Impact of Large Landslides in the Mountain Environment: Identification and Mitigation of Risk

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Deliverable D16

Relevant criteria to assess vulnerability and risk

1. Expression of Vulnerability for large landslides

In order to assess the risks induced by large landslides, it is necessary to determine in which way the hazard situations investigated in a dangerous area may affect the population, the buildings and infrastructures, as well as the environment. Indeed, the risks do exist only if a potential damage of a given magnitude may be determined, whatever are its characteristics.

Degree of loss to a given element at risk, or set of such elements, resulting from the occurrence of a natural phenomenon of a given magnitude is defined Vulnerability (V). Vulnerability is usually expressed in relative terms, using words such as 'no damage', 'some damage', 'major damage', 'and total loss', or by a numerical scale between 0 (no damage, 0 %) and 1 (total loss, 100 %).

Although the state of the art for identifying the elements at risk and their characteristics is relatively well developed, the state of the art for assessment of vulnerability is in general relatively primitive.

The vulnerability is affected by the nature of affected facility, whether it is uphill, on, or downhill of the landslide, and the nature of the element at risk. The velocity of movement, also affect the vulnerability, with higher velocities usually leading to greater vulnerability. This can lead to different degrees of damage on or in the travel path of a landslide. For structure and persons onto which a landslide travels, the greater the depth of slide material, generally the greater damage and vulnerability.

For structures the assessment of damage and, hence, vulnerability, depends on modelling the landslide-structure interaction. This is relatively well documented for rock falls (where structures have been designed to withstands impacts), and to a lesser extent for debris flows and extremely slow and very slow movements. For higher velocity slides, spreads and topples there is very little guidance available. Often, it is necessary to use judgement. In any case the notion of direct and indirect impacts has to be defined first.

1.1 Direct and indirect impacts

Any natural phenomenon modifying the geometrical and geomechanical conditions of a slope may induce impacts on the population, buildings and activities which can be classified as direct or indirect consequences. In the direct consequences all the physical impacts are gathered, leading either to a destruction, a damage (cracks in buildings, failure of pipes) or ever an excessive deformation (inclination of a house due to the movement of a slide, without any damage to the structure of the building). These direct consequences include the infrastructures hit by blocks, the buildings on a sliding slope affected by differential movements, but also the constructions in the valley downstream of a slide, which might be destroyed by a flash flood induced by the failure of a dam caused by a slide blocking the valley floor. The impacts on animals are also included in the direct damage.

The direct consequences include of course the population which may be killed, wounded, or affected by the loss of their houses and properties due to the landslide phenomenon. This even includes the population that needs to be evacuated before the occurrence of the landslide, because they might be affected by the mass itself or by the consequences of the induced phenomena, like the flash flood mentioned above. The direct consequences can also relate to the environment, in the way that a landslide may destroy forests, animals or a habitat zone of a certain type of protected animal; it may also affect the springs of water available at the toe of a rockfall.

As far as indirect consequences are concerned, they deal with all the disruptions or hindrances of the economic activities induced by the considered landslide, due mainly to the interruption of the traffic, the reduction of the tourist demand and other indirect consequences related to the modification of the state of the landslide surface. These indirect consequences are fairly difficult to assess, because they may imply a spatial extent much larger than the landslide zone itself. Their nature may also change with time because, when a hindrance is suddenly introduced in an economic system, other solutions are found by all the partners to limit the negative consequences of this perturbation.

The definition introduced by Varnes (1978) can be refined first by considering that a significant probability can be established for each reference scenario on the basis of the recurrence of historic events or by considering the occurrence probability of triggering causes like rainfall. Then it can be more significant if, instead of assuming only one vulnerability coefficient, its different components (i.e. physical, social, economic, environmental) are considered.

The methodology that will be used in this project is therefore a separate analysis of different risk components (due to different vulnerability), for each respective scenario with different return periods, and then a global comparison of the computed risks.

1.1.1 Physical vulnerability

This term expresses the degree of loss or potential damage to a given element or set of elements at risk when they are affected by the behaviour of an unstable mass, which is qualified by a given magnitude or intensity. Such an impact must be assessed first in terms of structural failure, by the analysis of the effect of differential settlements or movements on a structure crossing a scarp, or by the impact of rock blocks hitting a building. It has also to be evaluated in terms of operational failure, for instance when the tilting of a house or a road exceeds an acceptable value, even though no cracks are observed. The physical damage also depends on the quality of the materials used in the building or the infrastructures under study, as well as on the maintenance of these structures, especially when wooden buildings are concerned.

No theory has been elaborated up to now to model the damaging effects due to all types of landslides, with the exception of the sudden impact of a block on a wall; however the number of variable parameters for this case (velocity, mass of the block, angle of impact, position of the impact point on the wall, potential deformation of the whole structure, detailed geometry of the wall, strength of the material) does not allow to obtain a significant result in terms of global risk analysis of a large landslide area. On the other hand, in most situations where limited damage has occurred, no systematic monitoring procedure has been carried out, which would have allowed a proper evaluation of the effect of the landslide movements.

One exception is the enquiry organized in 1983 concerning the damage observed at the houses of the village of Arveyes, located on the slide bearing the same name, located in the Prealps of the Canton of Vaud, in Switzerland (Gabus et al., 1988). This slide, the volume of which reaches 20 mio m^3, had experienced some years before a renewed activity, with average annual velocities varying between 2 and 4 cm/year. From the 150 owners concerned, some 50 answers were received, most of the time quite complete despite of the fairly complex questionnaire sent (DUTI, 1986a). Finally 42 complete questionnaires dealing with significant buildings (no barns) were analysed, out of which 22 were in a good state or presented only minor problems; within the other buildings, 5 showed fairly serious damage and 5 others presented a quite serious situation. In these ten last cases, 40 % had walls made of stones and 80 % made of masonry (some buildings combine both systems), but no one was built in concrete. About half of them had a base slab, and half of them did not, but in no one, this slab was made of concrete.

As far as the localization of the buildings was concerned, most of the damaged buildings were located near the outside limits of the slide or the main scarp, or in active zones where shear cracks related to superficial movements were observed. It can also be mentioned that several owners indicated that the cracks had appeared progressively and not specifically during the crisis period of 1980-1982 during which high rainfall was recorded. Finally, the notion of damage is difficult to define, as many owners first judged the state of their building as satisfactory, whereas it displayed many cracks. Only a few owners did specific repair works that are more serious than normal maintenance works (like sealing of cracks and drainage in the cellar).

As a conclusion, the main criteria to determine the value of the physical vulnerability coefficients are, in decreasing order :

- the intensity of the phenomenon (velocity for slides, energy for rockfalls);
- the types and function of the structure, as far as its strength is concerned;
- the state of maintenance and capacity of deformation.

The classification of these criteria may vary when networks are considered (electric lines, water pipes, sewage ducts) instead of buildings and roads.

1.1.2 Social vulnerability

This term expresses the rate of impact due to a landslide on the exposed population. In many rockfall cases even of a limited intensity, this rate is 100 % as it may cause death. Serious wounds leading to a permanent important handicap are also assessed as near 100 %, because the long-term costs they induce for the society are high. Temporary wounds (like a leg broken) are considered on the contrary as a minor vulnerability, as the persons can recover after a short time.

The coefficient of social vulnerability also includes the psychological consequences of the loss of a home, as it is often observed as more difficult for the victims to loose their affective roots than to be wounded. Even the fact of being provisionally evacuated, for a certain duration, constitutes an impact on the population that deals with social vulnerability.

Thus the main criteria to determine the value of the social vulnerability coefficients are, in decreasing order :

- the intensity of the phenomenon (which is in relation with the warning time);
- the sensitivity of the population, depending on its age and capacity to anticipate a landslide;
- the capacity of understanding the phenomenon and to move away from the exposed zone.

1.1.3 Environmental vulnerability

In order to face all the direct impacts of a landslide, it is necessary to add a third category after the physical and social domains, which deals with the natural environment. Indeed, it is often the first "target" of landslides, like livestock, as the slopes where they occur are generally not densely populated nor crossed by major infrastructures. On the other hand, the damage to these natural components cannot be evaluated in monetary terms, especially as far as forests (which have now nearly no merchant value), wild animals and rare plants are concerned. For the forests, this impact may be important as several zones are considered as protective forests against rockfall and avalanches, so that their potential value has to be assessed through the analysis of their global function (productive, protective, recreational).

As far as impacts on water resources and flow conditions in rivers are concerned, it is also important to analyse the potential loss of springs due to a rockfall, even if they are not yet equipped for water consumption, and the potential loss of fish if the river flow is disturbed by a slide mass obstructing its course.

Thus, the main criteria to determine the value of the environmental vulnerability coefficients are :

- the intensity of the phenomenon, in relation to its disrupting effect on nature;
- the function of the forest or of the endangered animal and vegetal species;
- the sensitivity and rareness of these species.

1.1.4 Economic vulnerability

Beyond the potential destruction of assets on or near the landslides, such phenomena may induce indirect economic impacts when they block a road or a railway line, destroy an electric line or a water pipe, or dam a valley causing a lake that represents a danger downstream, so that the economic activity in the valley below must be stopped, but maybe without final destructive consequences.

It is important to realise that, in most studied real situations, the indirect economic impacts are much larger than the direct impacts. As an example, for the avalanches of the winter 1999-2000 in Switzerland, it was assessed that the indirect impacts were 4 to 5 higher than the direct impacts. In the case of La Josefina landslide in Ecuador, the threat on the Paute hydroelectric scheme located downwards, that might have been seriously affected by the overflow of the dam caused by the landslide in 1993, would have represented the loss of 70 % of all the electric energy production in the country; happily only limited damage were registered when the flow reaching 10’000 m^3/s filled the previously emptied reservoir, but this flood brought the equivalent of 2 years of siltation in the reservoir, which means several hundreds of thousands of US dollars for its pumping and evacuation, in order to maintain the regulation capacity of the lake.

The economic impact on a road blocked by a landslide depends of course on the average expected traffic, but also on the existence of an alternative route. For example, Ceppo Morelli rockfall, when it reached the access road to Macugnaga resort station, impeded any traffic to and from this important station for several weeks; an alternative road now exists on the other side of the valley, but its position does not guarantee its operation in case of large rockfall.

In other cases, an alternative road exists, but requires a very long bypass of several dozens of kilometres, as it is the case for La Frasse Landslide, in Switzerland, so that a large part of the tourist traffic coming in the area for one day will give up and join other resorts, especially in winter and spring. If a threat of rockfall is known and publicised, many people will not drive to the concerned area, even if the risk is effectively limited.

As far as transport of goods is concerned, some may be stockpiled for a certain time, like logs of wood, but other products, like milk or cheese, need to be transported continuously to the factories or warehouses, so that there is a direct economic loss in case of disruption of traffic, or an indirect economic loss if a longer transport distance must be foreseen by an alternative route.

The main criteria to be considered in the assessment of the economic vulnerability are thus:

- the types of services implied (industry, tourism, transport);
- the types of economic activities affected;
- the traffic and the cost of blocking a route (which is very high for railways);
- the possibilities of alternative routes.

Finally, this aspect must include an analysis of the potential damage due to the secondary consequences of a landslide, like the formation of a dam in a valley, inducing flooding upstream and a potential catastrophic flow downstream.

2. Vulnerabilty assessement

As pointed out previously the element at risk vulnerability depends on the typology of the element (T, and therefore on its shock resistance features) and on process intensity (I):

$$V = f\,(T, I)$$

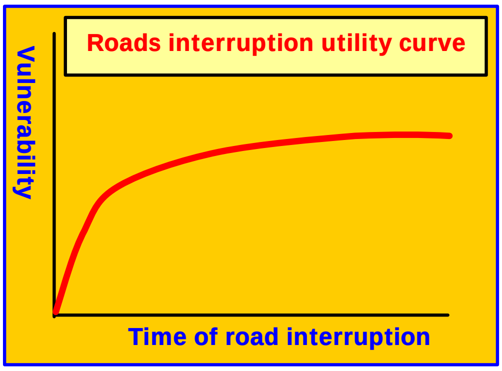
From the practical point of view, two approaches can be followed in order to evaluate the vulnerability:

Social vulnerability	
Vulnerability description	**Index**
Non affected persons	0
Non physical damages, evacuated persons	0.25
Physical damages (person continue their activities)	0.5
Seriously wounded persons (50% disability)	0.75
Died, 51-100% disability	1

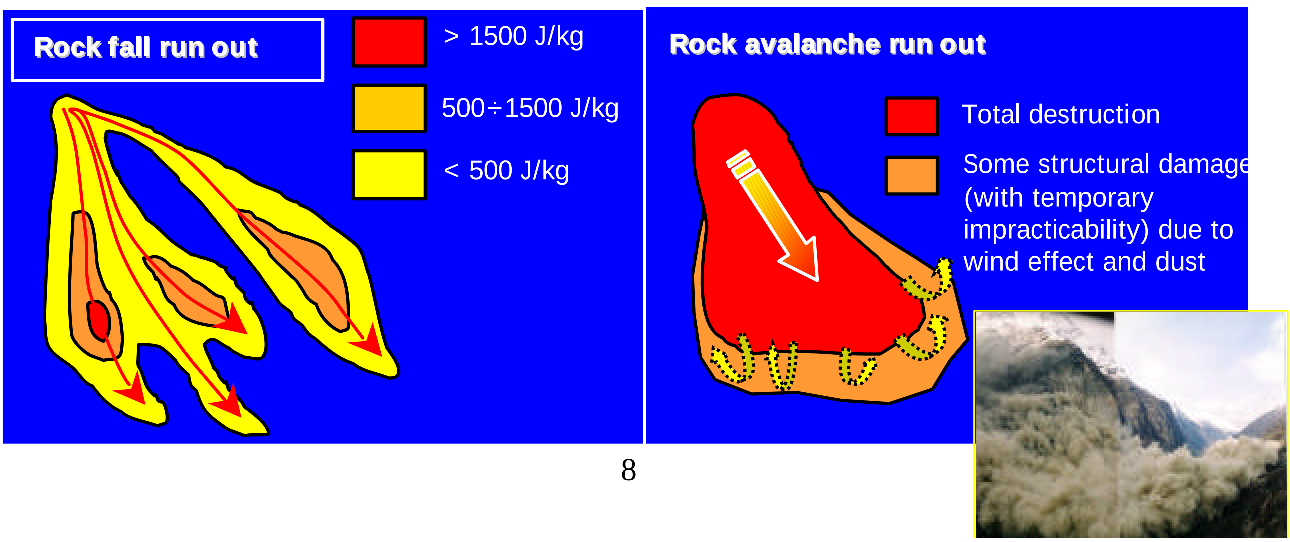
Physical vulnerability		
Vulnerability description	**Loss range**	**Index**
Intact structures	0	0
Local damages	1÷25%	0.25
Seriously damages (possible to repair)	26÷50%	0.5
Mostly destroyed (difficult to repair)	51÷75%	0.75
Total destruction (out of use; e.g. >5% inclination)	76÷100%	1

a) Simply on the basis of effects on the element at risk

In this case 5 classes of loss percentage (0, 0.25, 0.5, 0.75, 1) have been applied to each vulnerability category. Through detailed studies it could be however possible to attribute various weights at various percentage classes based on "utility curves".



E.g.: in the roads interruption case (economical vulnerability) some studies have evidenced a logarithmic curve type, as the vulnerability diminishes with the time passing for the alternatives roads opening (e.g.: 0, 0.5, 0.8, 0.95, 1)



Several scales have been developed in order to qualify the intensity of the different types of landslides phenomena. For instance, the Swiss recommendations published in 1997 provide orders of magnitude in order to differentiate low, medium and high intensity for block fall, rockfall, slides and flows. They are expressed, either in terms of impact energy, or in terms of average velocity, or in terms of depth of the potentially erodable soil zone (OFAT, OFEE, OFEFP, 1997). For large rockfall, it is evident that the intensity level in the exposed zones is always high to very high, whereas for slides, many large phenomena display low to medium intensity, according to the proposed scale.

A more detailed analysis implies however the consideration of the acceleration phase, or the volume of potential unit blocks of a rockfall, as well as their possible interaction. But in any case the limit values proposed for the intensity classes are indicative and have to be considered rather as qualitative references than as quantitative parameters

3. Final considerations

It has been often observed that the consideration of landslide risks by the local authorities is either too optimistic (the risk is nearly denied) or too pessimistic (major prohibitions are pronounced, major protection works are carried out, without a reasonable risk analysis). It is therefore difficult to measure the real impact of a proper risk assessment on local development, because the analysis and consecutive political measures are not founded on a systematic approach. This leads often to the realization of apparently efficient protection works, but which do not solve the stability problem nor limit the hazard in case of rare events and rather aim at giving a good conscience to the authorities.

After a serious event with some direct impacts on the exposed structures, even if it implies only a small portion of the whole landslide phenomenon, the authorities tend to favour extremely safe solutions and adopt preventive measures which may be excessive with regard to the real risk analysis results. This perspective is inappropriate for two reasons; first it leads to an unnecessary investment with respect to the real necessity of protection of the exposed objects; then it creates precedents in the risk management policy, so that the need of safety seems to grow unnecessarily. A rational approach is thus needed, especially in the European perspective which must aim at dealing the similar problems in a proportionate way.