management. The responsibility and duties of national, provincial and municipal entities need to be clarified with regards to geohazards, with matching funding mandates. Furthermore, hazard information should feed into the land use planning process. Codes and guidelines must be introduced and mandated to aid and regulate the planning and engineering professions.¹⁷ National strategies dealing with the prevalent hazard or hazards can also be developed.¹⁸

(ii) Carry out hazard and risk mapping exercises, and use GIS systems to determine the nature and extent of hazards and their likelihood of occurrence. A level of risk that can be tolerated must then be defined to enable easier

¹⁶Refer to GO-ELS (2008) Report for World Bank supported project.

¹⁷ See for example the Australian Geomechanics Society guidelines available at www.australiangeomechanics.org and US guidelines available at the Federal Emergency Management Agency (FEMA) website: www.fema.gov among others.

¹⁸ See for example Elliott C. Spiker & Paula L. Gori (2003), "National Landslide Hazard Mitigation Strategy : A framework for loss reduction". U.S. Geological Survey Circular 1244.

decision making. Modern geo-referenced database systems (GIS systems) for data management, visualization, risk evaluation and planning are a powerful instrument in the decision making process.

(iii) Where deemed appropriate, install monitoring and warning systems. Monitoring and warning systems are a cheap option in the hazard mitigation process. These can range from sensors and geophones to detect rock movements or landslide movements, to installing rain gauge stations, or the regular taking of water levels to monitor flooding risks and events. They can be installed when hazards are identified or developed after construction. They can mitigate the loss of human lives but have no value in physically preventing damage to the road structure.

(iv) Funding mechanisms must be established to deal with emergency situations. For more efficient geohazards recovery and restoration efforts, agencies in charge of road maintenance and construction in geohazard prone zones should be provided line items in their budgets.

(v) Incorporate geohazards management in the asset management process from pre-project to project phase through implementation and finally to maintenance. During the feasibility studies, preliminary engineering designs, and detailed engineering designs, geo-technical issues (where relevant) should be thoroughly investigated.

- **Project alternatives must be explored** with route selections chosen to avoid hazard prone areas as far as possible based on hazard and risk maps, and historical records.
- **At project feasibility study, an investigation of potential existing geohazards must be performed.** This is to later avoid costly increases to project cost estimates during the detailed design and operation phases. Preliminary identification can be done by rapid screening. Such screening consists of the evaluation of topographical and geological maps, satellite images and other available documents together with field reconnaissance. These investigations should be performed by an experienced senior geologist or geotechnical engineer. A checklist procedure for the investigation of phenomena in nature, for example, identification of sliding land masses, and interviews of local people may be used.

- **Based on the preliminary identified hazards, the traffic route must be optimized in terms of avoidance of hazards as a priority.** The type of hazards that need to be taken into account must be noted together with estimations of their likelihood of occurrence, intensity and extent. Hazards must be investigated individually and then ranked and prioritized.
- **Where the chosen route or project includes geohazards, proactive risk mitigation measures should be designed and incorporated into the construction.** This work should be done by geo-technical engineers and the construction costs of the mitigation measures included in the bidding cost estimates for the construction works. Socio-economic evaluations must be made to justify proposed solutions. It is highly recommended to implement proactive counter measures instead of reactive ad-hoc actions since the former is a more cost-effective approach.
- **Maintenance of the mitigation infrastructure should be a key component of cyclic routine maintenance of the transport assets.** Sufficient human and financial resources must be assigned to maintain installed measures throughout the lifetime of the transport asset.

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