Landslide impacts on the road network of Lao PDR and the feasibility of implementing a slope management programme

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Abstract. The Peoples' Democratic Republic of Lao is a landlocked country bordered by Vietnam to the east, Thailand to the south and west and China to the north. It is predominantly hilly or mountainous, and experiences a sub-tropical climate defined by a distinct rainy season during the summer. Annual rainfall varies in the mountainous regions of the north between 1.5m and 4m per year, most of which falls during the summer months, sometimes in association with typhoons developed in the South China Sea. Forest occupies the majority of slopes that neighbour the road network.

The road network of Laos is impacted upon by landslides. These landslides occur most frequently as shallow and localised slope failures in roadside cuttings, though below-road slope failures are also common and deep-seated hillside failures less so. The majority of landslides result in temporary partial or complete blockages to short sections of road. These failures can give rise to several hours of delay to traffic and also require ongoing investment in debris clearance, repairs to walls and roadside drains and road pavement.

Although the risk posed by landslides to mountain roads in Laos appears to be relatively low when compared to some other countries in the Asian region, there are both technical and economic justifications for the development of an enhanced slope management programme. An evaluation of landslide costs in engineering terms concludes that the economic justification for investment is marginal. However, when the costs of traffic delays are taken into account the case for increased investment in enhanced slope management becomes strengthened. The proposed programme for this investment combines capacity building through training with the implementation of pilot slope improvement projects. Improved data collection and monitoring systems are also proposed.

Keywords. Laos, landslide impacts, economic evaluation slope management, capacity building.

1. Background to the study

Through the Transport Sector Project, the World Bank is assisting the Ministry of Public Works and Transport (MPWT) of the Lao PDR to move to a sector-wide approach in the planning and management of transport infrastructure. This is wide-ranging in scope and includes both technical and institutional development. The MPWT priority investment programme for the next few years will be formulated as part of this process.

A national slope stabilisation programme has been identified as an important need for the road sector. The intention would be to align donor resources to finance this as a component of the overall sector-wide project approach. Consequently, the World Bank requested the Department for International Development (DFID), UK to support a study to assess the feasibility of a slope management programme through its South East Asia Community Access Programme (SEACAP).

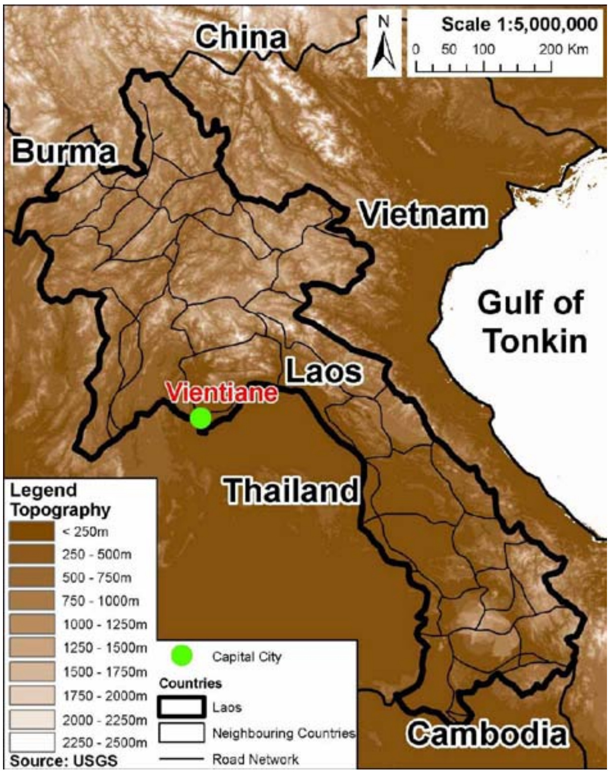
2. Geography and geology of Laos

Lao PDR (Fig 1) has an area of 236,800 sq km of which more than 75% can be described as steep hilly or mountainous, with elevations usually varying from 500 to 2,000 metres above sea level. Most of the mountainous areas are located in the north of the country and in the Annamite chain in the east, which forms much of the natural watershed between Laos and Vietnam. The country is roughly 1,000 km long and has a width varying from 140 to 500 km. Forest is the predominant land use in the hilly and mountainous areas of the country.

The geology of Laos is described by Workman (1977) in relation to the region as a whole. Metamorphic rocks of Proterozoic age underlie a significant proportion of the country. Shallow and deep water marine sediments prevail as outcrop in many areas and were intruded by granitoid plutons during the Devonian to Triassic Period and extrusive acid rocks, mostly dacites and rhyollites during the Permo-Triassic. The outcrop pattern is extremely complex. Rock masses at surface are often intensely folded and faulted, and weathering has given rise to the development of deep weathering profiles and residual soils, especially on the metamorphic rocks (phyllites and schists).

The climate pattern in Laos is dominated by the Asian monsoon. The northeast monsoon coincides with the dry season from November to April, while the southwest monsoon between May and October constitutes the rainy season, and is characterised by thunderstorms during which rainfall in excess of 100 mm in 24 hours is not uncommon. In the higher rainfall areas of the mountainous north, east and southeast of the country such rainfall may occur several times a year; in drier areas it can be expected on average every three or four years.

Fig 1. Lao PDR and the national road network



3. Landslide hazards and the road network

Data on the extent and volume of landsliding affecting Lao roads are difficult to obtain, as to date there has been no systematic record or study into the magnitude of the problem. Road maintenance data collected by the DPWT tends not to be specific to landslide impacts and includes, for example, damage to drainage structures, retaining walls and road pavement, all of which are not necessarily due to landslides and earthworks failures. Nevertheless, the expenditure on emergency repairs is documented in such a way that it has been possible to broadly differentiate between repairs due to landslides (including earthworks failures) and other works (Table 1). At current exchange rates the expenditure on emergency landslide repairs appears to range between US$ 3 and 5 million per year.

Table 1. Summary of emergency maintenance expenditure over recent years (US$ millions)

Fiscal Year	Landslide removal and repair	Carriageway repairs and road grading	Total emergency maintenance expenditure
2004-05	5.15	1.19	6.34
2005-06	3.17	3.43	6.59
2006-07	3.14	2.08	5.21

In total between 50% and 80% of emergency repair works is spent on dealing with landslides and related effects. This equates approximately to an average landslide expenditure of between US$ 1,000 and 1,500 per kilometre of road per year.

Generally, the management of these landslide hazards takes place through reactive interventions (clearance and repair) rather than pro-active interventions (slope improvement and pre-emptive measures, such as reduced cut slope angles, retaining walls and bio-engineering applications for example).

In order to gain a greater understanding of the causes and mechanisms of landslides along the Lao PDR road network, and the levels of hazard and risk that they pose, an inventory was carried out of selected alignments. This inventory covered a little over 1,500 kilometres of the Lao PDR national road network. This network is slightly more than 7,000 kilometres in length, of which approximately half is judged to be in steep hilly or mountainous terrain. The inventory therefore covered about 50% of the national road network located through steep hilly or mountainous areas where landslide and earthworks failures are likely to pose the greatest hazards. In total over 150 landslides were recorded in the inventory, and a hazard and risk classification was assigned to each based on the definitions shown in Table 2 below. Table 3 explains the manner in which the classifications were applied. It should be noted that the assessment of the size and impact of recorded slope failures was based on an interpretation of landslide scars, remaining slide debris and evidence of road damage. Some of this evidence will have been removed by landslide clearance and repair operations, and so a degree of interpretation was required.

Table 2. Hazard and risk computation

Risk (R) = Magnitude (M) x Probability (P) x Value (Va) x Vulnerability (Vu)

Where:
Magnitude is the size of the landslide or slope failure;
Probability is the likelihood of a ground movement or slope failure occurring within a given time, such as a road design life;
Value is the value of elements judged to be at risk (e.g. a retaining wall or a side drain);
Vulnerability is the degree of damage considered likely to occur to a given element at potential risk should the ground movement or slope failure occur.

The **higher** risk numbers calculated represent landslides and slope failures that pose potentially significant concern to road stability, while the **lower** risk numbers commonly represent ‘nuisance’ problems for the section of road concerned.

Table 3. Definition of hazard and risk values assigned

Risk Components	Assigned Relative Values			
	0	1	2	3
Magnitude of hazard (M)		Small (shallow and extending over up to 500m^2)	Moderate	Large (deep and extending over area of 5000m^2 or more)
Probability of hazard occurring during 20 year period (P)	Not expected to happen	Possible	Expected to happen	Definite
Value of road elements at risk (Va)		Existing slope works and side drain	Existing slope works, side drain, and up to 50% of carriageway width (one lane)	Entire carriageway and adjacent structures
Vulnerability of elements to the hazard, should it occur (Vu)	No effect	Deformation or blockage	Partial loss	Total loss
Risk = M x P x Va x Vu				

The majority of the landslides recorded appeared to have been caused by the effects of higher wet season groundwater and perched water levels in soils and weathered rock masses exposed in steep roadside cuts. Slope failures were often observed to originate from the upper portions of cut slopes where colluvium or the weaker, more weathered material, predominates in the weathering profile. Ground movements affecting the carriageway or outside edge of road from below appeared to be associated with localise shallow failures in fill slopes and construction spoil or more extensive areas of deeper failure of the natural hillside, in some instances associated with river scour. It should be noted that ground movements taking place on slopes below the road are often less easily identified than those above, and some of these may therefore be missing from the inventory.

Table 4 shows the percentage distribution of landslide risk number assigned according to whether failures were recorded above, below or through the road (involving failure of the road formation itself).

Table 4. Percentage distribution of recorded landslides according to risk number and location relative to the road

	Risk Number								
	3	**6/8**	**12**	**18**	**24/27**	**36**	**54**	**81**	**Total %**
Above Road	21	20	20	6	4	0	0	0	**71**
Below Road	0	0	6	0	5	6	4	5	**26**
Through Road	0	0	0	0	0	0	0	3	**3**

This summary shows that over 70% of recorded roadside slope failures had taken place above the road. The majority of these constituted shallow failures in cut slopes, and predominantly within the weathering profile. Most of these slope failures appeared to have resulted in blockage to roadside drains and adjacent areas of carriageway. Approximately 60% of recorded landslides were assigned the low risk categories (≤ 12, Table 4) associated with these types of failures (eg Fig 2).

Fig 2. Typical above road failure (assigned Risk No 6)

Fig 3. Typical below road failure (assigned Risk No 18)

The larger slope failures recorded above the road tended to be controlled by adverse jointing and the visual evidence suggested that these failures had resulted in temporary blockage to the entire carriageway. Only 4% (six in number) of recorded landslides fell into this category. Although only a quarter of recorded landslides and slope failures had occurred in below road locations (eg Fig 3), higher risk numbers were assigned to these failures. The likely impacts of these failures on adjacent sections of road were interpreted to have ranged between deformation and loss of the road edge (Fig 3) to the entire failure of the carriageway. Finally, only 3% (five in number) of landslides were considered likely to have involved failure of the entire slope, above, below and through the road.

The risk categories assigned in the inventory were used as a mean of prioritising and selecting pilot projects for slope stabilisation trials (section 6).

4. Economic and environmental costs of landslides affecting the national road network

Table 1 summarises the cost of landslide clearance and damage repair during the last three years. The total cost of landslides should, however, include the costs of economic disruption brought about by temporary road closures, and any environmental and social costs brought about by landslides within road corridors. The MPWT provided data on average annual daily traffic (AADT) volumes and these ranged between approximately 100 and 350 vehicles per day. Most of these vehicles are either private or public passenger transport vehicles or trucks carrying essentially non-perishable goods to both domestic and international markets. The economic losses associated with road closures are therefore predominantly related to the cost of lost time (Value of Time – VOT) and Vehicle Operating Costs (VOCs). Estimates for the value of time were carried out to provide an indication of the average economic costs associated with delays in travelling time due to landslides. Parameters included in this assessment were:

- GDP per head;
- Percentage of population within working age;
- Unemployment rates (within the working population);
- Estimated working hours per annum.

From these data the estimated cost in lost time due to road blockage is US$ 0.55/hr per vehicle. In addition to the value of time, VOCs were considered. These relate to the cost associated with hiring or purchasing a vehicle, the labour costs associated with a driver and assistant, in the case of goods vehicles, and fuel costs. Typically, vehicle purchase prices are US $ 19,000 and US $ 67,000 for a car and a heavy goods vehicle respectively. Assuming that the average life expectancy of a vehicle is ten years, and adopting a weighted average price of US $ 28,000 per vehicle, this would mean an average daily cost of US $ 76/day. Driver and assistant costs were estimated to be US $ 1.2/hour and $ 0.3/hour respectively. Fuel costs linked to landslide blockages would probably be insignificant as most vehicles are likely to wait for landslides to be cleared with their engines switched off.

Table 5 shows the calculated rates of economic loss associated with road blockages caused by landslides for varying AADTs and blockage periods. The data indicate that the costs of landslide blockages increase exponentially (to the power of 2) with increasing blockage time. The MPWT works on the policy that all road blockages should be cleared within six hours.

Table 5. Estimated economic losses incurred by landslide road blockages according to period of blockage and AADT

Blockage Period	**Economic Losses (US$)**					
	AADT 100			**AADT 300**		
	VOT	**VOC**	**Total**	**VOT**	**VOC**	**Total**
3 hrs	93	686	779	280	2,057	2,337
6 hrs	373	2,742	3,115	1,119	8,227	9,346
12 hrs	1,491	10,969	12,460	4,474	32,907	37,381
24 hrs	5,966	43,876	49,842	17,897	131,627	149,524

Environmental damage due to landslides in Laos includes:

- Loss of trees of commercial value, either for timber or other products;
- Permanent loss of topsoil and nutrients, representing the degradation of the overall national land resource;
- Increased sediment in water-courses, affecting water supplies and fisheries downstream;
- In extreme cases, downstream sedimentation can cause changes to river beds, leading to altered flood patterns, with additional consequences;
- In catchments above reservoirs, sediment from landslides can gradually reduce the water storage capacity.

The environmental costs of landslides occurring on roadside slopes essentially relate to the first two categories of damage listed above. Table 6 identifies the value of forest resources that could potentially be lost as a result of a typical landslide of 1,500m^2 in surface area and 500m^3 in volume.

Table 6. Estimated environmental costs associated with an average landslide occurrence along the national road network in steep hilly or mountainous terrain

Damage type	**Assumptions**	**Value (US$)**
Loss of trees and plants of commercial value	2 large timber trees 6 trees of alternative commercial value. Herbaceous plants of value.	3,000 4,800 100
Permanent loss of topsoil	Equivalent to the lost value of one rotation of an agricultural crop.	150
Effects of increased sediment in water courses	Damage to drinking water supplies in terms of blocking intakes and time lost in going to other clear water sources. Damage to fish stocks through loss of productivity (reduced fish growth and temporary prevention of fishing).	50 50
Total cost of wider environmental damage		**8,150**

The figures in Table 6 are based on the following assumptions:

- The forest gate price of rosewood is US \$ 300/m^3; one large tree is about 5 to 8 m^3;
- The forest gate price of a "general tree" is US \$ 100/m^3; one large tree is about 8 to 10 m^3;
- Topsoil for upland rice cultivation is valued at US $ 100/ha.

However, these losses only become effective in those cases where economic use would otherwise have been made of the forest resources involved. On most roadside slopes, and especially those within the Right of Way, this is unlikely to be the case. The estimated potential environmental costs associated with roadside slope failures were therefore not considered any further in the assessment.

The population density of the hilly and mountainous areas of the country is considered to be low when compared to other areas of similar topography in south and southeast Asia. The direct social impact of landslides within the corridor of the national road network is also considered to be low. There are no known instances of deaths due to landslides occurring on roadside slopes in Laos, and the impact of landslides on utilities, including water supply, also appears very limited.

5. Economic modelling of slope stability interventions

Engineering interventions aimed at reducing the incidence of roadside landslides can take the form of those that are implemented during the design and construction phase of new roads and those that aim to enhance stability of slopes along existing roads. With regard to the former, an assessment has been made (Table 7) of the potential costs and savings that might be accrued as a result of investment in enhanced slope management during design and construction. These figures are obviously speculative but are based on experience gained in the region and cost information obtained during the design and implementation of slope stabilisation trials in Laos during other stages of the SEACAP project (Hearn 2007).

From the assumptions made in Table 7 the inclusion of increased slope stability considerations results in an approximate 10% increase in the combined cost of design and construction, i.e. from US $ 25.0 million to $ 27.0 million. As a result the annual maintenance cost (emergency and routine combined) is reduced by 28%, from US $ 110,000 to $ 79,050. Using the Net Present Value[1] (NPV) cash flow stream, this investment only starts to become beneficial in economic terms after 50 years, i.e. longer than the notional design life of most mountain roads. However, this takes no consideration of the recurring losses brought about by landslide blockages on travel times, vehicle operation and any associated environmental damage.

Table 7. Estimated additional costs (positive values) versus potential benefits (negative values) associated with the introduction of increased consideration of slope stability during design and construction

Potential improvement of standards	Additional cost to initial investment (US$)		Annual return in reduced maintenance costs (US$)	
	Design* 750,000	Construction* 25,000,000	Emergency* 75,000	Routine* 35,000
Improved alignment design to avoid instability	75,000	0	-7,500	-3,500
Cut slope grades adapted according to materials	22,500	210,000	-2,250	-1,750
Formation of fill slopes following best principles	0	630,000	-2,250	-700
Increased slope drainage	37,500	250,000	-3,000	700
Pro-active additional slope stabilisation (i.e. retaining walls etc)	75,000	502,500	-3,000	-1,750
Pro-active slope protection measures (i.e. bioengineering etc)	7,500	530,000	-1,500	-700
Reduction of geometric standards in unstable sections	0	-93,750	-3,750	0
Total estimated change	**217,500**	**2,028,750**	**-23,250**	**-7,700**

*Base case cost without increased investment in slope stability.

The NPV was also used to assess the economic benefits associated with investments made to enhance slope stability along existing roads, i.e. as an operational intervention. The scenario considered comprised the following:

- slope improvement measures are put in place in 2009 at a cost US$100,000 and the ongoing annual maintenance of these works amounts to US$2,500;
- during a particularly heavy wet season five years later in 2013 a number of landslides take place The reinstatement costs incurred as a result of these landslides amount to US$50,000. However, had the investment in slope improvement measures in 2009 not been implemented then the cost of landslide damage in 2013 would have totalled US$200,000.

A NPV cash flow profile for this scenario, using a discount rate of 10 percent, yielded a negative economic return of

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[1] The NPV is the difference between the sum of the discounted cash flows that are expected from an investment and the amount that is initially invested.

approximately US$5,000 following the investment in slope improvement measures in 2009. This implies that, from the perspective of engineering costs alone, it would not be worthwhile to construct the proposed slope improvement measures. However, the results are sensitive to the discount factor, the timing of the landslide in relation to the investment and the estimated extent of damage (with and without the investment). A decrease in the discount factor from 10% to 5% leads to an NPV change of approximately US$19,000 (from a negative US$5,000 return to a positive of nearly US$14,000). If the anticipated landslides take place in 2012 instead of 2013, the NPV result again swings from negative to positive.

The economic assessments outlined above indicate that investments in pro-active slope improvement works during design, construction and operation are marginal in terms of returned economic benefit. However, for roads where landslides are most frequent, and their engineering impacts are judged to be most significant, investment in slope improvement is likely to be justifiable on economic grounds. Furthermore, these economic assessments are made solely in terms of engineering costs and engineering benefits and do not take account of traffic disruption costs. These are controlled by traffic volumes and blockage periods, and are likely to pose potentially significant costs on the busiest of roads in the national network.

6. Recommended programme for enhanced slope management

Following a capacity analysis of the MPWT and related agencies active in the roads sector, a number of recommendations were made for strengthening slope management. A skills enhancement programme was designed and costed with the aim of strengthening the MPWT and its constituent departments, as well as the university and consulting sectors, in the following areas:

- Improved landslide data collection and slope/road stability monitoring;
- Landslide recognition and engineering geology;
- Risk assessment for prioritisation and selection of alternatives;
- Site investigation and slope monitoring;
- Design and construction techniques for improved slope stabilisation and protection.

In parallel with this, the risk classifications contained in the landslide inventory (section 3) were used to develop a shortlist of seven landslide sites for pilot slope improvement works. The total estimated cost of the training and pilot project implementation amounted to approximately US$1.5 million.

7. Discussion

The impact of landslides on the national road network of Laos is, on the whole, considered to be less than it is in some other Asian countries (see for example Petley et al 2007). The majority of landslides affecting the national road network appear to be related to shallow and localised slope failures in cut slopes. Nevertheless, failures occurring on slopes below sections of road are also common and these have given rise, in places, to loss of road edge and sometimes failure of adjacent carriageway. The economic evaluations undertaken indicate that the engineering benefits to be accrued from increased investment in pro-active slope management are marginal. However, for those road alignments within the network that suffer the greatest degree of landslide hazard, investment in pro-active slope management is considered likely to be beneficial, in terms of the combined engineering return on the investment (reduced operational and maintenance costs) and reduced costs associated with traffic delays.

Furthermore, there are considerations other than pure economics to be taken into account. There is in most countries likely to be a growing public expectation of accessibility within the national road network. Levels in the perception and tolerance of landslide hazards will differ, but it could be argued that access within existing road networks is increasingly seen by road users as a permanent utility. There are also strategic considerations of road access. National roads in Laos represent important links within international highways connecting China and Vietnam with Thailand, and traffic hold-ups caused by landslides will therefore have wider significance, and especially given anticipated growth rates in traffic volumes, both domestically and internationally.

The outcome of the feasibility study into enhanced slope management has been the development of a series of recommendations for strengthening of the road sector in this sphere. This strengthening might, for example, benefit from approaches developed under similar DFID-funded work in Nepal, and could be usefully integrated with related activities in other parts of the SEACAP region, most notably Vietnam and Cambodia.

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