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Environmental monitoring: landslide assessment and risk management

(Test site: Vernazza, Cinque Terre Natural Park)

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Introduction

Natural disasters, whether of meteorological origin such as cyclones, floods, tornadoes and droughts or having geological nature such as earthquakes, volcanoes and landslide, are well known for their devastating impacts on human life, economy and environment. Over recent decades, the people and the societies are becoming more vulnerable; although the frequency of natural events may be constant, human activities contribute to their increased intensity. Indeed, every year millions of people are affected by natural disasters globally and, only in the last decade, more than 80% of all disaster-related deaths were caused by natural hazards. Scientific predictions and evidence indicate that global climate changes are increasing the number of extreme events, creating more frequent and intensified natural hazards such as floods and windstorms. Moreover, the population growth and urbanization increase the number of people that are vulnerable to natural hazards. Also the complexities of the technological and human systems have increased sharply. The demographic pressures and territory mismanagement have also largely contributed to an increase in natural disasters and environmental emergencies to society.

Despite the development of risk prevention, it is noted that the developed approaches have not managed to successfully reduce the impact of the natural hazards so a better knowledge of the phenomenon is required to mitigate increasing losses. In recent years, the critical importance of disaster management has been widely recognized and their impacts has intensified and risen closer to the top of the development agenda (World Conference on Disaster Reduction (WCDR) Kobe, January 2005). The purpose is to reduce, or avoid, the potential losses from hazards, assure prompt and appropriate assistance to victims of disaster, and achieve rapid and effective recovery, using measures taken before (pre-disaster phase), after (post-disaster phase) and during (disaster phase) the event. It involves plans, structures, and arrangements established to engage the normal endeavors of governments, voluntary and private agencies in a comprehensive and coordinated way to respond to the whole spectrum of emergency needs.

In the field of natural disasters recovery, reduction and emergency management, ITHACA (Information Technology for Humanitarian Assistance, Cooperation and Action), a non-profit association founded by the Politecnico of Torino and the Higher Institute on Innovation Territorial Systems (Si.T.I.), has as main aim to develop research and education in environment and territory sectors. The different skills characterizing ITHACA are related to the acquisition, management and elaboration of geographic and cartographic data. The projects deal mainly with the thematic maps production and related products and services supply, useful to correctly plan and manage natural disaster mitigation operations. The main application fields for these products are the mitigation and warning assistance. Mitigation activities are environmental/social analysis and evaluation activities devoted to the identification of effects caused by natural and manmade disaster events and to the correct planning and support of necessary relief operations. On the other hand, the main aim of warning activities and analyses is to foresee catastrophic events and their effects on population and territory.

In this context, my experience has focused on landslide disaster management. Over recent years, the total land area subject to landslides is about 3.7 million square kilometers with a population of nearly 300 million, or 5 percent of total world population. The relatively high-risk areas cover about 820,000 Km sq with an estimated population of 66 million. Slope failures are generally not so costly as earthquakes, major floods, hurricanes or some natural catastrophes, but they are more widespread, and over the years may cause more property loss than any other geological hazard. In many developing regions slope failures constitute a continuing and serious impact on the social and economic structure.

Specifically, the Italian territory has always been subject to instability phenomena, because of the geological and morphological characteristic and because of "extreme" weather events that are repeated more frequently than in the past, in relation to climate change. Currently these disasters lead to the largest number of victims and damages to settlements, infrastructure and historical and cultural environmental, after the earthquakes.. The urban development, especially in recent decades, resulted in an increase of the assets at risk and unstable areas, often due to constant human intervention badly designed that led to instability also places previously considered "safe". Prevention is therefore essential to minimize the damages caused by landslides.

In recent years, experts and planners are therefore becoming increasingly aware of the importance of predicting where, how and why landslides will occur in a given area and numerous approaches to landslide hazard/risk assessment have been developed. The landslide risk management consists of several steps. Firstly, the risk analysis, with scope definition, hazard and risk identification and risk estimation (hazard analysis and consequence analyses). Secondly, risk assessment that takes the output from risk analysis and assesses these against values judgments, and risk acceptance criteria. Finally, risk management that takes the output from the risk assessment, and considers risk mitigation in order to reduce the likelihood and consequences by developing monitoring, warning and evacuation plans or transferring risk.

An important starting point is the hazard analysis, that involves characterizing the landslide (classification, size, velocity, mechanics, location, travel distance) and the corresponding frequency (annual probability) of occurrence. These investigations may include geotechnical and engineering assessments, geomorphological and geographical analysis. The goal can be reached using different methodologies, such as reference data, contained in the classic cartography, traditional surveys and information coming from satellite and aerial data processing, classic surveys and GPS/GNSS acquisition on the field.

The objectives of the conducted research were to investigate the different techniques and to check their potentiality, in order to evaluate the most appropriate instrument for landslide hazard assessment in terms of better compromise between time to perform the analysis and expected results. The attempt is to evaluate which are the best methodologies to use according to the scenario, taking into consideration both reachable accuracies and time constraints. Careful considerations will be performed on strengths, weaknesses and limitations inherent to each methodology. The characteristics associated with geographic, or geospatial, information technologies facilitate the integration of scientific, social and economic data, opening up interesting possibilities for monitoring, assessment and change detection activities, thus enabling better informed interventions in human and natural systems. This is an important factor for the success of emergency operations and for developing valuable natural disaster preparedness, mitigation and prevention systems.

The activities object of this thesis has been performed in the framework of a multidisciplinar project carried out by the cooperation between Politecnico of Torino and ITHACA. The study area is located in the Cinque Terre Natural Park, affected in recent years by a number of hydro-geological phenomena, the last, (25th October, 2011) causing extensive damage to the area, with mudslides and mud on a large portion of slopes, mainly in the towns of Monterosso and Vernazza..

The thesis is organized as follows:

- Chapter 1: in this chapter theoretical concepts that are thought fundamental to understand the disaster risk management are reviewed and illustrated. Moreover, the natural disaster management themes are presented.
- Chapter 2: in this chapter basic concepts about landslides (classification criteria, mechanism of sliding process, slope stability analysis) are described.

- Chapter 3: this chapter illustrates the landslide risk assessment and management. Fundamental concepts about risk management process, landslide susceptibility, hazard and risk zoning at different working scale and a general overview of data modelling are provided.
- Chapter 4: in this chapter the essential methods adopted in the disaster/risk and consequences management are presented and their applicability discussed. Methods can be used in order to forecast and to mitigate the landslide disasters, in recent years; the importance in predicting where, how and why landslides will occur in a given area is increased.
- Chapter 5: in this chapter a classification of the main investigation and monitoring approaches are discussed; advantages and disadvantages of different methods, relationship between type of approach and scale of work are evaluated in order to define scenarios and to implement warning system and/or civil protection plans.
- Chapter 6: this chapter shows a development/test based on traditional surveys and geomatic techniques in order to improve the effectiveness of emergency response and post disaster analysis of natural disaster. Results of the performed survey are also summarized.
- Chapter 7: in this chapter an evaluation of the most appropriate instruments to use is proposed, based on both literary review and surveys carried out in the Vernazza case study. The selection of adequate instruments depends on several factors, such as time to install and get results, instruments vulnerability, site accessibility, weather conditions.
- Conclusions: this final part of the thesis discusses and summarizes the main results obtained in the conducted study.

The review of the methodology of landslide-hazard zonation is only the first step in a communication process whose outcome in terms of effective public and private action may not only be delayed but is usually uncertain and commonly disappointing

1. Disaster Risk Management

In everyday life the human being is in constant contact and continuously compares himself with the natural environment; human life conditions are strictly related to the environmental conditions. Moreover, the increase of large scale disasters in recent year have caused fatalities, disruptions of livelihood, and economic loss. The people and the societies are becoming more vulnerable, although the frequency of dramatic natural events may be constant, human activities contribute to their increased intensity. Impacts depends on development practices, environmental protection, regulated growth of cities, distribution of people and wealth and government structures. Human activity also has an impact on the planet's climate, which may result in increased sea levels and potential disasters.

Many research centres, universities, international community and organisations, national and local governments put continuous efforts in studying the relations between human and environment, for reason of managing the emergency caused by natural disasters and for human security from risks of other kind.

The World Conference on Disaster Reduction (WCDR) (Kobe, January 2005) formulated the goal of creating societies more resilient to disasters. The development of a system of indicators of disaster risk and vulnerability that would enable the decision makers to assess the potential impact of disasters and to promote the formulation of appropriate policy responses is viewed as a key activity to accomplish this goal.

1.1. Disaster Risk Description

The trend during the last three decades shows an increase in the number of natural hazard events and an increase in the number of affected populations. Disasters not only affect the poor and characteristically more vulnerable countries but also those thought to be well protected.

The disaster risk is a combination of the factors that determine the potential for people to be exposed to particular types of natural hazard. The definition of disaster risk reflects the concept of disasters as the outcome of continuously present conditions of risk. The disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socio-economic development, disaster risks can be assessed and mapped, in broad terms at least (UNISDR, 2009).

The concept and practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters is the disaster risk reduction (DRR). There are different definitions of the term in the technical literature but the most commonly definition of DRR is one used by UN agencies such as UNSDR and UNDP: "The conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development." (UNISDR, 2009). Reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment and improving preparedness for adverse events are all examples of disaster risk reduction.
The disaster risk reduction framework is composed of several fields:

- Risk awareness and assessment including hazard analysis and vulnerability/capacity analysis;
- Knowledge development including education, training research and information;
- Public commitment and institutional frameworks, including organizational, policy, legislation and community action;
- Application of measures including environmental management, land-use and urban planning, protection of critical facilities, application of science and technology, partnership and networking and financial instruments;
- Early warning systems including forecasting dissemination of warnings, preparedness measures and reaction capacities.

The term disaster risk management (DRM) is often used in the same context and to mean much the same thing: a systematic approach to identifying, assessing and reducing risks of all kinds associated with hazards and human activities. It is more properly applied to the operational aspects of DRR, namely the practical implementation of DRR initiatives. The UNDP presents a basic definition on DRM: "the systematic process of using administrative decisions, organization, operational skills and capacities to implement policies, strategies and coping capacities of the society and communities to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards" (ISDR, 2004).

There are three main components at the base of disaster risk and disaster risk reduction: hazard, exposure and vulnerability, as visualised in the "risk triangle" (Crichton, 1999).

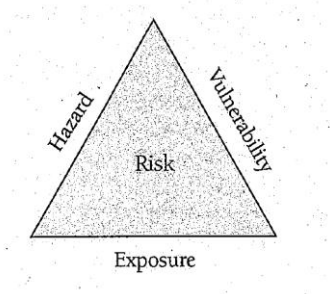


Figure 1 – The risk triangle (Crichton, 1999)

1.1.1. Hazard

The hazard is a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009). It can be distinguish between natural hazard (such as earthquakes) and socio-natural hazard (such as floods and landslides), in this case there is a combination of natural events and human intervention in nature.

The term natural hazard implies the occurrence of a natural process or phenomenon that many cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social, economic and environmental damage (UNISDR, 2009) in a defined space and time. In the past, different definitions have been assigned at the concept of natural disaster, they reflect the approach of the disciplines involved in their study; a natural hazard has been expressed as the elements in the physical environment harmful to man (Burton and Kate, 1964); an interaction of people and nature (White, 1973) the probability of occurrence of a potentially damaging phenomenon(UNDRO, 1982); and as a physical event which makes an impact on human beings and their environment (Alexander, 1993). Natural hazards are mainly geophysical events, such as earthquakes, landslides, volcanic activity and flooding. They have the characteristic of posing danger to the different social entities, nevertheless, this danger is not only the result of the process (natural vulnerability), but also it is the result of the human systems and their associated vulnerabilities towards them (human vulnerability). In the following table (Table 1) there is a list of natural hazard and their classification. Only a few hazard, such as earthquakes, occur as purely natural phenomena, while others, such as forest fires, floods and landslides, can happen with or without human intervention.

Hazards can be confined to a locality or threaten entire regions, so a hazard is a variable whose intensity and probability can be differ by a place. This has a considerable influence on the levels of possible damage.

To be able to reduce hazards or mitigate them, it is important to ascertain their potential, it is possible to obtain a description of possible hazards from the history of past event, however, this information must be supplemented by professional assistance and modern technology, in order to identify the possible size of the hazard.

List of natural hazard	Hazard posed by pure natural phenomena	Hazard also due to human intervention
Volcanic eruptions	x	
Earthquakes	x	
Floods	x	x
Droughts	x	x
Storms	x	
Hurricanes and tornadoes	x	
Forest fires	x	x
Landslides	x	x
Avalanches	x	x
Tsunamis	x	
Heat and cold waves	x	

Table 1 – Extreme natural events and their classification

1.1.2. Vulnerability

The vulnerability is generated by social, economic and environmental factors, that influence a person or a group of people and their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process) (Wisner B et al., 2003). In order to understand disasters it must know about the different levels of vulnerability of different groups of people. In the literature, a first definition of vulnerability is given by Westgate and O'Keefe (1976): it is the degree to which a community is at risk from the occurrence of extreme physical or natural phenomena, the risk refers to the probability of occurrence and the degree to which socio-economic and socio-political factors affect the community's capacity to absorb and recover from extreme phenomena. For Varley (1991), vulnerability is a function of the degree of social and self-protection available to potential victims. It is clearly related to the ability of households or communities to cope with and recover from outside events and particularly to shocks and sudden changes (Maskey, 1993). Recent definition considers the vulnerability the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UNISDR, 2009).

Therefore, the vulnerability can be divided in several aspects: livelihood and reliance (degree of resilience of the particular livelihood system of an individual or group and their capacity for resisting the impact of hazard); health (the robustness of individuals, and the operation of various social measures); preparedness (determined by the protection available for a given hazard, something that depends on people acting on their own behalf, and social factors).

There are so many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. The main factors, that may influence the degree of vulnerability, can be summarized below:

- Political-institutional factors (such as lean legislation, inadequate personnel and financial resources, underdeveloped democratic institutions, lacking or inadequate mechanisms and instruments for spreading financial risk, culture of prevention obstructed or insufficiently promoted);
- Economic factors (like governmental financial resources insufficient for disaster risk management, poverty, low level of economic diversification, influence of economic activities on disaster risk);
- Socio-cultural factors (such as poor education and insufficient, the tradition of slash-and-burn clearance or the application of out-data method in the natural environment, population not prepared to engage in mutual support schemes or to search for greater levels of general welfare).

These aspects cover a great proportion of the different kinds of vulnerabilities, furthermore each aspect has different components and the combinations of them can be so numerous that it is necessary specify the particular types of vulnerability of each threatened entity. The latter provide an adequate understanding of the total vulnerability to natural disasters so that prevention can be effectively accomplished. Vulnerability is given by the coupling between the natural and human systems, it can be divided into natural vulnerability and human vulnerability. Natural vulnerability depends on the threatening natural hazard, there is volcanic vulnerability, flooding vulnerability, landslide vulnerability, and so on. On contrast, human vulnerability is based on the social, economical, political and cultural systems.

1.1.3. Exposure

The exposure is described as the characteristic of people, property or other elements present in hazard zones that are subject to potential losses (UNISDR, 2009). Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest. Generally, hazard and exposure can be determined by using physical parameters and demographic datasets; the vulnerability is more complex and more difficult to describe.

1.1.4. Risk

The risk is the combination of the probability of an event and its negative consequences. The risk has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in “the risk of an accident”; whereas in technical settings the concept is usually focused on the consequences, in terms of “potential losses” for some particular cause, place and period. It can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks. In disaster management, risk refers to the combined susceptibility and vulnerability of the community to potential damage caused by a particular hazard within a specified future time period. Risk is rooted in conditions of physical, social, economic and environmental vulnerability that need to be assessed and managed on a continuing basis.

It can express the risk to a disaster as follows (R=risk, H= hazard, E= exposure, V= vulnerability):

$$R_{ah} = H_{ah} \text{ x } E_a \text{ x } V_{ah}$$

Where the subscripts *h* is related to the type of hazard (severity and temporal extent) and *a* is the geographical region affected by hazard *h*. For example, the resulting risk refers to the potential lives lost regarding hazard *h* in area *a*, whereas the vulnerability is people’s capacity to overcome difficulties with hazard *h* in area *a*, and the exposure is the number of people in the same area.

It can note that:

- The result of expression is 0 if one of three components is 0, for example the region affected is not populated or/and the population is not vulnerable or/and there is no likelihood of an event occurring;
- The vulnerability and the hazard change with the type of hazard and the region affected, for example, the houses might be built earthquake proof but vulnerable to floods;
- The exposure changes only with the geographical region affected.

1.2. Global Risk Index

Three international indexes for measuring disaster risk and its management were published between the 2004 and the 2005, these are the results of partnerships between scientific institutes and funding agencies.

These are:

- Disaster Risk Index (DRI);
- Hotspots;
- Americas Indexing Programme.

Each index comes from the particular elements and values chosen as important for measurement, the subjects and units (individuals, countries, etc) of analysis, the methodology used to generate the index from input data and the specific data sources used (UNDP, 2004). Indexing approaches can be characterised as inductive or deductive. Inductive approaches model risk through weighting and combining different hazard, vulnerability and risk reduction variables. Deductive approaches are based on the modelling of historical patterns of materialised risk (Cardona, 2003). The Americas programme is an example of an inductive approach, these are characterized by the absence of a universally accepted procedure for assigning values and weights to different inputs. The measurements of vulnerability is built on by available socio-economic and performance variables. Conversely the DRI and Hotspots programmes both follow deductive approaches, these find it difficult to accurately reflect risk when disasters occur infrequently or historical data is not available. In this case, the measurements of vulnerability and risk are hazard specific data and tied to disaster impact data. The two approaches can support one another, for example with deductive indexes being used to validate results from inductive models.

Moreover, each programme has specific goals, which direct the character of each indicator, its concepts and methodological development. Moreover, each model has a framework and methodology to ensure cross-country comparison (UNDP, 2004). For instance, the DRI programme aims to identify the relationship between national development pathways and its level disaster risk, Hotspots' primary goal is to map at a sub-national scale the places exposed to multiple hazard risk and the Americas programme aims to investigate countries at their national levels of vulnerability and disaster risk management performance. The three programmes share a common theory of disaster causality: the losses in disasters are caused by three sets of factors, exposure to hazard, the frequency/severity of hazard and the vulnerability of exposed elements.

1.2.1. The Disaster Risk Index

The Disaster Risk Index (DRI), realized by United Nations Development Programme (UNDP) in partnership with UNEP/GRID Geneva[1], aims to demonstrate the ways in which development influences disaster risk and vulnerability, this index represents the first effort to produce a statistical methodology. The DRI has global coverage and a national scale of resolution. The DRI is applied in full to earthquake, tropical cyclone and flooding, but preliminary analysis is also undertaken for volcano, landslide and drought. The starting point for the DRI is to obtain or produce hazard maps for earthquake, cyclone and flooding (and also drought) which are then overlain by population maps in a GIS system to identify national human exposure to each hazard type (Pelling M, 2006).

The DRI produces two measures of human vulnerability. The first, Relative Vulnerability, is calculated by dividing the number of people killed by the number of people exposed to a particular hazard type. Higher relative mortality equates to higher relative vulnerability. The simplicity of the model means that no country is excluded for showing outlier characteristics. The second measure of vulnerability aims to identify the socio-economic variables that best explain recorded mortality to individual hazard types. A step-wise multiple regression is used with disaster mortality from the Emergency Disaster Data Base (EM-DAT) as the dependent variable. Independent variables include physical exposure and a list of 24 socio-economic parameters selected by an expert group to represent: economic status, type of economic activities,

[1] http://www.undp.org/bcpr/disred/rdr.htm and http://gridca.grid.unep.ch/undp/

environmental quality, demography, health and sanitation, education and human development. These independent variables that best explain the variation in the dependent variable are chosen to describe the global characteristics of vulnerability for each hazard type.

DRI multi-hazard index combines hazard specific values and socio-economic variables. Hazard specific models, based on identified global vulnerability parameters, are run at the national level. For each hazard it is calculated the expected mortality for each country and territory based on the values of the globally selected vulnerability variables. The multiple-hazard risk index for each country is made by adding modelled deaths from individual hazard types. A final stage in the modelling process is to run a Boolean process in order to allocate the five statistically defined categories of multi-hazard risk to each country. In order to examine the fit between modelled mortality and mortality recorded in EM-DAT, the data from both sources are categorised into five country-risk classes and a cluster analysis performed to assess the closeness of fit (ISDR, 2004; Pelling M, 2006).

Some countries are excluded from the model; they are the countries marginally affected by a hazard, the countries known to be exposed but with no loss data and the countries where the distribution of risk could not be explained by the model (i.e. for drought in Sudan, where food insecurity and famine is more an outcome of armed conflict than of meteorological drought as defined in the model).

1.2.2. Hotspots

The Hotspots was implemented by Columbia University, the World Bank and numerous collaborating partners (ProVention Consortium) [2]. It aims to identify the places where risks of disaster-related mortality and economic losses are highest, based on the exposure of people and GDP to major hazards and historical loss rates. Hotspots operates at the global level with a sub-national scale of resolution and earthquakes, volcanoes, landslides, floods, drought and cyclones are included in the analysis. For Hotspots, hazard severity is indicated by event frequency or their probability. Exposure for each grid cell faced with hazard is calculated based on the population and economic assets of that cell. It is assumed that people and economic assets within a single grid cell are equally exposed to hazard.

Two sets of vulnerability coefficients have been calculated, one based on historical disaster mortality rates per hazard event, the other on historical rates of economic losses. Both vulnerability measures follow the same logic: 28 mortality and economic loss coefficients are calculated for each hazard. For both mortality and economic losses there is one loss rate for each of 7 regions (Africa, East Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, Middle East and North Africa, North America, South Asia) and 4 country wealth classes (high, upper-middle, lower-middle and low), defined according to standard classifications of the World Bank. For each hazard, historical mortality or economic losses per event for all countries in each region/wealth class are aggregated to obtain a loss rate for hazard for the region/wealth class.

These weights, are aggregated for each of the 28 region/wealth classes rather than calculated for each country individually because there is an insufficient number of hazard events to calculate them for most individual countries. Calculating the loss rates across groups of similar countries creates a larger pool of events across which to calculate them. Once calculated, these loss rates or vulnerability coefficients are used to weight hazard exposure of population or GDP for each grid cell to obtain risk. For each grid cell, the weight from the corresponding region/wealth class in which the grid cell is located is used (Pelling M, 2006; UNDP, 2004).

A multi-hazard Hotspots index is an aggregate of single hazard Hotspot values. To allow aggregation, a uniform adjustment is made to all values within a given region-wealth class so that the total mortality or economic loss for the class equals the mortality or economic loss recorded in EM-DAT for that hazard type. The Hotspots results are presented as relative risk values.

Hotspots produced relative risk maps for mortality, economic loss and economic loss as a proportion of GDP.

[2] http://www.proventionconsortium.org/projects/identification.htm

1.2.3. The Americas programme

The Americans Indexing Programme, of the the Instituto de Estudios Ambientales, Universidad Nacional de Colombia - Sede Manizales and the InterAmerican Development Bank[3], aims to aid national decision makers in assessing disaster risk and undertaking risk management. The system of indicators presents a benchmarking of each country in different periods from 1980 to 2000 and the basis for cross-national comparisons. Four independent indexes have been developed, each represents disaster risk or disaster risk management in different ways and is targeted at specific audiences. Each index has a number of variables that are associated with it and empirically measured:

- The Disaster Deficit Index (DDI) measures a country's financial exposure to disaster loss and the financial resources available for recovery.
- The Local Disaster Index (LDI) represents the proneness of a country to locally significant disaster events, and their cumulative impact. Spatial variability and sub-national dispersion of disaster risk is also indicated.
- The Prevalent Vulnerability Index (PVI) represents prevailing conditions of national level human vulnerability.
- The Risk Management Index (RMI) measures a country's performance in disaster risk management.

The suite of indexes was applied in 12 countries in Latin America and the Caribbean (Mexico, El Salvador, Costa Rica, Guatemala, Jamaica, Trinidad and Tobago, Dominican Republic, Colombia, Ecuador, Peru, Chile and Argentina). The sub-indexes have national scales of resolution.

The DDI is a function of the expected losses received by the state and the capacity of the state to generate reconstruction funds from private, government and international sources when hit by a maximum considered disaster event (MCE). MCEs with return periods of 50, 100 and 500 years related to rapid-onset hazards are considered. Vulnerability is formally included as part of the derivation of the DDI. It is used to represent the proportion of an asset that is calculated to be lost in an event of a given intensity (the MCE). A DDI value greater than 1.0 indicates a lack of financial capacity to cover the costs of disaster impact (UNDP, 2004).

The LDI includes four hazard types (landslides and debris flows, seismo-tectonic, floods and storms, and other events including biological and technological phenomena) based on the categorisation of hazard used in the data source for this index: the DesInventar database managed by La Red[4]. Values of local disaster magnitude and geographical distribution are calculated from three sub-indexes: mortality, people affected and physical loss (housing and crops) applied to sub-national regions or municipalities. Local data is combined to build the national LDI. A high LDI indicates high regularity in the magnitude and geographical distribution of disaster events recognised in the local reports and media across the country (UNDP, 2004).

The PVI is a composite index of national level inherent vulnerability. It is derived from the aggregation of measures collected at the national level for three dimensions of human vulnerability: exposure and physical susceptibility, socio-economic fragility and lack of resilience. The PVI measures intrinsic vulnerability, no specific hazard type or scale of impact is required, neither is any disaster response capacity considered. Each dimension of vulnerability is calculated from eight quantitative components, which are weighted and aggregated to provide a final index value (UNDP, 2004).

The RMI is also a composite index. Four dimensions of disaster risk management are included in its calculation: risk identification, risk reduction, disaster management and governance and financial protection. Each dimension has six qualitative components to be valued at the national level by expert judgement. The components are weighted and aggregated to arrive at the final index value. A sensitivity analysis is used to test for the influence on the results of the chosen weightings (UNDP, 2004).

[3] http://idea.unalmzl.edu.co/

[4] http://www.desinventar.org/desinventar.html

1.2.4. Observation and Discussion: models and measuring hazard and vulnerability

Table 2 provides a summary of the similarities and differences between the three indexing approaches.

	DRI	**Hotspots**	**Americas programme**
Objective	To demonstrate the ways in which development contributes to human vulnerability and risk.	To identify those subnational places in the world with high multihazard risk.	To reveal national vulnerability and risk due to natural hazards, and risk management performance.
Coverage	Global	Global	Regional (12 countries of the Americas to date)
Principal audience	National and international agencies	International and national agencies	National authorities and international agencies
Units of analysis	National	Sub-national (2.5' grid cells)	National and sub-national
Key contributions	Maps earthquake, tropical cyclone hazard and flood hazard worldwide. Identifies independent hazard specific socioeconomic indicators of national vulnerability. Proposes a simple measure of relative vulnerability	Maps flood, earthquake, landslide, drought, volcano and cyclone hazard worldwide. Identifies relative risks of mortality and economic loss for populations and economic assets exposed to single and multiple hazards. Estimates relative risks of mortality and economic losses.	Provides a group of four independent but related indexes covering local disaster loss, economic exposure and financial preparedness, intrinsic human vulnerability and national disaster risk reduction performance
Hazard	Earthquake, cyclone, flood, and drought. Landslide has been partly studied through work coordinated by NGI.	Earthquake, cyclone, flood, landslide, drought and volcano.	Two of the indexes include hazard type. For the LDI hazard types are landslides and debris flows; seismotectonic; floods and storms and other technological and biological events defined by the Desinventar database. For the DDI a maximum considered event is calculated based on the most important sudden onset hazard type (flood, cyclone or earthquake).
Vulnerability	1) The ration between mortality and population exposed. 2) Derived from socio-economic indicators calibrated against disaster mortality.	Represented by historical disaster mortality and economic loss rates for 28 groups of regions and country wealth classes for each hazard type.	In the DDI vulnerability is a function of financial exposure and resiliency. In the PVI vulnerability was not hazard specific and is characterized by social and economic subindicators.
Risk	Disaster mortality calculated as a product of hazard, population exposed and vulnerability variables.	Disaster mortality and economic losses calculated as products of hazard, elements exposed and vulnerability.	Expressed through four independent indexes covering: financial exposure and capacity to finance reconstruction, local risk accumulation, socio-economic vulnerability and risk management performance.

Limitations	Short time-span for mortality loss data compared to hazard frequency (volcano and earthquake). Limited availability of appropriate socio-economic variables.	Lack of sub-national data on mortality and economic loss. Does not identify specific vulnerability factors.	As the indexes are inductive the results are not empirically verifiable against specific disaster-related outcomes. Selection of sub-index components (and their valuation in the RMI) rests on the judgement of national experts, making international comparison difficult. National level resources and support for data collection and dissemination are required.
Comparative advantage	National dimensioning of vulnerability factors and disaster risk. Focus on large and medium events.	Sub-national dimensioning of hazard exposure and disaster risk. Focus on large and medium events	National dimensioning of vulnerability factors and disaster risk. Characterisation of risk management performance at the national level. Includes large and medium as well as small (locall significant) events.
Future possibilities	Measuring disaster risk to ecological and environmental systems that impact of human welfare. National and sub-national case-study ground truthing. Time-series analysis. Dynamic risk assessment. Contribution to benchmarking.	Measuring disaster risk to ecological and environmental systems that impact of human welfare. National and sub-national case study ground truthing. Temporal comparisons. Dynamic risk assessment	Benchmarking for disaster risk reduction performance. A family of indicators could be developed for individual economic and social sectors at the national and sub-national levels.

Table 2 - Comparing the index approaches (UNDP, 2004)

As can be seen in the table, the models DRI and Hotspots used the past hazard exposure to calculate vulnerability and risk values; in fact knowing the hazard, vulnerability and disaster impact in the past it is important to improve their experience in the future. This assumption become less tenable in situation where development pressure, such as rapid urbanization and local environmental changes linked to global climate change, have the potential to radically alter local distributions of population, wealth, hazard and vulnerability over a short time period relative to hazard frequency. In this context become important the local vulnerability measurements, than can include contextual information and use local knowledge to verify results. It is also necessary a multi-hazard based analysis, this is significant in the multi-hazard environment of urban settlements (Pelling M, 2005c).

The mortality indicators are also used by DRI and Hotspots in calculations of vulnerability; mortality is the most reliable comparative indicator of human loss at global scale. Data on people affected are far less reliable, reliance or mortality gives statistical rigour but limits policy impact. Hotsposts furthermore uses economic loss as an indicator of disaster impact, also in this case the pointer has several constraints, such as the focus on economic impacts that excludes assessments of local economic loss and very rarely the economic impacts of long term are evaluated, including changes in national balance of payments, international debt or price inflation in the period following a disaster.

About the Americas programme, the inductive approach acts in a different way; for example, the PVI index includes several socio-economic variables that capture the political and governance aspects of vulnerability, the choice of input variables is based on technical rationality, moreover the selection of parameters must be constantly under review. The LDI index includes the number of people affected and economic loss alongside mortality, but the reliability of information on people affected is problematic, clear definitions of exactly constitutes an affected person and adherence to this definition are required if meaningful national comparisons are to be made, but these are difficult to achieve. The LDI measure of economic loss includes also an assessment of housing damage with estimates of loss in the informal housing sector (Pelling M., 2006).

For all three of the indexing programmes, the future trend will increase as the accessibility and robustness of input data is improved. This is a long-term goal the aim is making a lasting and cumulative contribution as enhanced datasets build-up data over time. Improvements in the quality and consistency of data collection, and in the higher resolution mapping of information on disaster mortality, economic loss, damage to infrastructure and the number of people affected in global data would contribute to the DRI and Hotspots. Similar gains made at the national level by DesInventar would contribute to the Americas programme, LDI index (UNDP, 2004).

1.3. Risk management for natural disaster

A natural disaster is commonly defined as the impact of an extreme natural event on a exposed and vulnerable society, this can cause loss of life or property damage, and typically leaves economic damage, the severity of which depends on the affected population's resilience, or ability to recover. Natural disasters are a global issue and they occur all over the world (Figure 2, Figure 3).

There are great differences in which continents are more affected by the different types of disasters. Asia and Africa bear a disproportionate burden of losses due to disasters. Over the last 30 years, approximately 88% of the total people reported killed and 96% of the people reported affected lived in these two regions alone. Of the total number of people killed by natural disasters worldwide over the last decade, more than 75% were in Asia. Of the total of those reported killed by volcanic eruptions, Africa takes the lead with close to 62%. Only forest/scrub fire fatalities are more or less evenly spread out across the continents.

The natural disasters cause three main impacts: humanitarian, economic and ecological. Humanitarian effects include the loss of life, people affected and psychological post-disaster consequences; ecological effects comprise the damage of ecosystem; economic effects are rather grouped into direct (physical impacts on infrastructure and buildings), indirect (consequence of physical destruction) and macroeconomic or secondary (aggregate impacts on economic variables like gross domestic production GDP, consumption and inflation due to the effects of disaster) consequences. The probability of impacts and losses are controlled by the interaction of hazard with exposure and vulnerability, determining the risk. Natural hazard trigger disaster events, but it is the elements at risk and their degree of vulnerability that define the final consequences.

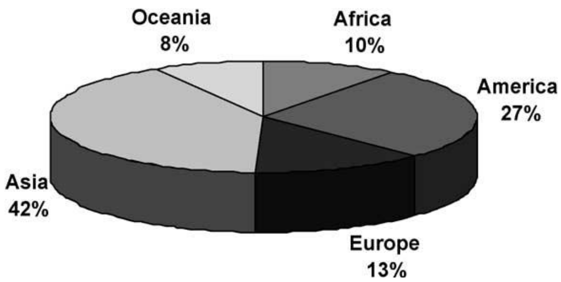


Figure 2 - Percentage of disasters registered from 1900 until 1999 by regions of the world (Source: EM-DAT database).

Considering the different definition of natural hazard and natural disaster, the main idea have changed from a perspective of a physical or natural event, towards the integration of the human system. Initially, the efforts were directed towards coping with impacts and also towards the prediction of hazard events. Technological advances and the development of prediction models for volcanic activity, hurricanes, tsunamis, flooding, landslides, etc. were developed seeking a better understanding of the phenomena and to some extent to offer possibilities to cope with the impact of natural hazards. At the present time, the socio-economic character of some regions prone to natural hazards ins considered, as one of the main factors of vulnerability to natural disasters (Alca´ntara-Ayala, 2002). For instance, the social economic and institutional aspects are considered within the management of the crisis of Galeras volcano in Colombia (Cardona, 1997); moreover, a framework to analyze human vulnerability in the case of Furnas volcano in the Azores is proposed (Dibben and Chester, 1999), they recognized that people's vulnerability to volcanic hazards implies an interaction of different elements related to the social context and the corresponding physiological and psychological characteristics.

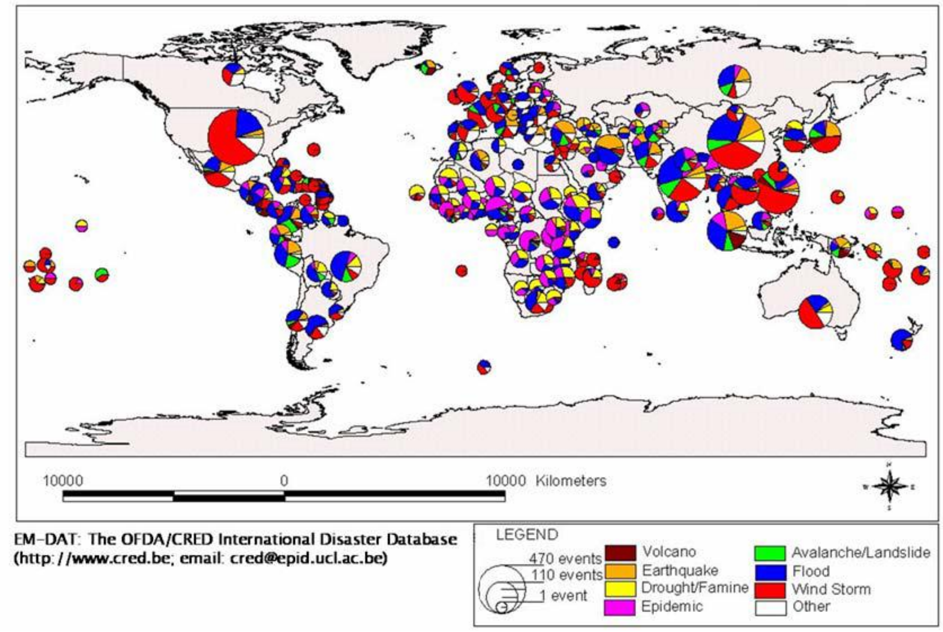


Figure 3 – Pie charts show the percentage of each disaster in a given region (Source: EM-DAT database 1975-2001).

The disaster management includes measures taken before (pre-disaster phase), after (post-disaster phase) and during (disaster phase) the event; it aims to reduce, or avoid, the potential losses from hazards, assure prompt and appropriate assistance to victims of disaster, and achieve rapid and effective recovery. This process can be represented as cycle.

The *disaster management cycle* illustrates the procedure plan for and reduce the impact of disasters, react during and immediately following a disaster, and take steps to recover after a disaster has occurred. The four disaster management phases illustrated here do not always, or even generally, occur in isolation or in this precise order. Often phases of the cycle overlap and the length of each phase greatly depends on the severity of the disaster. The mitigation and preparedness phases occur as disaster management improvements are made in anticipation of a disaster event. The response and recovery aim to minimize the hazards created by a disaster and to return the community to normal. Appropriate actions at all points in the cycle lead to greater preparedness, better warnings, reduced vulnerability or the prevention of disasters during the next iteration of the cycle. The complete disaster management cycle includes the shaping of public policies and plans that either modify the causes of disasters or mitigate their effects on people, property, and infrastructure.

Figure 4 – Disaster management cycle

Mitigation activities aim to eliminate or reduce the probability of disaster occurrence, or reduce the effects of unavoidable disasters. Mitigation measures include building codes; vulnerability analyses updates; zoning and land use management; building use regulations and safety codes; preventive health care; and public education. Mitigation will depend on the incorporation of appropriate measures in national and regional development planning. Its effectiveness will also depend on the availability of information on hazards, emergency risks, and the countermeasures to be taken. The mitigation phase, and indeed the whole disaster management cycle, includes the shaping of public policies and plans that either modify the causes of disasters or mitigate their effects on people, property, and infrastructure.

The goal of emergency *preparedness* programs is to achieve a satisfactory level of readiness to respond to any emergency situation through programs that strengthen the technical and managerial capacity of governments, organizations, and communities. Preparedness measures include preparedness plans; emergency exercises/training; warning systems; emergency communications systems; evacuations plans and training; resource inventories; emergency personnel/contact lists; mutual aid agreements; and public information/education. Preparedness can also take the form of ensuring that strategic reserves of food, equipment, water, medicines and other essentials are maintained in cases of national or local catastrophes.

The focus in the *response* phase is on meeting the basic needs of the people until more permanent and sustainable solutions can be found. The emergency response is aimed to provide immediate assistance to maintain life, improve health and support the morale of the affected population. Such assistance may range from providing specific but limited aid, such as assisting refugees with transport, temporary shelter, and food, to establishing semi-permanent settlement in camps and other locations. It also may involve initial repairs to damaged infrastructure.

The *recovery* phase aims to restore the community to normal, there are many opportunities during the recovery period to enhance prevention and increase preparedness, thus reducing vulnerability. Ideally, there should be a smooth transition from recovery to on-going development. Recovery measures, both short and long term, include returning vital life-support systems to minimum operating standards; temporary housing; public information; health and safety education; reconstruction; counselling programs; and economic impact studies. Information resources and services include data collection related to rebuilding, and documentation of lessons learned.

The application of disaster management cycle denotes a planned and structured attitude to dealing with natural hazard risk before the occurrence of events. Risk management analyzes risk exposure and aims to reducing danger and potential loss before events, there are different areas that can be distinguished: risk identification and assessment where risk exposure and potential impact are assessed, risk mitigation concerning also risk reduction and risk financing dealing with the ex-ante financing of risk. During events, the activity is focused on rescue and relief efforts, the humanitarian assistance is provided to those affected and repair measures is conducted and financial resources for financing the losses and reconstruction are mobilized. After disaster, rehabilitation and reconstruction are the primary objectives, critical infrastructure and other capital stock are reconstructed. The reconstruction efforts can incorporate disaster mitigation components, so that risk in the rebuilt structures is kept as low as possible.

The management of risk follows four sequential steps:

- The identification of possible risk in a particular region;
- To define the potential impacts;
- To plan the risk control measures, these consist of risk reduction and risk financing options;
- The analysis of costs and benefit of the risk control measures (Cost-efficiency should be an important consideration, it is crucial to optimally allocate available resources for reducing risk.).

In the first step, *risk identification and assessment*, it is important to identify potential effects and losses assessed, natural disaster risk is determined by the natural hazard and the vulnerability of a community/society in which these events occur, these two determinants need to be assessed and combined for a risk assessment. Hazard assessment involves creating hazard maps that show expected peak intensities for an event or the frequency of occurrence in a given area. Historical events provide the main basis for this assessment. Vulnerability assessment evaluates the elements, structures, infrastructure and institutions, that may potentially be struck by hazard. Bringing together hazard and vulnerability assessment allows the creation of damage functions and probability curves that measure the likelihood of losses (Mechler, 2004).

Such loss estimates provide a valuable basis for decision-makers: Investors and insurance companies can examine their risk exposure. Governments or public institutions can use these estimates to plan risk mitigation or risk transfer measures, plan response requirements post-event or employ it for general developmental planning purposes. Crucial is also to determine who bears which losses. Governments usually are responsible for dealing with the following losses:

- Losses of public assets and infrastructure;
- Losses to private entities due to the failure of insurance markets to provide cover,
- Risk to the poor when they lack the capacity to deal with losses themselves.

Risk mitigation (reduction or prevention) is concerned with reducing risk due to disasters. There are two ways for addressing risk: one is to modify the intensity, frequency or location of a given hazard, reinforcing existing structural engineering measures or using hazard resistant design; other is to modify vulnerability by educating people, devising land-use measures in order to decrease environmental degradation, installing early warning systems. To date, the focus in mitigation approaches has traditionally been on physical and structural measures to modify the hazard.

Two basic approaches can be used: avoidance of disasters with using land use and development planning and e.g. bans settling in hazard-prone areas, and resistance which is focused on increasing the capacity to withstand hazards by building safer structures.

Concerning the *risk financing*, if, after risk reduction measures have been taken, the remaining risk level and potential costs are considerable, risk financing options have to be evaluated. The strategy consists in arranging the financing of risk prior to actual events so that in case of an event, sufficient financing will be. The dominant risk financing instrument used is risk transfer by means of insurance or reinsurance.

Risk financing and mitigation measures are closely linked: Incentives for mitigation are directly related to insurance and reinsurance schemes and premiums and the perception of being bailed out post-disaster by the government.

The following table (Table 3) summarizes the important elements of natural disaster management.

Pre-disaster phase: Risk Management			**During disaster**	**After disaster**
Risk identification and assessment	**Risk reduction: mitigation**	**Risk financing**	**Rescue and relief**	**Rehabilitation and reconstruction**
Hazard identification and assessment	Physical and structural mitigation works	Risk transfer for public infrastructure and private assets	Humanitarian assistance	Reconstruction of damaged buildings
Vulnerability assessment	Land-use planning and building codes	Alternative risk transfer	Clean-up temporary repair and restoration of service	Reconstruction of damaged critical infrastructure and private capital
Risk assessment (function of hazard and vulnerability)	Economic incentives for active risk management	National and local calamity funds	Damage assessment	Macroeconomic and budget management
	Education training and awareness			
	Early warning systems, communication systems			
	Contingency planning, networks for emergency response		Mobilization of financial resources, insurance	Revitalization of affected ecomonic sectors, incorporation of disaster mitigation in reconstruction activities
	Shelter facilities, evacuation plans			

Table 3 – Important elements of natural disaster management (source: Mechler, 2004)

2. Landslide, an overview

Landslides is one of the major natural hazards and produces each year enormous property damage in terms of both direct and indirect costs. Landslides can be triggered by a variety of external stimulus, such as intense rainfall, water level change, storm waves or rapid stream erosion that cause a rapid increase in shear stress or decrease in shear strength of slope-forming materials. However, landslides are often the result of earthquakes, floods, and volcanic activity and may in turn cause subsequent hazards; for example, an earthquake-induced landslide can cause a tsunami if sufficient material slides into a body of water to displace a large volume of water. Another example would be a volcanic eruption-induced or earthquake-induced landslide that blocks a river, causing water to back up behind the mass and flood the upstream area.

In addition, as development expands into unstable hillslope areas under the pressures of increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites, etc., have become important triggers for landslide occurrence.

Literature suggests several terminologies and definitions of various landslide types, the most widely accepted systems is the classification of Varnes (Varnes 1954, Varnes 1978) and Hutchinson (Hutchinson 1968, Hutchinson 1988). Modifications to the Varnes classification is proposed by Cruden and Varnes (Cruden and Varnes, 1996), which introduce a multi-dimensional taxonomic framework. A recent classification suggests a new division of landslide materials, based on genetic and morphological aspects rather than arbitrary grain-size limits (Hungr et al, 2001).

2.1. Classification Criteria

The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. They are widespread over the world and often affect urban centres (Figure 5).

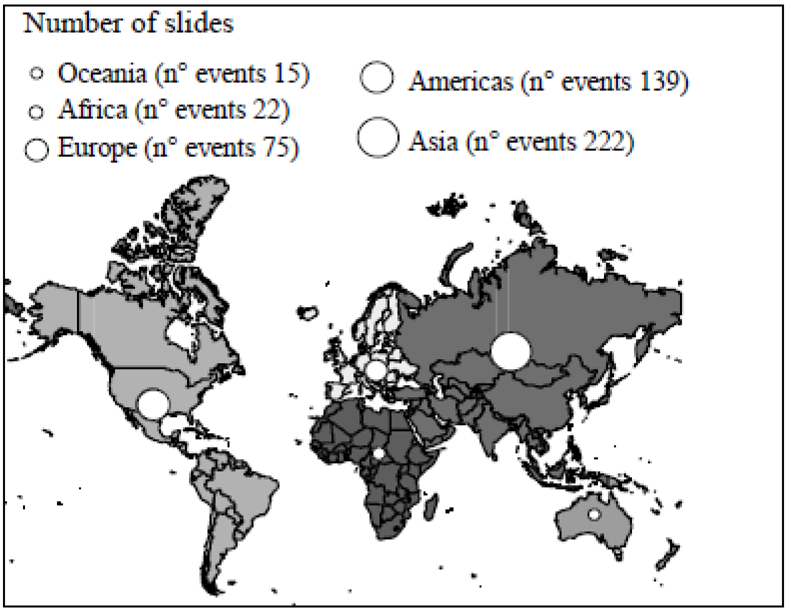


Figure 5 – Number of occurrences of slides disasters by continent (1903-2004) (Source: EM-DAT:OFDA/CRED database).

The landslide classifications are based on different discriminating factors, sometimes very subjective. The factors are discussed by dividing them into two groups: the first one is made up of the criteria utilized in the most widespread classification systems that can generally be easily determined. The second one is formed by those factors that have been utilized in some classifications and can be useful in descriptions.

These factors are, for the first group:

- *Type of movement*: this is the most important criteria, even if uncertainties and difficulties can arise in the identification of movements, being the mechanisms of some landslides often particularly complex;
- *Type of material*: rock, earth and debris are the terms generally used to distinguish the materials involved in the landslide process. the distinction between earth and debris is usually made by comparing the percentage of coarse grain size fractions;
- *Velocity*: this factor has a great importance in the hazard evaluation. A velocity range is connected to the different type of landslides, on the basis of observation of case history or site observations (Table 1);
- *Activity*: the classification of a landslide based on its activity is particularly relevant in the evaluation of future events. The recommendations of the WP/WLI (1993) define the concept of activity with reference to the spatial and temporal conditions, defining the state.

For the second group:

- *Age of movement*: landslide dating is an interesting topic in the evaluation of hazard. The knowledge of the landslide frequency is a fundamental element for probabilistic evaluation. Furthermore, the evaluation of the age of the landslide permits to correlate the trigger to specific conditions, as earthquakes or periods of intense rains. It should be noted that, it is possible that phenomena could be occurred in past geological times, under specific environmental conditions which no longer act as agents today;
- *Geological and morphological condition and topographical criteria*: important in the reconstruction of the technical model;
- *Geographical location*: this criterion describe, in a general way, the location of landsides in the physiographic context of the area. Some authors have therefore identified landslides according to their geographical position so that it is possible to describe "alpine landslides", "landslides in plains", "hilly landslides" or "cliff landslides";
- *Climate*: particular importance to climate in the genesis of phenomena for which similar geological conditions can, in different climatic conditions, lead to totally different morphological evolution;
- *Causes of movements*: causes of the triggers is an important step, these can be as "internal" and "external" referring to modifications in the conditions of the stability of the bodies. The internal causes induce modifications in the material itself which decrease its resistance to shear stress, the external causes generally induce an increase of shear stress, so that block or bodies are no longer stable. The triggering causes induce the movement of the mass. Predisposition to movement due to control factors is determining in landslide evolution. Structural and geological factors, as already described, can determine the development of the movement, inducing the presence of mass in kinematic freedom.

Concerning the terminology, several publications discussed this subject, but the more influential is that of Cruden and Varnes (1996), this is consistent with the terminology suggested by UNESCO's Working Party on the World Landslide Inventory (WP/WLI, 1993) and provides a historical perspective of landslide terminology. The figure 2 shows a graphic illustration of landslide, with the accepted terminology describing its features.

This features are (Highland, L.M. and Bobrowsky, P. 2008) (Figure 6):

accumulation - The volume of the displaced material, which lies above the original ground surface.

crown - The practically undisplaced material still in place and adjacent to the highest parts of the main scarp.

depletion - The volume bounded by the main scarp, the depleted mass and the original ground surface.

depleted mass - The volume of the displaced material, which overlies the rupture surface but underlies the original ground surface.

displaced material - Material displaced from its original position on the slope by movement in the landslide. It forms both the depleted mass and the accumulation.

flank - The undisplaced material adjacent to the sides of the rupture surface. Compass directions are preferable in describing the flanks, but if left and right are used, they refer to the flanks as viewed from the crown.

foot - The portion of the landslide that has moved beyond the toe of the surface of rupture and overlies the original ground surface.

head - The upper parts of the landslide along the contact between the displaced material and the main scarp.

main body - The part of the displaced material of the landslide that overlies the surface of rupture between the main scarp and the toe of the surface of rupture.

main scarp - A steep surface on the undisturbed ground at the upper edge of the landslide, caused by movement of the displaced material away from the undisturbed ground. It is the visible part of the surface of rupture.

minor scarp - A steep surface on the displaced material of the landslide produced by differential movements within the displaced material.

original ground surface - The surface of the slope that existed before the landslide took place.

surface of separation - The part of the original ground surface overlain by the foot of the landslide.

surface of rupture - The surface that forms (or which has formed) the lower boundary of the displaced material below the original ground surface.

tip - The point of the toe farthest from the top of the landslide.

toe - The lower, usually curved margin of the displaced material of a landslide, it is the most distant from the main scarp.

top - The highest point of contact between the displaced material and the main scarp.

toe of surface of rupture - The intersection (usually buried) between the lower part of the surface of rupture of a landslide and the original ground surface.

zone of accumulation - The area of the landslide within which the displaced material lies above the original ground surface.

zone of depletion - The area of the landslide within which the displaced material lies below the original ground surface.

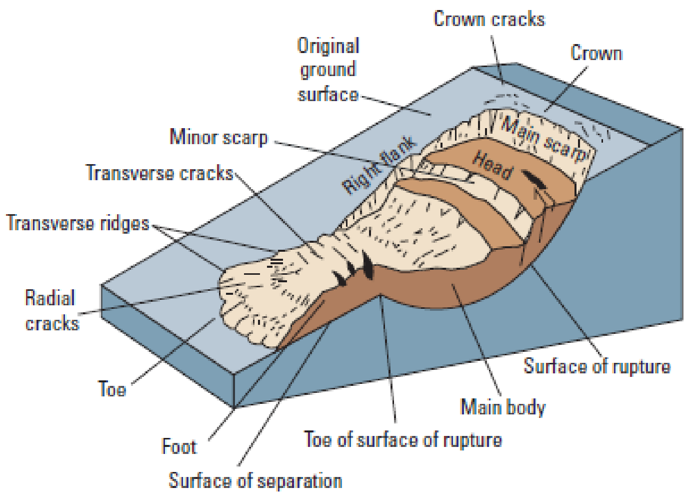


Figure 6 - Parts of a landslide (Source: Highland, L.M. and Bobrowsky, P. 2008)

2.2. Definitions of classes based on type of movement and material involved

Landslides can be classified into different types on the basis of the type of movement and the type of material involved. The following table shows a schematic landslide classification adopting the classification of Varnes (Varnes, 1978) and taking into account the subsequent modifications (Cruden and Varnes, 1996). This classification suggests a subdivision on basis of the movement and the type of material involved (Table 4).

Material in a landslide mass is either rock or soil, also regarding soil a difference is suggested between earth and debris. The rock is defined as a hard or firm mass that was intact and in its natural place before the initiation of movement, on the contrary the soil is an aggregate of solid particles, minerals and rocks, that either was transported or was formed by the weathering of rock in place. Gases or liquids filling the pores of the soil form part of the soil.

The distinction between debris and earth materials is based on percentage content of coarse material: earth describes material in which 80% or more of the particles are smaller than 2mm, the upper limit of sand sized particles, while debris contains a significant proportion of coarse material, 20% to 80% of the particles are larger than 2 mm, and the remainder are less than 2mm (Varnes, 1978). However, the limit of 20 percent content of coarse clasts may have little significance with respect to mechanical behavior, for this reason it may be useful to replace grain size criteria by genetic concepts (sorted/unsorted, cohesive/not cohesive, etc.) (Hungr et al., 2001). These criteria can be determined by geomorphical techniques in the field, or by remote sensing, without the need to impose arbitrary textural parameters.

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow (soil creep)
COMPLEX		Combination of two or more principal types of movement		

Table 4 – Classification of slope movements. Abbreviated version of Varnes' classification of slope movements (Varnes, 1978)

2.2.1. Fall

Falls are abrupt, downward movements of rock or earth, or both, that detach from steep slopes or cliffs. The material descends mainly by falling, bouncing, or rolling. The falling mass may break on impact, may begin rolling on steeper slopes, and may continue until the terrain flattens. Separation occurs along discontinuities such as fractures, joints, and movement occurs by free-fall, bouncing, and rolling.

Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water. The movement is characterized by speed from very to extremely rapid. The main causes are vibration, undercutting, differential weathering, excavation or stream erosion.

The following figures show the type of fall based on the material involved, the first one is a Rock fall, the second one is a debris fall and the last one is a earth fall (Figure 7).

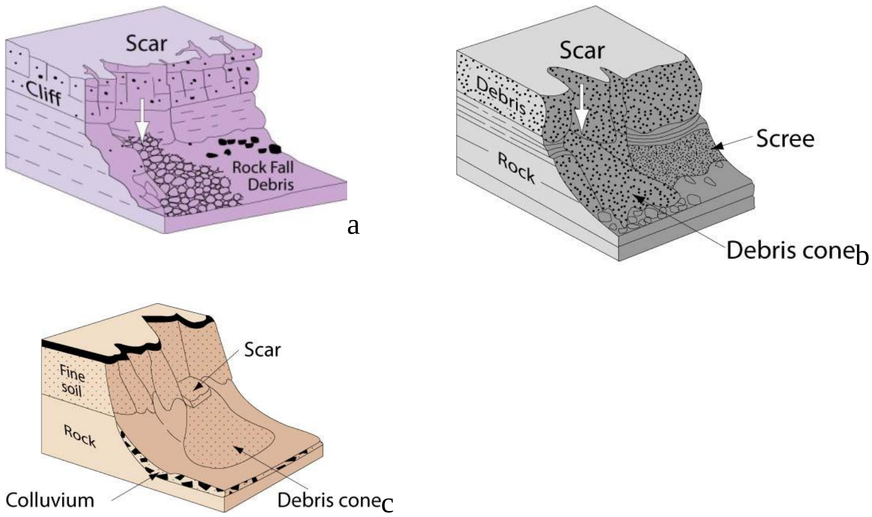


Figure 7 – Example of fall based on material involved (a bedrock, b debris or c earth)

2.2.2. Topple

Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks. This is a slope movement that occurs due to forces that cause an over-turning moment about a pivot point below the centre of gravity of the slope. The movement in the rock mass can be of two types: flexural and collapse (Figure 8). A topple is very similar to a fall, but not involve a complete separation at the base of the failure. The movement can be extremely slow up to extremely rapid. The main causes are vibration, undercutting, differential weathering, excavation or stream erosion. The Figure 9 shows the type of topples based on the material involved, the first one is a rock fall, the second one is a debris fall and the last one is a earth fall.

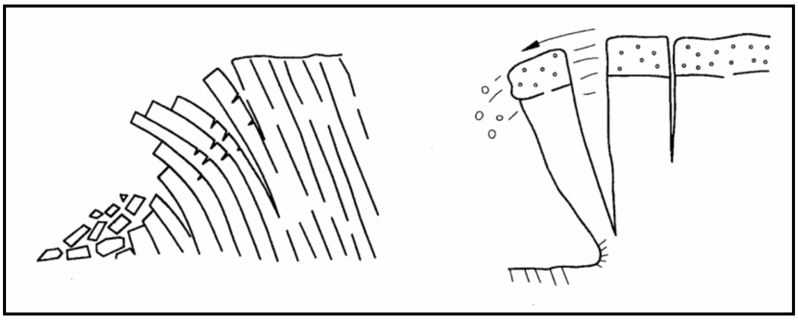


Figure 8 – Type of movement, flexural (left) and collapse (right)

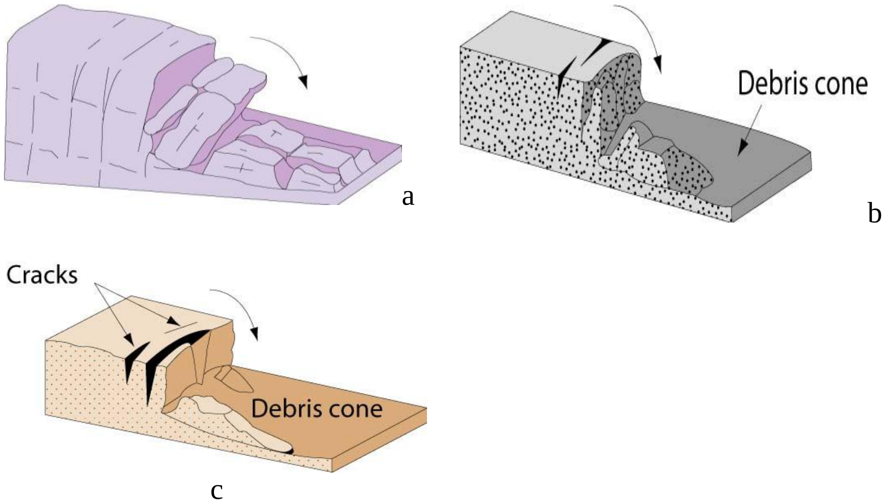


Figure 9 - Example of topple based on material involved (a bedrock, b debris or c earth)

2.2.3. Slide

Although many types of mass movements are included in the general term "landslide," the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides.

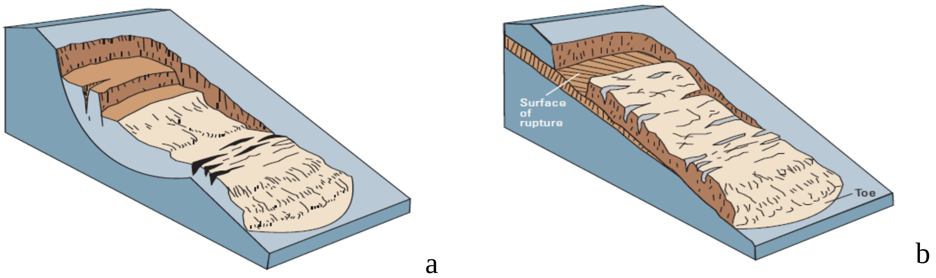


Figure 10 – Slide rotational (a) and translational (b) movements.

Rotational slide: a landslide on which the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that parallel to the contour of the slope (Figure 10 a). The displacement mass may move as a relatively coherent mass along the rupture surface with little internal deformation. The head of the displacement material may move almost vertically downward, and the upper surface of the displacement material may tilt backwards toward the scarp. If the slide is rotational and has several parallel curved planes of movement, it is called a slump. The main causes are vibration, undercutting, differential weathering, excavation or stream erosion, while the control factors are morphology and lithology.

Translational slide: the mass in a translational slide moves out or down and outward, along a relatively planar surface with little rotational movement or backward tilting (Figure 10 b). This type of slide may progress over considerable distances if the surface of rupture is inclined, in contrast to rotational slides, which tend to restore the slide equilibrium. The material in the slide may range from loose, unconsolidated soils to extensive slabs of rock, or both. Translational slides commonly fail along geologic discontinuites such as faults, joints, bedding surface, or the contact between rock and soil.

2.2.4. Flow

A flow is a slope movement characterized by internal differential movements that are distributed throughout the mass and in which the individual particles travel separately within the mass. The distribution of velocities in the displacing mass resembles that in a viscous liquid. The lower boundary of displaced mass may be a surface along which appreciable differential movement has taken place or a thick zone of distributed shear (Cruden and Varnes, 1996) (Figure 11).

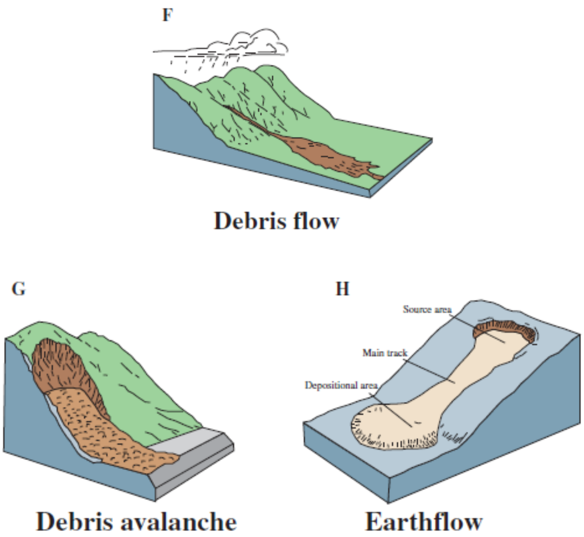


Figure 11 - Schematic of debris flows.

There are five basic categories of flows that differ from one another in fundamental ways:

- *Debris flow*: a debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows down slope. Debris flows include <50% fines. They are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Their source areas are often associated with steep gullies and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies.
- *Debris avalanche*: this is a variety of very rapid to extremely rapid debris flow.
- *Earth flow*: this movement have a characteristic "hourglass" shape. The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.
- *Mud flow*: a mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."
- *Creep*: this slope is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges.

The distinction between *debris* and *earth* should not be based solely on grain-size distribution (Figure 12), but should instead be derived from the context oh each landslide class. In particular, earth flow and mud flow involve material of similar texture, but different in the velocity of movement and average water content.

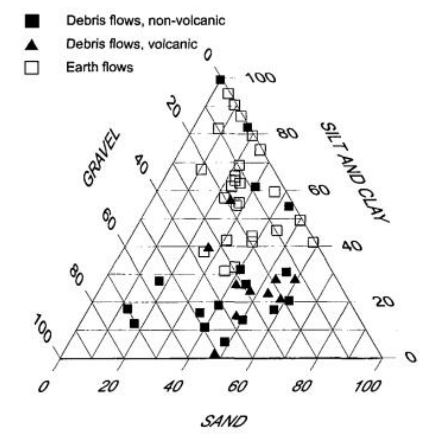


Figure 3. Textural composition of the matrix material in debris flows and earth flows: gravel, 2–18 mm; sand, 0.074–2 mm; silt and clay, < 0.074 mm. Data from Bovis (unpublished), Bull (1964), Pierson (1980), Keefer and Johnson (1983), Hutchinson (1988), Takahashi (1991), Major and Pierson (1992), Scott and others (1992), and Jordan (1994).

Figure 12 – Matrix compositions of earth flow, debris flow and mud flow from (Source: Hungr et al., 2001)

In general, debris flow contain less than 30 percent silt and finer particles, on this basis it can be distinguished from earth flow. However, mud flow cannot be distinguished from earth flow on a textural basis.

For this reason is proposed a scheme for the classification of materials involved in flows (Figure 13) (Hungr et al., 2001). The distinction between sorted and unsorted soil and fragment rock can be achieved using geomorphological techniques, which can identify the likely character of deposits based on genesis. The difference between cohesive and not cohesive materials may also be derived from geomorphological analysis (field observation and laboratory testing). Moreover, the distinction between saturated or dry, liquid or plastic, can be derived by inference from the observed landslide behavior, since the condition of the material in the vicinity of the rupture surface during motion may be difficult to ascertain. High velocity and long runout on slope flatter than the effective dynamic friction angle often signifies the presence of saturation and excess pore pressure (Hungr et al., 2001).

Origin	Character	Condition[1]	Name
SORTED (marine, lacustrine, fluvial, eolian, volcanic, anthropogenic)	Non-cohesive **P.I. < 5%**	Dry or Saturated	- Gravel - Sand - Silt
	Cohesive **P.I. > 5%**	- Plastic (I_L < 0.5) - Liquid (I_L > 0.5)	- Clay - Sensitive Clay
UNSORTED (residual, colluvial, glacial, volcanic, anthropogenic)	Non-cohesive **P.I. < 5%**	Dry or Saturated	- Debris[2]
	Cohesive **P.I. > 5%**	- Plastic (I_L < 0.5) - Liquid (I_L > 0.5)	- Earth - Mud
PEAT	Organic	Saturated	- Peat
ROCK	Fragmented	Dry or Saturated	- Rock

[1] Related to the material found in the vicinity of the rupture surface at the time of failure, if it can be determined. In many cases, the material condition must be deduced from the behavior of the landslide, especially velocity.
[2] Debris may contain a considerable proportion of organic material.

Figure 13 – Material involved in landslides of the flow type (Source: Hungr et al., 2001)

Concerning the velocity, a clear distinction has been made between extremely rapid processes (debris flow, mud flow, debris avalanche) and a slow processes (earth flow) (Figure 14).

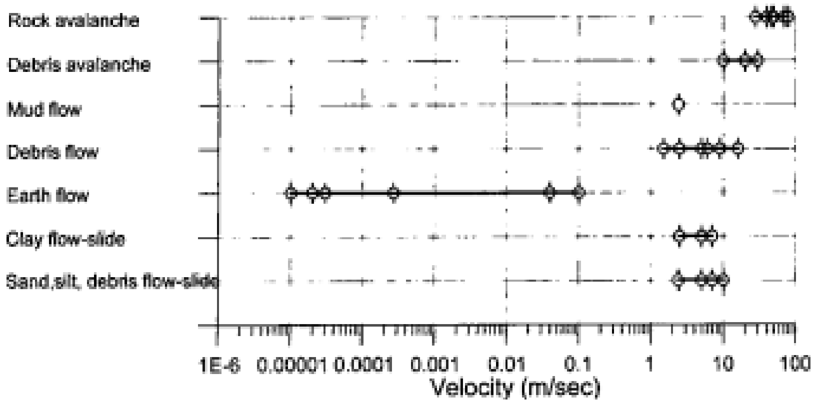


Figure 14 – Maximum velocities for various types of flow landslides.

2.2.5. Lateral spreads

Lateral spreads usually occur on very gentle slopes or essentially flat terrain, especially where a stronger upper layer of rock or soil undergoes extension and moves above an underlying softer, weaker layer (Figure 15). Such failures commonly are accompanied by some general subsidence into the weaker underlying unit. In rock spreads, solid ground extends and fractures, pulling away slowly from stable ground and moving over the weaker layer without necessarily forming a recognizable surface of rupture. The softer, weaker unit may, under certain conditions, squeeze upward into fractures that divide the extending layer into blocks. In earth spreads, the upper stable layer extends along a weaker underlying unit that has flowed following liquefaction or plastic deformation. If the weaker unit is relatively thick, the overriding fractured blocks may subside into it, translate, rotate, disintegrate, liquefy, or even flow.

The movement may be slow to moderate and sometimes rapid after certain triggering mechanisms, such as an earthquake. Ground may then slowly spread over time from a few millimeters per day to tens of square meters per day. Triggers that destabilize the weak layer include liquefaction of lower weak layer, plastic deformation, natural or anthropogenic overloading of the ground above an unstable slope.

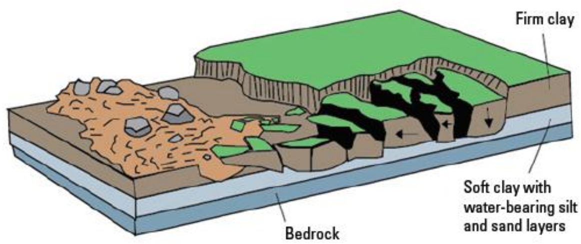


Figure 15 - Schematic of a lateral spread

2.3. Velocity Class

The velocity of landslide movement is a function of time and space and can be mapped in detail. In the 1978, Varnes proposed a classification based on the rate of movement, this has been modified by the IUGS Working Group (WP/WLI, 1995). Seven classes have identified on the rate of movement, increasing the uppermost limit of the scale and decreasing the lowest limit of the scale. An important division is between very rapid and extremely rapid movement, approximates the speed of a person running (5 m/sec.). Another important boundary is between the slow and very slow classes (1.6 m/year), below which some structures on the landslide are undamaged.

The following table (Table 5) defines the velocity class, specifying for each type of landslide the appropriate rate. The clay flow slides are always extremely rapid events, both at initiation, retrogression and during flow-like travel. The same can be said about flow slides in loose saturated sands, often subaqueous. In fact the term flow slide signifies a slide accompanied by liquefaction of a zone of saturated soil at the rupture surface, which invariably leads to catastrophic acceleration. Many extremely rapid flow slides appear to consist largely of dry or moist soil, with liquefaction affecting only a thin saturated layer at the base. Soils susceptible to spontaneous liquefaction and extremely rapid flow sliding span a very wide range of gradations in the silt, sand and gravel classes. Rotational, translational or compound slides in non - sensitive clay are usually rapid or slower. They may transform into earth flows and continue moving at moderate speeds for hundreds of metres. In stiff over-consolidated clays and silts, care must be taken to account for physical changes caused by soil disturbance. Most slides nearly always begin during heavy rain, ensuring perched saturation of the loose layer. As fast movement occurs, soil situated down slope of the initial failure is over-ridden, liquefied by rapid undrained loading and incorporated in a growing debris avalanche. When debris avalanches enter established steep stream channels or gullies, they become channelized, incorporate further material as well as water and turn into surging, extremely rapid debris flows. Rock slides in stronger rock, usually with a high degree of structural control, are extremely rapid due to sudden loss of cohesion. Many become fragmented and flow-like, forming extremely rapid rock avalanches. Of these, rock collapses are especially sudden and rapid, and involve failure of strong rock controlled by a combination of non systematic joints and intact rock bridges. In contrast, rotational rock slumps and some non-rotational compound slides in very weak rock are slow, or at best rapid. Block topples, in stronger rock and deriving stability from block equilibrium, are sudden and extremely rapid. Flexural topples, often involving large slopes in weak, highly anisotropic foliated rocks, rely on their stability through interlayer friction and tend to be slow.

VELOCITY CLASS	VELOCITY DESCRIPTION	VELOCITY LIMITS
7	Extremely Rapid	>5m/s
6	Very Rapid	3m/min – 5m/sec
5	Rapid	1.8m/hr - 3m/min
4	Moderate	13m/month – 1.8m/hr
3	Slow	1.6m/year - 13m/month
2	Very Slow	16mm/year – 1.6m/year
1	Extremely Slow	<16mm/year

Table 5 - International union of geological sciences working party on the world landslide inventory (1995) – velocity class.

Moreover, in addition to the involved material and the affected volume, the instance of risk of hazard is closely related to velocity of movement, for each class is given a pprobable destructive potential:

- Extremely Rapid (class 7): catastrophe of major violence; buildings destroyed by impact of dislpaced material and many deaths;
- Very Rapid (class 6): some live lost, velocity too much to permit to the person to escape;
- Rapid (class 5): escape evacuation possible, structures, possessions and equipment destroyed;
- Moderate (class 4): some temporary or little damageable structures can be temporarily maintained;
- Slow (class 3): remedial construction can be undertaken during movement, intensive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase ;
- Very Slow (class 2): some permament structures cannot be damaged from the movement;
- Extremely Slow (class 1): imperceptible without monitoring instruments, construction possible with precaution.

TYPE	*VELOCITY CLASS**							*COMMENT*
	ES	*VS*	*S*	*M*	*R*	*VR*	*ER*	
SLIDES IN ROCK								
Translational (or Wedge) Rock Slide							■	May be slow in very weak rocks
Rotational Rock Slide(Slump)	■	■	■	■	■			Very weak rock mass
Compound Rock Slide	■	■	■	■	■	■	■	Various types of mechanisms
Rock Collapse							■	Strong rock, joints, rock bridges
FALLS AND TOPPLES								
Rock (Debris) Fall							■	Fragmental fall, small scale
Rock Block Topple							■	Single or multiple blocks
Rock Flexural Topple	■	■	■	■	■			Very weak rock mass
SLIDES IN SOIL								
Clay Slump (Rotational)	■	■	■	■	■			Non- sensitive
Clay Slide (Compound)	■	■	■	■	■			Non- sensitive
Sand (Gravel, Talus, Debris) Slide					■	■	■	Usually shallow
FLOW-LIKE LANDSIDES								
Dry Sand (Silt, Gravel, Talus Debris) Flow	■	■	■	■	■			No cohesion
Sand (Silt, Debris, Peat) Flow Slide							■	Liquefaction involved
Sensitive Clay Flow Slide							■	Quick clay
Debris Avalanche							■	Non-channelized
Debris (Mud) Flow						■	■	Channelized
Debris Flood						■	■	High water content
Earth Flow	■	■	■	■	■			Plastic clay
Rock Avalanche							■	Begins in bedrock
Rock Slide-Debris Avalanche							■	Entrains debris

* Extremely Slow, Very Slow, Slow, Moderate, Rapid, Very Rapid, Extremely Rapid (>5m/sec; Cruden & Varnes 1996).

Figure 16 - A simple classification of landslides, showing typical ranges of velocities(Source:Hungr et al.,2005)

2.4. Causes Landslides

There are two main categories of causes: natural and human-caused. Sometimes, landslides are caused, or made worse, by a combination of the two factors.

The ***natural category*** includes geological, morphological and physical causes; effects of all of these causes are vary widely and depend on factors such as steepness of slope, morphology, soil type, underlying geology. This category has three major triggering mechanisms that can occur either singly or in combination: water, seismic activity and volcanic activity (Highland, L.M. and Bobrowsky, P., 2008).

Slope saturation by *water* is a primary cause of landslides. This effect can occur in the form of intense rainfall, snowmelt, changes in ground-water levels, and water-level changes along coastlines, earth dams, and the banks of lakes, reservoirs, canals, and rivers. Landslides and flooding are closely associated because both are related to precipitation, runoff, and the saturation of ground by water. In addition, debris flows and mudflows usually occur in small, steep stream channels and commonly are mistaken for floods; in fact, these two events often occur simultaneously in the same area. Landslides also can cause flooding when sliding rock and debris block stream channels and other waterways, allowing large volumes of water to back up behind such dams. This causes backwater flooding and, if the dam fails, subsequent downstream flooding. Moreover, solid landslide debris can "bulk" or add volume and density to otherwise normal streamflow or cause channel blockages and diversions, creating flood conditions or localized erosion. Landslides also can cause tsunamis (seiches), overtopping of reservoirs, and (or) reduced capacity of reservoirs to store water.

The occurrence of *earthquakes* in steep landslide-prone areas greatly increases the likelihood that landslides will occur, due to ground shaking alone or shaking-caused dilation of soil materials, which allows rapid infiltration of water. For instance, the 1964 Great Alaska earthquake in the United States caused widespread landsliding and other ground failure. Other areas such as California, and Emilia Romagna (earthquake on May 2012), have experienced slides, lateral spreading, and other types of ground failure due to moderate to large earthquakes.

Landslides due to *volcanic activity* represent some of the most devastating types of failures. Volcanic activity can form a mixed of rock, soil, ash, and water that accelerates rapidly on the steep slopes of volcanoes. These volcanic debris flows (lahars) can reach great distances after they leave the flanks of the volcano and can damage structures in flat areas surrounding the volcanoes. Moreover, volcanic edifices are young, unconsolidated, and geologically weak structures that in many cases can collapse and cause rockslides, landslides, and debris avalanches. The 1980 eruption of Mount St. Helens, in Washington triggered a massive landslide on the north flank of the volcano, the largest landslide in recorded times.

The ***human category*** includes causes such as land use change, deforestation, excavation, water management, mining, ect (Highland, L.M. and Bobrowsky, P., 2008).

Populations expanding onto new land and creating neighborhoods, towns, and cities is the primary means by which humans contribute to the occurrence of landslides. changing drainage patterns, destabilizing slopes, and removing vegetation are common human-induced factors that may initiate landslides. However, landslides may also occur in once-stable areas due to other human activities such as irrigation, lawn watering, draining of reservoirs (or creating them), leaking pipes, and improper excavating or grading on slopes. New construction on landslide-prone land can be improved through proper engineering (for example, grading, excavating) by first identifying the site's susceptibility to slope failures and by creating appropriate landslide zoning.

Further, both of these categories can be divided into *preparedness* and *triggering* causes. The preparedness factors include all those processes that led to the formation of the slope and have led to some geometry and materials with specific physical properties mechanical; while the triggering causes represent actions which cause the movement. Three causes of instability have been identified (Varnes, 1978):

- shear increase: main actions are represented by rainfall, erosion, seismic activity, human activity as excavation or building;
- pore pressure increase: main activities are given by rainfall, seismic activity, increase in water level and in debris accumulation, human activities as excavation, building, deforestation, water management;
- resistance decrease: main actions are given by alteration and mitigation processes, physical and/or chemical, erosion and excavation activities.

2.5. Mechanics of the sliding process

Four different stages of slope movements can be considered (Figure 17):

- The pre failure stage, when the slope is strained throughout, but is essentially intact, this phase includes the deformation processes that lead to break, these processes determine a speed relatively modest;
- The onset of failure characterized by the formation of a continuous surface of rupture (eg. a shear band) through the slope;
- The post failure stage, which includes movement of the material in the landslide from just after failure until it;
- The reactivation stage, when the slope slides along one or several pre existing shear surfaces: this reactivation can be occasional or continuous with seasonal (or longer period) variations in the rate of movement.

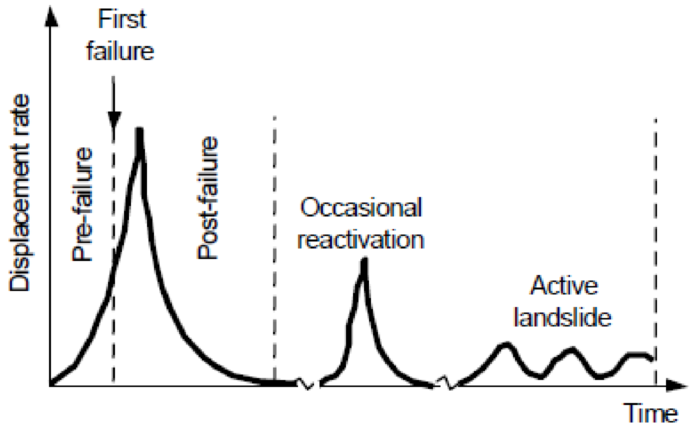


Figure 17: Different Stages of Slope Movements (Leroueil et al 1996)

There are various ideas on what causes creep, defined as deformation with time under stress.

At the micro scale (soil substance), it has been attributed to several actions such as the breaking of bonds and the re-orientation of soil particles, visco-frictional sliding relating to the inter-particle contacts, pore pressure increases and weakening of the clay skeleton by a fatigue phenomenon (in undrained creep) in unstructured clays. There is also evidence that the effects of strain rate and temperature combine in a unique viscosity law, which could be explained by the rate process theory related to the activation energy at the level of molecules, atoms or particles (Fell et al., 2000). At the macro scale, creep is explained as shear deformations that cause dilation and development of negative pore pressures, which do not develop uniformly, but concentrate along planes where the greatest shearing stresses develop. With time during sustained loading, water migrates into zones of high negative pore pressures leading to softening and strength decrease relative to the strength in "normal" undrained strength tests (Fell t al., 2000).

Creep deformation is observed at all levels of deviatoric stress and its stress conditions move according to loading at the crest or erosion at the toe or seasonally change of groundwater regime, indeed the creep rates also vary with the seasons, being much higher when water conditions are high. Local failure as initiated when the stress state reaches the peak strength envelope corresponding to the age or the strain rate of the slope. After the peak, the phenomenon of progressive failure can extend into a continuous shear surface through the entire soil mass, and then trigger a landslide. Progressively, the stress conditions decreases, followed by decreasing movements.

The process of creep has been defined as occurring in 3 stages (Figure 18): primary (at a decreasing strain rate), secondary (at a constant strain rate), and tertiary (at an accelerating strain rate), generally to creep rupture or failure. Varnes (1982) and others have noted the short period of secondary creep, and the possibility that it is due to concurrent processes of primary and tertiary creep.

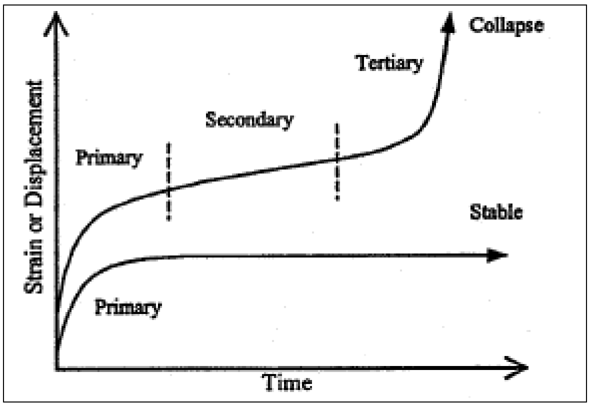


Figure 18 – Diagrammatic representation of creep for moving scope (Source: Fell et al., 2000)

Progressive and Retrogressive Failure

The *Progressive failure* describes situations where the soil (or rock) is strain weakening, normally in areas of high stress in a slope reducing in strength as the soil yields (either in drained or undrained loading) with the stresses in the slope redistributing to adapt to the changed yield strength. To have progressive failure, it is necessary to have non-uniformity of shear stresses, and boundary conditions such that strains exceeding failure may develop. This may progress through to collapse of the slope. Progressive failure may occur in any strain weakening material such as dense sand, loose sand, normally and near normally consolidated clays and quick clays, heavily over-consolidated, high clay content clays, and fissured clays, and rock.

The process of progressive failure can be described as follows. If shear stresses locally reach the peak shear strength of the material, there is local failure. If the soil presents some strain-softening behaviour, the failed soil elements will support a decreasing shear stress as strain increases. The part of the shear stress which is not supported anymore by the failed elements is then transferred to the neighbouring soil elements that can fail in turn. The process continues until an equilibrium between shear stresses and strains (or displacements) has been reached. At that time, along a potential failure surface, part of it can exceed the peak, with possibly some elements at large deformation or residual strength, whereas another part of the potential surface has not reached the peak. If such equilibrium cannot be obtained, the process will continue until failure conditions extend along the entire failure surface. This process depends to a large extent on the brittleness of the soil.

An example of progressive failure mechanism is shows in the Figure 19, it is the case of a cutting or slope in gently sloping (stiff clay or weak, rock with a strain weakening layer).

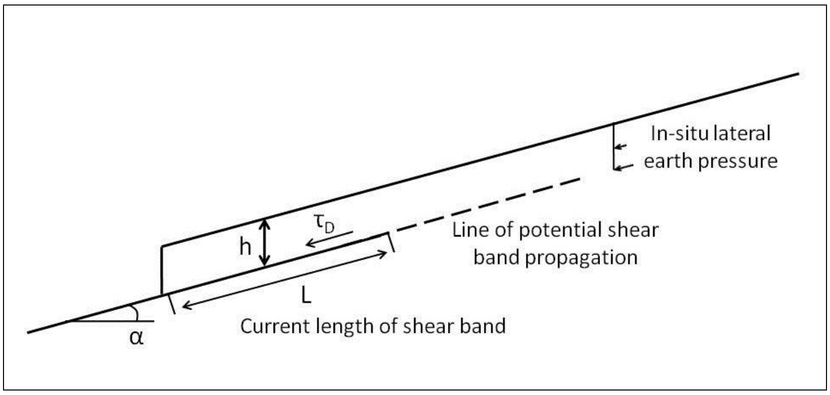


Figure 19 – Example of progressive failure (Quinn et al,., 2012)

Retrogressive failure refers to the situation where part of a slope fails, and removal of the support from this part of the slope, results in the failure extending into a region where previously the factor of safety was greater than one (Figure 20). The retrogressive failure may occur in clays, in these situations the retrogression may be rapid because of the large loss of strength in undrained shear. Many factors make retrogressive sliding likely: the ability of the clay to be remoulded and to flow away from the toe of the slope when remoulded. Retrogressive failure, with flow, is a characteristic of collapse type failures in granular soils. Retrogressive failure is also a common feature of landslides and failures of cuts and fills, in less brittle soils, even though the failed material does not flow away from the slope.

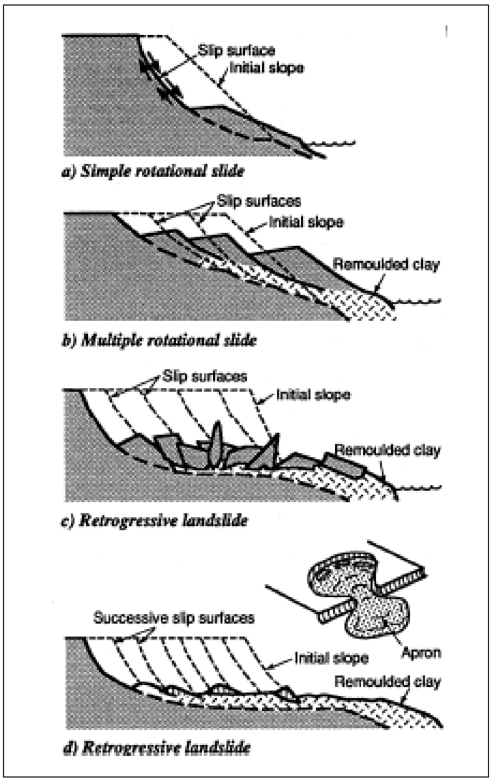


Figure 20 – Example of retrogressive failure (Source: Fell et al., 2005)

The Shear Strength of Fissured Soils

Fissures are discontinuities in soils which have similar implications to the strength and permeability that joints have in rock masses, they reduce the mass strength, and (usually) increase the mass permeability. Fissures have a wide range of characteristics relating to the properties of the soil mass, the depositional and weathering history, climate (when the fissures were formed and now). It is useful to log, and classify the fissures systematically.

They are caused by one or more factors as stress relief due to erosion or retreat of glaciation, freeze-thaw, shrink-swell (desiccation) due to seasonal moisture content changes and differential consolidation and settlement in sedimentary soils. It is important to recognise that the fissures are often formed in a different geological and climatic condition to the present, eg. in periods of glacial retreat, or when the sea level was lower than now. The shear strength of fissured soils is dependent either on the peak softened and residual strength of the soil substance and on the continuity, orientation, shape and, spacing of the fissures and nature of the fissure surface. These are in turn related to the origin of the fissures (Fell et al.,2000).

Cracking and Softening

Cracking of soil slopes can have a major influence on the stability by allowing water to enter the slope from the surface, increasing pore pressures generally, but more particularly as pore pressures in the crack, and/or sllowing softening of the soil around the crack, reducing the undrained strength, and/or by the crack itself having zero strength if it stays open.

In the *post-failure*, several types of analytical approach have been formulated, in order to identify post-failure velocity and travel distance. The simplest type of analytical approach is the sliding block model, which describes the landslide as a dimensionless body moving down the profile of the path. The movement is controlled by a single force resultant, representing the gravity driving force as well as all movement resistance. The correct application of this "lumped mass" approach is to consider the movement of the centroid of the displaced mass. This approach is probably correct for small scale rockslides of limited displacement, which do not disintegrate during motion. It always predicts high velocities. Slides with long displacement, even if they do not break-up, become distorted and change shape in plan and profile. While large, deep-seated landslides may exhibit velocity dependent reduction of dynamic shear strength, the opposite appears to be true for most slides and rotational slumps in over-consolidated clays and weak rocks.

2.6. Slope Stability Analysis

The field of slope stability encompasses the analysis of static and dynamic stability of natural and artificial slopes. The main objectives of slope stability analysis are finding endangered areas, investigation of potential failure mechanisms, determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with regard to safety, reliability and economics, designing possible remedial measures. Choice of correct analysis technique depends on site conditions and potential mode of failure, careful consideration being given to the varying strengths, weaknesses and limitations inherent in each methodology.

All site investigations, whether for natural or constructed slopes, should be carried out with a clear objective, and with a set of questions to be answered. The Table 6 give examples of the questions, is applicable to all classes of slopes, although clearly some questions are more applicable to large, natural landslides and other larger slopes than to a constructed fill (Fell et al., 2000).

The figure lists the applicability of the methods to typical classes of slope problem (Figure 21):

- Shallow natural landslides there is a reliance on geological, topographical geomorphological and historic information without detailed drilling, sampling, laboratory testing and analysis.
- Medium natural landslides have a similar emphasis on geology, geomorphology and historic records, but a greater emphasis on sub-surface exploration, sampling, monitoring of pore pressures and laboratory testing.
- Large natural landslides there is a greater emphasis on monitoring of deformations and groundwater pressures, less emphasis on laboratory testing and more on back-analysis to assess strengths.

- Existing cuts and fills, there is a reliance on topography, geology, geomorphology and historic performance. For larger structures, more subsurface investigation, sampling and laboratory testing will be carried out.
- New cuts and fills, there is a reliance on the performance of structures in similar conditions, and monitoring post construction. It is essential that geomorphological studies be included to identify existing natural landsliding.
- Embankments and cuts in soft clays, the emphasis is on stratigraphy and strength, often obtained by in-situ tests, and careful drilling, sampling and laboratory tests.

1. TOPOGRAPHY?	1.1 In the landslide source and potential travel path 1.2 Effect and timing of natural and human activity on the topography
2. GEOLOGICAL SETTING?	2.1 Regional stratigraphy, structure, history (eg. glaciation, sea level submergence and emergence) 2.2 Local stratigraphy, slope processes, structure, history 2.3 Geomorphology of slope and adjacent areas
3. HYDROGEOLOGY?	3.1 Regional and local groundwater model? 3.2 Piezometric pressures within and around the slide? 3.3 Relationship of piezometric pressures to rainfall, snowfall and snowmelt, temperature, streamflows, reservoir levels, both seasonally and annually? 3.4 Effect of natural or human activity? 3.5 Groundwater chemistry and sources 3.6 Annual exceedance probability (AEP) of groundwater pressures
4. HISTORY OF MOVEMENT?	4.1 Velocity, total displacement, and vectors of surface movement? 4.2 Any current movements and relation to hydrogeology and other natural or human activity? 4.3 Evidence of historic movement and incidence of sliding eg. lacustrine deposits formed behind a landslide dam, shallow natural slides, or failures of cuts and fills 4.4 Geomorphic or historic evidence of movement of slope or adjacent slopes
5. GEOTECHNICAL CHARACTERISATION OF THE SLIDE OR POTENTIAL SLIDE?	5.1 Stage of movement (pre failure, post failure, reactivated, active) 5.2 Classification of movement (eg. slide, flow) 5.3 Materials factors (classification, fabric, volume change, degree of saturation)
6. MECHANISMS AND DIMENSIONS OF THE SLIDE OR POTENTIAL SLIDE?	6.1 Configuration of basal, other bounding, and internal rupture surfaces? 6.2 Is the slide part of an existing or larger slide? 6.3 Slide dimensions, volume? 6.4 Is a slide mechanism feasible?
7. MECHANICS OF SHEARING AND STRENGTH OF THE RUPTURE SURFACE?	7.1 Relationship to stratigraphy, fabric, pre existing rupture surfaces 7.2 Drained or undrained shear? 7.3 First time or reactivated shear? 7.4 Contractant or dilatant? 7.5 Saturated or partially saturated? 7.6 Strength pre and post failure, and stress-strain characteristics.
8. ASSESSMENT OF STABILITY?	8.1 Current, and likely factors of safety allowing for hydrological, seismic and human influences? 8.2 AEP of failure (factor of safety ≤ 1)?
9. ASSESSMENT OF DEFORMATIONS AND TRAVEL DISTANCE?	9.1 Likely pre failure deformations? 9.2 Post failure travel distance and velocity? 9.3 Likelihood of rapid sliding?

Table 6 – Questions to be addressed in slope stability and landslide investigations (Source: Fell et al., 2005)

Site Investigation Method	Natural Slopes			Constructed Slopes				
	Small/Shallow	Medium	Large	Existing Cut	Existing Fill	New Cut	New Fill	Soft Clay
Topographic mapping and survey	A	A	A	A	A	A	A	A
Regional Geology	A	A	A	A	A	A	A	A
Geological mapping of project area	B	B	A	A	B	A	B	C
Geomorphological mapping	A	A	A	B	B	B	B	D
Satellite imagery interpretation	D	D	C	D	D	D	D	D
Air photograph interpretation	A	B	A	C	C	C	C	C
Historic record	A	B	B	A	B	B(2)	B(2)	B(2)
Dating past movements	B	C	B	D	D	D	D	D
Geophysical methods	C	C	B	C	C	C	D	C
Trenches and Pits	B	A	B	B	B	B	B	C
Drilling/boring	C	A	A	C	B	B	B	A
Downhole inspection	C	B	B	C	D	C	D	D
Shafts and tunnels	D	C	B	D	D	D	D	D
In-situ testing of strength and permeability	C(3)	C(3)	C(4)	D	B(3)	C	C	A(3)
Strength and permeability monitoring pore pressures, rainfall etc.	C	A	A	A	A	C	C	A(5)
Monitoring of displacements	C	B	A	B	B	B(5)	C(5)	A(5)
Laboratory testing	C	A	B	B	B	B	C	A
Back analysis of stability	C	B	A	C	B	B(2)	C(2)	C(2)

Notes: (1) A – Strongly applicable,
B – Applicable,
C – May be applicable,
D – Seldom applicable
(2) In similar areas
(3) SPT, CPT, CPTU
(4) Permeability
(5) During construction

Figure 21 – Application of site investigation methods to slope classes (Source: Fell et al., 2005)

2.6.1. Uncertainties

The slide stability analysis includes uncertainties, which can be expressed probabilistically. They arise from parameters and from models. The categories are (Einstein, 1995):

- spatial and temporal variability of geological factors or nature;
- errors introduced by measuring and estimating engineering properties;
- model uncertainty;
- load uncertainty
- omissions

In the stability analysis, emphasis is placed on the first three categories.

Most of the uncertainties are caused by spatial and temporal variability, if nature is tested and documented, it also involves estimation and statistical fluctuation errors. The **Figure 23** attempts to list parameters describing the state of nature and what extent they are affected by each of the source of uncertainty.

Moreover, in the physical identification, in the qualitative and/or quantitative description of the possible event and in the location of the danger, uncertainties can range from not knowing location phenomena time period. The Figure 22 is an attempt at associating uncertainties with phenomena. There is a connection between the uncertainties evaluated in the state of nature and these in the identification and description of danger.

DANGER IDENTIFICATION	SOURCES OF UNCERTAINTY			
	Spatial/Temporal Variability	Measurement Uncertainty		Model Uncertainty (model = interpretation of exploration or test results)
		Error	Bias	
Type of Phenomenon	×		×	×
Size of Phenomenon	×	×	×	×
Exact Location	×	×	×	
Time	×		×	(×)

Figure 22 – Sources of uncertainties affecting danger identification (Source: Karam K.S., 2005)

STATE OF NATURE	SOURCES OF UNCERTAINTY			
	Spatial/Temporal Variability	Measurement Uncertainty		Model Uncertainty (model = interpretation of exploration or test results)
		Error	Bias	
TRIGGER ZONE				
GEOLOGY				
SOIL				
Thickness	H	M	L	L
Stratigraphic Setting (homogenous/heterogeneous)	L	M	M	L
Strength Properties	M	M	M	L
Unit Weight	L	L	L	L
Pore Size Distribution	M	M	M	M
Grain Size Distribution	M	M	M	M
Porosity	M	M	M	M
Conductivity	M	M	L	M
BEDROCK				
Fracture Geometry	M	M	H	M
Strength	L	M	M	H
Conductivity	M	M	M	M
SURFACE CONDITIONS				
Vegetation	M	L	L	L
Cracks and Micro-Pores	M	M	M	M
HYDROLOGY				
Depth to Water Table	M	M	L	L
Subsurface Flow Regime	M	M	H	M
Antecedent Moisture Content	M	M	M	M
RAINFALL				
Intensity	H	H	M	H
Duration	M	M	L	L
SLOPE GEOMETRY				
Inclination	M	L	L	L
Depth to Bedrock	M	M	L	L

LEGEND:	
H	In most cases
M	In some cases
L	Rarely

Figure 23 – State of nature with sources of uncertainty (example landslide trigger zone)

A possible approach in order to reduce the uncertainties is to simplify the decision analysis procedure through elimination of variable and simplification of models. This simplification can be structured using influence diagrams and it can be implemented based on sensitivity analyses. Influence diagram is classic tool of decision analysis which represent all state and decision variables, and connect them amongst themselves and with the results, to show dependencies. The influence diagrams can be expanded by comments on the connecting lines, such comments would be largely based on judgment. For instance, it can mention the degree of uncertainty and the importance of a particular variable on the connecting line, this can be used to eliminate some of the variables.

Whereas, the sensitivity analysis includes state and decision variables, models have to be selected to perform sensitivity analyses, and these, by themselves are subject to model uncertainty. The sensitivity analyses also serve an important purpose in decision making by simplifying the relationships and pointing out where it is necessary and worthwhile to get detailed information on uncertainties (Karam K.S., 2005).

They are analytical models resulting from the theories assumed to apply to physical process, and they are therefore subject to uncertainties as they attempt to represent reality. They are subject to model uncertainty.

The effect of model uncertainty are more significant in probabilistic analyses than they are in deterministic analyses. The effects of model uncertainty, for both analyses type, depend on the shape of failure surface, these effects are not very significant for regular translational surface, but become significant for surface more irregular and rotational. In such instances, different stability models can lead to different conclusions regarding slope stability. Model uncertainty in stability model comes from models themselves and from models used within the stability models (submodels, they typically in stability models include soil strength parameters and probability distribution parameters.). Model uncertainty from stability models depends on the shape on the failure surface; however, submodels are a significant source of model uncertainty, because the numbers of parameters.

2.6.2. Stability Models

Once the slope geometry and subsoil characteristics have been determined, the stability can be assessed using different approaches. These models vary in scale, dimensionality and complexity. Stability models can be classified into models that satisfy force equilibrium, moment equilibrium and models that satisfy both force and moment equilibrium (rigorous methods).

They can be deterministic models or probabilistic model.

The deterministic model

In the deterministic phase, it selects initial variables and creates deterministic models. Models used in stability analysis combine strength model with geometric and equilibrium representations. The figure below (Figure 24) shows the possible models used for stability analysis.

Stability models are large based on the Limit Equilibrium method, this model range in complexity from one dimensional (Infinite Slope Model), to two dimensional (Bishop’s Semplified, Rigorous, Janbu's Simplified, Morgenstern-Price) and three dimensional (Azzouz and Baligh) models. The Infinitive Slope models has been the most used stability model because of its simplicity, but this is also the principal problem with this method, it is simplistic to accurately represent reality, because the assumption one dimensional is too simple to be used in accurate landslide analyses. Moreover, the landslide mechanisms remain poorly understood because the complexity of the phenomena and the many factors that affect it, and also the use of simple models to represent them. For this reason, have been developed advanced models more rigorous. Often, the models do not allow one to formally incorporate uncertainties in parameters for probabilistic analyses.

The probabilistic model

In the probabilistic phase, it expresses probabilities and creates probabilistic model. Several probabilistic models have been created in the field of stability modeling (for example Ang and Tang 1974; Hassan and Wolff, 2000). Furthermore, nearly all these studies consider parameter uncertainty as the only source of uncertainty. Few studies have looked at model uncertainty, although it is issue recognized in recent studies (Einstein and Karam, 2001; Harrison J.P., 2012).

For example, the Monte Carlo methods is used to estimate the probability of slope failure from an assumed distribution of the uncertain strength parameters, this is done by generating a distribution of Factor of Safety which probabilities of failure are directly computed. Monte Carlo analyses will also allow one to examine the effects of stability model uncertainty on the distribution of the Factor of Safety.

- STABILITY MODELS
  - STRENGTH MODELS
    - Saturated Soils
      - Coulomb
      - Others
    - Unsatured Soils
      - Effective Stress (Bishop)
      - Indipendent state variable (Frediund et al.)
      - Others
  - STABILITY MODELS
    - Limit equilibrium
      - 1D
        - Infite slope (Skempton&DeLory)
        - Others
      - 2D
        - Force equilibrium
        - Moment equilibrium
        - Rigorous
      - 3D
        - Azzouz&Baligh
        - Chen&Cherneau
        - Others
    - Finite element (displacement type)
      - 2D
        - Wilson&Frediunnd
        - Others
      - 3D
        - SLOPE/W
        - Others
    - Others

Figure 24 – Possible models used for stability analysis

3. Landslide Risk Assessment and Management

Disasters caused by landslides have continued to increase during the last decades, the reason for a risk increase is essentially related to demographic pressures and territory mismanagement. For this reason, some countries and regions have already progressed in the development of procedures for managing urban and population growth as well as for minimizing the associated risks. The procedures are based on hazard and risk zoning, these investigations are a diverse and complex undertaking and may include geotechnical and engineering assessments, geomorphological and geographical analysis, political and management perspectives, as well as economic and social considerations. The components necessary for risk reduction include hazard and risk identification, hazard and consequence analysis, risk calculation and risk evaluation.

The more formal applications of risk assessment and management principles, in a qualitative manner, have been practiced for landslide hazard zoning for urban planning and highway slope management since the 1970's. In the 1980's, and particularly in the 1990's, these have been extended to quantitative methods, and to management of individual slopes, pipeline routes, submarine slopes and more global slope risk management.

3.1. The risk management process

The risk management is defined as the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, mitigating and monitoring risk. It aims at reducing the risk below the threshold of tolerable or even acceptable risk, by taking into account the statutory and environmental protection constraints and by making sure that viable and economically tolerable solutions are proposed. The full range of procedures and tasks that ultimately lead to the implementation rational policies and appropriate measures for risk reduction are collectively referred to as risk management. The figure describes the process for landslide risk management (Figure 25).

The choice of measures for reducing risk and the operational actions are made in view of other constraints and risks affecting the area of interest. The ambitions for development, the financial resources available, the needs of society and the regulation restrict the field of potential solutions, on the basis of economic, social, environmental, cultural, legal, technical, political indicators, in order to reach acceptable solutions (Figure 26).

The risk analysis includes scope definition, hazard and risk identification and risk estimation (hazard analysis and consequence analyses). Hazard analysis involves characterizing the landslide (classification, size, velocity, mechanics, location, travel distance), and the corresponding frequency (annual probability) of occurrence. While, consequence analysis includes identifying and quantifying the elements at risk (property, persons), their temporal spatial probability, their vulnerability either as conditional probability of damage to conditional probability of damage to property, or conditional probability of loss of life or injury.

Risk assessment takes the output from risk analysis and assesses these against values judgements, and risk acceptance criteria.

Risk management takes the output from the risk assessment, and considers risk mitigation, including accepting the risk, reducing the likelihood, reducing consequences e.g. by developing monitoring, warning and evacuation plans or transferring risk (e.g. to insurance), develops a risk mitigation plan and possibly implements regulatory controls. It also includes monitoring of the risk outcomes, feedback and iteration when needed. Regarding this last point, it aims at reducing the risk below the threshold of tolerable or even acceptable risk, by taking into account the statutory and environmental protection constraints and by making sure that viable and economically tolerable solutions are proposed.

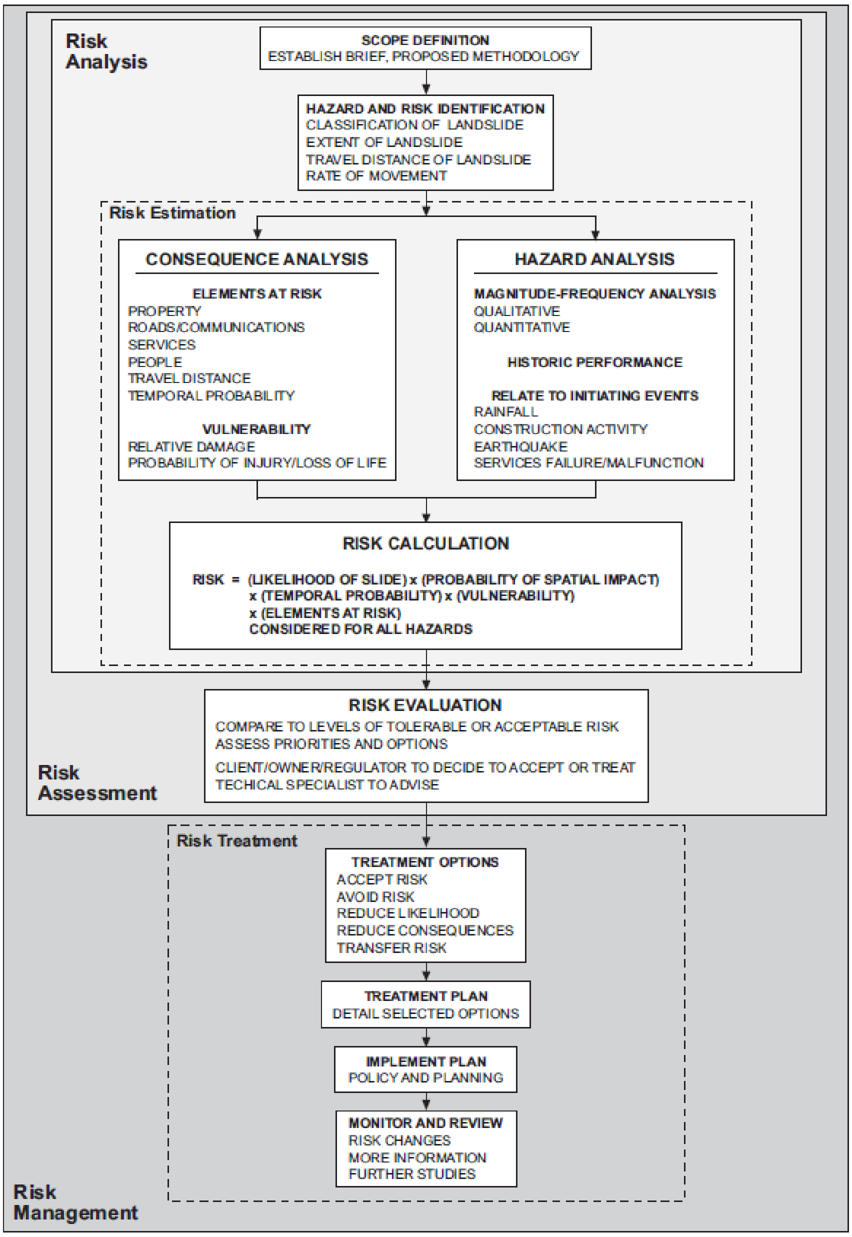


Figure 25 - Flow chart for landslide risk management (Crozier M.J. and Glade T., 2005)

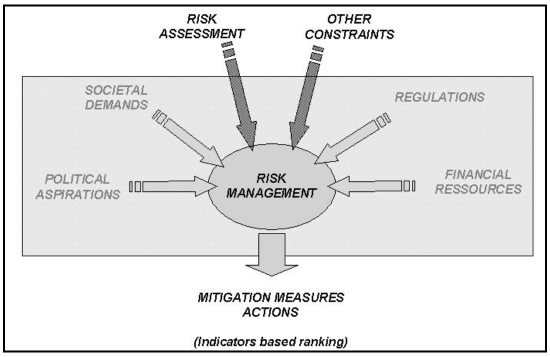


Figure 26 - The constraints to be taken into account in Landslide Risk Management (Leroi E., 2005)

3.1.1. Landslide risk analysis

It is important to define the scope of risk analysis. This is often dictated by scientific, economic, legal or social imperatives. It is also main to identify the time frame of interest, the resources available and the degree of detail required by the assessment. Several critical points needs to be addressed (Fell R. et al., 2005):

- Analysis for a single site (e.g. a road cutting, or a building) or a number of sites (e.g. all the road cuttings on a length of road) and analysis hazard zoning for land-use planning or “global risk assessment”;
- The geographic limits;
- The analysis to be restricted to property loss or damage, or also include assessment of the potential for loss of life and injury;
- The extent of geotechnical engineering and geological studies which will form the basis of the analysis. These can control the overall standard of the risk analysis.
- The approach to be used to characterise the landslides, and assess the frequency of landsliding, and their consequences;
- analysis be quantified or qualitative;
- Operational (e.g. land access) and financial constraints to the analysis;
- Legal responsibilities of all parties;
- The nature of the end product of the risk analysis – report, maps.

Having identified the scope of the study the next stage is hazard and risk identification. The hazard and risk identification stage essentially identifies those factors that should be further investigated and taken into consideration in risk estimation. The process of risk estimation integrates the behaviour of the hazard (hazard analysis) with the elements at risk and their vulnerability (consequence analysis) in order to allow risk calculation, usually in the form of the generic hazard/risk equation. The probability of occurrence of a landslide is given by the its magnitude (hazard), the valued attributes at risk (elements at risk) and the amount of damage expected from the specified *landslide magnitude*, expressed by the ratio of the value of damage to the total value of the element (vulnerability).

The approaches taken to analyze landslide hazard depend on the scope of the problem and social context. The initial concern is to characterize the problem by determining what physical hazards exist (hazard identification) and how they are likely to behave with respect to elements at risk.
Hazard analysis requires three steps: firstly, the analysis of all identified landslides to determine their types and potential behaviour; secondly, the determination of those members of the landslide population that are capable of producing damage on the basis of an analysis of impact characteristics, and; thirdly, the determination of the location, magnitude, frequency, and spatial extent of the potentially damaging landslides (Crozier M.J. and Glade T., 2005). The nature of information used to assess hazard may also differ depending on the type of site involved, natural slope or artificially, and on the presence of existing landslides areas compared to areas where no landslides exist or the hazard from first-time landslides is being assessed.
Moreover, landslide classification/identification requires a knowledge of the slope processes and the relationship of those processes to geomorphology, geology, hydrogeology, failure and slide mechanics, climate and vegetation.

Investigations generally are site-specific analysis or regional based investigations. Analysis of single landslides at a particular site have a long tradition and include field mapping, soil sampling and testing, and slope stability modelling by a wide range of techniques. In contrast, regional analysis tends to be less precise and more indicative in nature. The analysis generally involve inventory maps of old landslides, recent failures, or a combination of both, while new approaches include statistical analysis and process-based methods. Depending on the sophistication of the database and methods employed, hazard may be represented by spatial distributions, derived landslide susceptibility, and, in some instances, probability of occurrence (Crozier M.J. and Glade T., 2005). The range of credible consequence scenarios will need to be considered in societal risk calculations. It should take into account the nature of the landslide including its volume, and velocity, monitoring results, warning signs, evacuation systems, the elements at risk, and the mobility of the persons.

Additional factors appear to be important: the frequency and the susceptibility. The *frequency of landslide* can be expressed in terms of the number of landslides of a certain characteristic that may occur in a study area per year. There are several ways of calculating frequency, as shown in IUGS 1997, but for most hazard analyzes the estimation of frequency is based on historical data, geomorphological evidence, relationship to trigger event frequencies. These methods are more reliable than the apparently more rigorous and detailed probabilistic analyses because of the uncertainties involved and data constraints. Also, some of the causes and/or factors to slope instability may not be amenable to conventional limit equilibrium analysis. This is particularly true for smaller slopes, and for landslides on natural hillsides, where it is very difficult to estimate pore water pressures, and where small variations in strengths, and geometry and geological anomalies have large effects on the outcomes.

The following figure (Figure 27) summarizes the common types of landslide hazards and the methods using in order to assess the frequency.

Hazard Scenario	**Applicable Methods (1)**
	Natural Slopes
First time slides and shallow existing slides not identified specifically	Hazard zones based on geomorphological mapping and interpretation should identify areas or slope facets more prone to failure. Frequency may be derived from inventories of the historic occurrence of landslides in a part of the landscape. Associations of occurrences with major triggers such as rainfall and seismic events may also form part of the analysis.
Rockfalls, boulder falls and debris flows	Hazard zones based on geomorphological mapping and interpretation should identify areas prone to failure and knowledge of apparent friction angles should indicate travel distances. Frequency may be derived from knowledge of the process rate within hazard zones allowing assessment of recurrence intervals. Associations of occurrences with major triggers such as rainfall and seismic events may also form part of the analysis. Note that process rate may change with time.
Deep slides in rock or soil	Geomorphological mapping of slide and environs should establish extent, geometry, controls and potential area of influence. Movement is likely to reflect piezometric response to rainfall or other source of water. Appropriate soil/rock mechanics principles will assist formulation of a geotechnical model. Frequency may be derived from regional studies of similar occurrences, geological history of site and timing of major movements, records of movement measurements, and/or recurrence interval of triggers such as rainfall patterns or seismic events in conjunction with stability analyses.
	Constructed Slopes
Cuts and fills	Geological and geotechnical mapping and inspection should establish typical performance of similar cuts or fills and information on existing failures. Data collection on the controls on stability (especially defects in rock masses) may provide statistical information for analysis. Engineering assessment of construction quality, performance history, drainage adequacy etc is useful. Frequency may be derived from statistics of similar cuts or fills, recurrence intervals of triggers such as rainfall patterns, or seismic events. Deterministic/probabilistic analyses based on geological and geotechnical data and soil/rock mechanics may be useful for very important cuts or fills in conjunction with other methods.

Note (1): Choice of applicable method may depend on whether a preliminary study or more detailed study is being carried out.

Figure 27 - Methods for estimating the frequency of landslide (Sources: AGS, 2000)

The *landslide susceptibility* is a function of the degree of the inherent stability of the slope together with the presence and activity of causative factors capable of reducing the excess strength and triggering movement. The identification of causative factors is the basis of many methods of susceptibility/stability assessment. The factors may be dynamic (e.g. porewater pressure), or passive (e.g. rock structure) and may also be considered in terms of the roles they perform in destabilising a slope (Crozier 1989). In this sense, the factors recognised are pre-conditioning factors (e.g. slope steepness), preparatory factors (e.g. deforestation) and triggering factors (e.g. seismic shaking).

Having identified the previous parameters, the consequences analysis becomes important. This involves:

- Identifying and quantifying the elements at risk including property and persons;
- Assessing temporal spatial probabilities for the elements at risk;
- Assessing vulnerability of the elements at risk, in terms of property damage and loss of life/injury as appropriate.

This has to be done for each of the landslide hazards. The consequences may include damage and loss of life/injury, loss of gain and increase of costs, (e.g. a road is closed for some time affecting businesses along the road), political repercussions, adverse social and environmental effects. Most of these may not be readily quantifiable, but may need to be systematically factored into the decision-making process as appropriate, at least for comprehensive risk analysis studies.

The *elements at risk* include the population, buildings, engineering works, infrastructure, vehicles, environmental features and economic activities which are in the area affected by the hazard, on the landslide, and/or in the area onto which the landslide may travel if it occurs. It may also include property immediately adjacent to or upslope by land sliding and infrastructure which may include power lines, water supply, sewage, drainage, roads, communication facilities. The population at risk includes persons who live, work, or travel through the area affected by the hazard. It would be usual to categorise vehicles into cars, trucks and buses, because of the different number of persons likely to be in the vehicles. The elements at risk are likely to be dependent on the nature of the landslide hazard e.g. for a boulder fall, or debris flow at a given site.

The *probability* of the landslide reaching the element at risk depends on the relative location of the element at risk and the landslide source, together with the path the landslide is likely to travel below the source. It is between 0 and 1. For buildings located on the source landslide the probability is 1; for buildings or persons located below the source landslide and in the path of the resulting travel of the landslide, the probability is calculated taking account of the travel distance of the landslide, the location of the source landslide, and the element at risk. For vehicles or persons in vehicles, or persons walking in the area below the source landslide in the path of the resulting travel of the landslide, the probability is calculated taking account of the travel distance of the landslide, and the path to be followed by the vehicle or person. Whether the vehicle or person is in the path at the time of the landslide is taken account through the temporal spatial probability.

The *temporal spatial probability* concerns the elements at risk mobile (e.g. persons on foot, in cars, buses and trains) or varying occupancy of buildings (e.g. between night and day, week days and weekends, summer and winter). It is necessary to make allowance for the probability that persons (or a particular number of persons) will be in the area affected by the landslide. This is between 0 and 1. For buildings on in the path of the landslide, the temporal spatial probability is 1. For a single vehicle which passes below a single landslide, it is calculated as the proportion of time in a year when it will be in the path of the landslide. For all the vehicles which pass below a single landslide, it is calculated as the proportion of time in a year when a vehicle will be in the path of the landslide. For persons in a building, it is considered such the proportion of time in a year which the persons occupy the building (0 to 1).

Vulnerability is the degree of loss (or damage) to a given element, or set of elements, within the area affected by the hazard. It is difficult to assess vulnerability to landslides due to the complexity and the wide range of variety of landslide processes (Leroi, 1996). Normally, for property it is expressed on a scale of 0 (no loss or damage) to 1 (total loss or damage), while for persons it is expressed on the likelihood of deaths and injuries or “vulnerability” of persons who are impacted by a landslide.

Factors that most affect vulnerability of property include:

- The volume of the landslide in relation to the element at risk;
- The position of the element at risk;
- The magnitude of landslide displacement and relative displacements within the landslide;
- The velocity of landslide movement.

Factors which most affect the vulnerability of persons include:

- The velocity of land sliding. Persons are more likely to be killed by a rapid landslide than slow regardless of the landslide volume;
- Landslide volume – persons are more likely to be buried or crushed by large landslides than small;
- The degree of protection the person has from the landslide impact;
- The building collapses, and the nature of the collapse.

The comprehensive *risk estimation* involves the sequential identification and analysis of a number of components that influence risk. The aim is to find reproducible standard measure of risk that can be compared and evaluated along with other similarly estimated risks. There are two sources of uncertainty in risk estimation: firstly, the uncertainty attached to both the hazard and consequence components of risk, and secondly, the accuracy of the estimate itself. The value of the estimate depends on the accuracy of initial hazard and risk identification.

The risk can be presented in a number of ways (Fell M.J. et al., 2005):

- The annual risk (expected value) in which the probability of occurrence of the danger is multiplied by the consequences summed over all the hazards. This is expressed as damage per annum or potential loss of lives per annum;
- Frequency – consequence (f – N) pairs – for example for property, the annual probability of minor damage; medium damage and major damage; and for risk to life, the annual probability of loss of 1 life, 5 lives, 100 lives etc.;
- Cumulative frequency – consequence plots (F – N plots), for example a plot of the annual probability of N or more lives being.

Estimates of risk can be expressed on qualitatively, semi quantitatively or quantitatively.

The *quantitative risk analysis* is carried out by expressing hazard frequency and consequences in measured, numerical terms and determining their product.

In the calculation are taken into account factors as risk to property or/and loss of life, annual probability of the hazardous event, probability of spatial impact by the hazard, vulnerability, element at risk.

For the property the risk can be calculated from:

$$R(Prop) = P(h) \times P(s:h) \times V(Prop:s) \times E$$

Where:

R(Prop) is the risk (annual loss of property value);

P(h) is the annual probability of the hazardous event (the landslide);

P(s:h) is the probability of spatial impact by the hazard (i.e. of the landslide impacting the property, taking into account the travel distance) and for vehicles, the temporal probability;

V(Prop:s) is the vulnerability of the property to the spatial impact (proportion of property value lost);

E is the element at risk (e.g. the value or net present value of the property)

It should be stressed that a quantitative approach such as indicated in equation provides an estimate of risk, dealing with components, essentially direct damage to property in economic terms. There are likely to be many other indirect consequences associated with property damage. For example, in the case of damage to an industrial plant, this may involve loss of profit, loss of clients, loss of employment and earnings, as well as the adverse effects experienced by retailers and suppliers of raw materials associated with that industrial plant (Crozier M.J. and Glade T., 2005).

For loss of life, the individual risk can be calculated from:

$$R(di) = P(h) \times P(s:h) \times P(t:s) \times V(d:t)$$

Where:

R(di) is the risk (annual probability of loss of life (death) of an individual);

P(h) is the annual probability of the hazardous event (the landslide);

P(s:h) is the probability of spatial impact by the hazard (e.g. of the landslide impacting a building (location) taking into account the travel distance) given the event;

P(t:s) is the temporal probability (e.g. of the building being occupied by the individual) given the spatial impact;

V(d:t) is the vulnerability of the individual (probability of loss of life of the individual given the impact).

It is useful to report the risk calculations as, for the property, annual total risk or annual probability and consequences for the different levels of hazards, e.g. for a specified hazard there may be different probabilities for different amounts of movement. For the loss of life, the risk calculation is reported as annual individual risk for the person most at risk i.e. the annual probability that this person may be killed, or annual total risk (summing the individual risk of all the persons affected by the landslide hazards), or the societal risk i.e. the pairs of probability that N or more persons may be killed, versus the number of persons killed (N).

The *qualitative and semiquantitatively risk analysis* use descriptors to illustrate the frequency of landslide and the consequences. In the analyses can be used (AGS, 2007c):

- As an initial screening process to identify hazards and risks which require more detailed consideration and analysis.
- When the level of risk does not justify the time and effort required for more detailed analysis.
- Where the possibility of obtaining numerical data is limited such that a quantitative analysis is unlikely to be meaningful or may be misleading.

Qualitative risk assessment is subject to limitations, which include potentially imprecise and subjective description of the likelihood term, for example “adverse or “could occur” and hence are liable to result in wide differences in the estimated risks, together with lack of risk acceptance criteria. Semi-quantitative methods may be a combination of qualitative and quantitative methods, for example considering risk to property qualitatively, and risk to life quantitatively based on the appropriate best estimates of likelihood. Extreme care must be exercised for estimating risk of loss of life (Fell M.J., 2005). Examples of qualitative assessment of frequency, consequences and risk with respect to property are given in following tables (Table 7; Table 8; Table 9). In these tables ,the likelihood incorporates the frequency of landslide, the probability of the landslide reaching the element at risk, and temporal spatial probability. The consequences incorporate the vulnerability and the value of the element at risk.
Concerning the risk estimation for loss of life, the annual probability of death for the person most at risk from the landslide should be estimated using the above mentioned equations. For situations where there is a potential for large numbers of lives to be lost in a single landslide event, it is necessary to estimate the frequency (f) –number (N) of lives lost pairs and total annual risk. In some situations where risk of loss of life is identified as an issue in semi quantitative analysis, it may be possible to immediate risk reduction measures without further assessment. Loss of life as a result of landslides often involves combinations of events. Quantifying the risk may involve multiplying together many quantified judgements. It is good practice to explain the basis of the judgements and the uncertainty involved.

Level	descriptor	Description	Indicative annual probability
A	Almost certain	The event is expected to occur	$>=10^{-1}$
B	Likely	The event will probably occur under adverse conditions	$=10^{-2}$
C	Possible	The event could occur under adverse conditions	$=10^{-3}$
D	Unlikely	The event might occur under very adverse circumstances	$=10^{-4}$
E	Rare	The event is conceivable but only under very exceptional circumstances	$=10^{-5}$
F	Not credible	The event is inconceivable or fanciful	$<=10^{-6}$

Table 7 - Qualitative measures of likelihood (Australian Geomechanics Society, 2000)

Level	Descriptor	Description
1	Catastrophic	Structure completely destroyed or large scale damage requiring major works for stabilisation
2	Major	Extensive damage to most of the structure, or extending beyond site boundaries requiring significant stabilisation works.
3	Medium	Moderate damage to some structure, or significant part of the site requiring large stabilisation works
4	Minor	Limited damage to part of structure, or part of sit requiring some reinstatement/ stabilisation works
5	Insignificant	Little damage

Table 8 - Qualitative measures of consequences to property (AGS, 2000)

Risk level	General guide to implications
Very High risk	Extensive detailed investigation and research planning and implementation of treatment options essential to reduce risk to acceptable levels: may be too expensive and not practicable
High risk	Detailed investigation, planning and implementation of treatment options required to reduce risk to acceptable levels.
Moderate risk	Tolerable provided implementation plan is implemented to maintain or reduce risks. May be accepted. May require investigation and planning of treatment options
Low risk	Usually accepted. Treatment requirements and responsibility to be defined to maintain or reduce risk
Very low risk	Acceptable. Manage by normal slope maintenance procedures.

Table 9 - Qualitative risk level implications (AGS, 2000)

3.1.2. Landslide Risk Assessment

Risk assessment involves taking the outputs from the risk analysis and comparing them against values and risk tolerance criteria to determine if the risks are acceptable, tolerable or intolerable. These judgements are however influenced by psychological, social and cultural values (Fischhoff et al., 1981). In a simple situation where the client/owner is the only affected party, risk evaluation may be a simple value judgement. In more complex situations, value judgements on acceptable risk appropriate to the particular situation are still made as part of an acceptable process of risk management.

Assessment of the risk may involve consideration of values such as, for property losses, cost benefit ratio, frequency of accidents, financial capability; for loss of life the value are individual risk, societal risk (frequency versus number of deaths, known as f-N, or cumulative frequency versus number of deaths, known as F-N criteria), cost to save a life, annual potential loss of life.

It is important to distinguish between acceptable and tolerable risks. This applies to both property and loss of life. *Acceptable risk*: a risk which everyone impacted is prepared to accept; action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort. *Tolerable risk*: a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible, and needing to be kept under review and reduced further if possible (Fell M.J., 2005). Tolerable risks may vary from country to country, as well as within a country, depending on historic exposure to landslide hazard, and the system of ownership and control of slopes and natural landslides hazards. The acceptable risks are usually considered to be one order of magnitude smaller than these tolerable risks.

There are some common general principles that can be applied when considering tolerable risk criteria about loss of life:

- The incremental risk from a hazard should not be significant compared to other risks to which a person is exposed in everyday life.
- The incremental risk from a hazard should, wherever reasonably practicable, be reduced: i.e. the As Low As Reasonably Achievable (ALARA) principle should apply.

- If the possible loss of large numbers of lives from a landslide incident is high, the probability that the incident might actually occur should be low. This accounts for society's particular intolerance to incidents that cause many simultaneous casualties and is embodied in societal tolerable risk criteria.
- Persons in society will often tolerate higher risks than they regard as acceptable when they are unable to control or reduce the risk because of financial or other limitations.
- Higher risks are likely to be tolerated for existing slopes than for planned projects, and for workers in industries with hazardous slopes, e.g. mines, than for society as a whole.
- Tolerable risks are thought to be higher for naturally occurring landslides than those from engineered slopes, but this has not been proven.
- Once a natural slope has been placed under monitoring, or risk mitigation measures have been executed, the tolerable risks may approach those of engineered slopes.
- Tolerable risks may vary from country to country and within countries, depending on historic exposure to landslide hazard, the system of ownership and control of slopes and natural landslide hazards, and the risks a person is exposed to in everyday life.

Fell and Hartford (1997) gives some details on the use of societal risk plots when considering individual and societal risk criteria. It should be remembered that (IUGS, 1997):

- Estimates of risk are inevitably approximate and the acceptance criteria should not be considered as absolute values. The assessed risk may span the acceptance criteria. Judgement is needed as to whether that may be acceptable in the light of the defensibility of the assessment.
- Tolerable risk criteria are themselves not absolute boundaries. Society shows a wide range of tolerance to risk and the risk criteria are only a mathematical expression of general societal opinion. There may be cases where risks higher than the upper limit tolerable risk criteria are adopted, because the ALARP principle, or Best Practical Technology (BPT), indicates it is not practicable to further reduce the risk.
- It is often useful to consider several different tolerable risk criteria (e.g. individual and societal risk, cost to save a life, etc).
- It must be recognised that risk estimation is only one input to the decision process. Owners, society and regulators will also consider political, social and legal issues in their assessments and may consult the public affected by the hazard.
- The risk can change with time because of natural processes and development. For example: removal of debris from slopes can lead to reduction in risk, removal of vegetation by natural processes (e.g. fire or human intervention) can lead to an increase in risk, construction of roads on, below or above a slope may increase the probability of slides and/or the elements at risk, and hence the risk.
- Extreme events should be considered as part of the spectrum of events. Inclusion of extreme events is important in assessing the triggers (landslides, earthquake), the size of the landslide and the consequences. However, often it is the smaller, more frequent, landslides that contribute most to risk, not the extreme event

Concerning individual risk, interim guidelines set by the Geotechnical Engineering Office of the Hong Kong Government for landslides and boulder falls on natural terrain indicate, in terms of annual loss of life, an 'acceptable' individual risk level at 1 x 10^{-5} for new developments and 1 x 10^{-4} for existing developments (Moore et al., 2001), the same recommendations are proposed by AGS and summarized in Table 10.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope (1) / Existing Development (2)	10^{-4} / annum
New Constructed Slope (3) / New Development (4) / Existing Landslide (5)	10^{-5} / annum

Table 10 - AGS Suggested Tolerable loss of life individual risk (Source: AGS, 2007c)

1. “Existing Slopes” in this context are slopes that are not part of a recognizable landslide and have demonstrated non failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
2. “Existing Development” includes existing structures, and slopes that have been modified by cut and fill, that are not located on or part of a recognizable landslide and have demonstrated non-failure performance over at least several seasons or events of extended adverse weather, usually being a period of at least 10 to 20 years.
3. “New Constructed Slope” includes any change to existing slopes by cut or fill or changes to existing slopes by new stabilisation works (including replacement of existing retaining walls or replacement of existing stabilization measures, such as rock bolts or catch fences).
4. “New Development” includes any new structure or change to an existing slope or structure. Where changes to an existing structure or slope result in any cut or fill of less than 1.0m vertical height from the toe to the crest and this change does not increase the risk, then the Existing Slope / Existing Structure criterion may be adopted. Where changes to an existing structure do not increase the building footprint or do not result in an overall change in footing loads, then the Existing Development criterion may be adopted.
5. “Existing Landslides” have been considered likely to require remedial works and hence would become a New Constructed Slope and require the lower risk. Even where remedial works are not required per se, it would be reasonable expectation of the public for a known landslide to be assessed to the lower risk category as a matter of “public safety”.

Societal risk needs not be considered for a risk evaluation in relation to a single dwelling. Societal risks should be evaluated for buildings having high numbers of occupants, such as schools, hospitals, hotels or motels where many lives are at risk. This then addresses society’s aversion to loss of many lives from single landslide events. Acceptability of societal risk can be recognised by plotting, on log–log scale, the cumulative frequency of landslides per year F, causing N or more fatalities, versus the number N of fatalitiesresulting from landslides (Fell and Hartford, 1997) (Figure 28)

Implicit or explicit in any decision on acceptability of risk is the exercise of risk/benefit analysis. This is the comparison of the level of risk with benefits associated with being exposed to that risk. Even though there might be a relatively high risk, the associated benefits are sufficient to accept or tolerate the risk. For example, living on the top of a coastal cliff may expose the inhabitants to landslide risk but the view and other attributes may be considered to outweigh that risk.

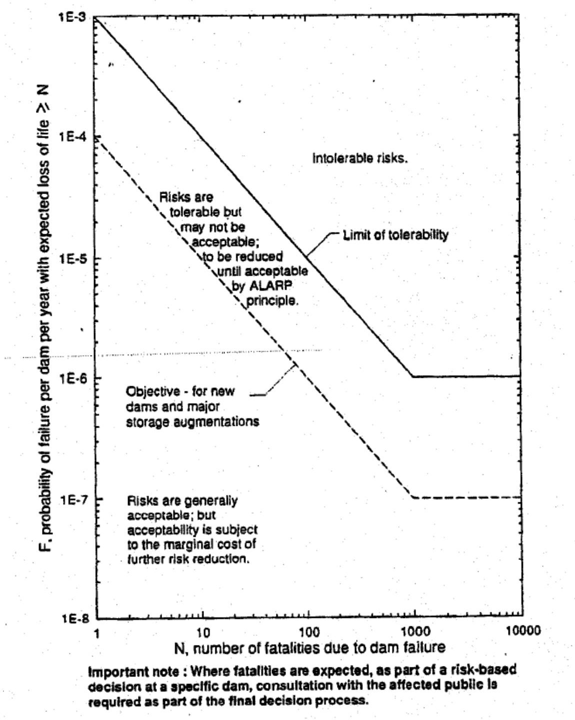


Figure 28 - Societal risk tolerance criteria, a schematic diagram showing the frequency, or probability of failure with expected loss of life equal or greater than 1 and the number of fatalities (Source:AGS, 2000).

The development of *quantitative risk assessment (QRA*) methods involves the formulation of a suitable hazard model and should be recognized as an additional tool to conventional deterministic methods in the quantification of landslide risk. It provides a framework in order to evaluate the problems and to mitigate them in a cost effective manner and to acceptance of the residual risk level.

QRA can be applied in a number of areas (Ho et al, 2000):

- Global risk assessment - to examine the scale of a problem and define the relative contribution of the different components to facilitate formulation of risk management policies and consideration of optimal resources allocation;
- Relative risk assessment - to determine the priority for follow-up action;
- Site-specific risk assessment - to evaluate the hazards and level of risk in terms of fatality at a given site;
- Preparation of hazard or risk mapping - for hazard zoning or planning control of a region or an area.

In the application of QRA, it will need to be supported by the detailed examination of landslide trigger factors, mechanisms and mode of failure and debris run out. In a formal QRA, the findings of a risk analysis with respect to public safety are often presented in the following format: individual risk (which relates to the risk posed to the most exposed and vulnerable and can be compared to other everyday risks), and societal risk (which relates to the risk posed to the affected population as a whole).

3.1.3. Landslide Risk Management

The risk management process evaluates the consideration of the risk mitigation options and the results of the implementation of the mitigation measures and of the monitoring. The outputs of the risk assessment will be either:

- The risks are tolerable or at least acceptable, then no mitigation options need to be considered;
- The risks are intolerable, then risk mitigation options need to be considered, such as reduce the frequency and probability of landslides and spatial probability of the element a risk.

The risk mitigation can use engineering and non engineering solutions (as public education campaigns, public information services to address the issue of risk tolerance by the general public). Risk communication to people forms a key element of the landslide risk management process in facilitating a better understanding of the nature and reality of landslide risk. Options for risk mitigation for each risk assessment are to be identified and discussed, several methods can be evaluated. Typical options include (AGS, 2000):

- *Accept the risk;* this would usually require the risk to be considered to be within the acceptable or tolerable range.
- *Avoid the risk;* this would require abandonment of the project, seeking an alternative site or form of development such that the revised risk would be acceptable or tolerable.
- *Reduce the likelihood;* this would require stabilization measures to control the initiating circumstances, such as re-profiling the surface geometry, groundwater drainage, anchors, stabilising structures or protective structures etc. After implementation, the risk should be acceptable or tolerable, consistent with the ALARA principle.
- *Reduce the consequences;* this would require provision of defensive stabilization measures, amelioration of the behaviour of the hazard or relocation of the development to a more favourable location to achieve an acceptable or tolerable risk.
- *Monitoring and warning systems*; in some situations monitoring (such as by regular site visits, or by survey), and the establishment of warning systems may be used to manage the risk on an interim or permanent basis. Monitoring and warning systems may be regarded as another means of reducing the consequences.
- *Transfer the risk;* by requiring another authority to accept the risk or to compensate for the risk such as by insurance.

- *Postpone the decision* where there is sufficient uncertainty resulting from the available data, provided that additional investigations or monitoring are likely to enable a better risk assessment to be completed. Postponement is only a temporary measure and implies the risks are being temporarily accepted, even though they may not be acceptable or tolerable.

However, the landslide risk management is not the same method used in each country, numerous factors lead to modification of the tools used, the approach followed and the objectives to be reached. Some are presented below:

- The nature of the phenomena and the assets to be taken into account. The tools, the approach and even the logic used will vary depending on type of landslide (active landslide or a potential landslide, slow or fast movement, phenomenon in rock or soil conditions, an isolated movement or a linear, private property (house, network…) or a public property, etc.). For example, if the phenomena are potential and concern the entire area, it will be wiser to start the analysis with the development ambitions and the stakes inventory; in this case, the financial means to mobilise will be less and generally will have various order of importance: technical ascending logic.
- Cultural, social and other issues (the culture, the laws, the organisation of the administration, public and private stakeholders, etc.). The philosophy of risk management can be radically different, whether in term of prevention, rescue organisation, risk reduction, compensation and information.
- Dependence on political choices. Independently from the laws and organisation systems which are, by nature, specific to each country, there are four fundamental criteria will affect the risk management modes, and their operational implementation: obligations, centralised national management / decentralized local management, principle of solidarity or not, link between prevention and compensation or not.

Wherever possible the above recommended options should be engineered to reduce the uncertainties, since risk mitigation options should reduce uncertainties and hence the risk at least tolerable levels. In many cases, the reduction to a tolerable level is a pragmatic result since reduction to acceptable levels is not viable in the context of the cost to the individual or community. In other cases, good practice may suggest that risk reduction be applied since it is relatively cheap or cost effective to implement even though risk levels are assessed to already be at acceptable levels. Evaluation of mitigation options may take into account relative costs and effectiveness of the measures and inherent uncertainties. The options should be reassessed if there is a need to reduce uncertainties or if suitable engineering options cannot be adopted. An issue will be who decides on what level of risk reduction is appropriate.

3.2. Landslide susceptibility, hazard and risk zoning

Landslide susceptibility, hazard and risk zoning can be considered an efficient way to reduce risk from landslides. There are examples of landslides susceptibility, hazard and risk zoning in use since the 1970s, the scientific literature highlights their extensive development during the last few decades. The Joint Technical Committee on Landslides and Engineered Slopes (JTC-1) proposes “International Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for land-use planning”, which provide definitions, terminology and international standards for methods, levels, scales and types of zoning (Figure 29). The purpose of zoning is to divide the studied area into homogeneous compartments (units) in which hazard or risk is expected to attain a similar level. The Guidelines also promote the use of quantitative risk-management principles, essential to compare risk from landslides with risks related to other hazards and with loss of life tolerance criteria (JTC-1, 2008a,b).

Type of Zoning	Risk Zoning						
	Hazard Zoning						
	Susceptibility Zoning						
	Inventory Mapping						
Zoning Level	Inventory of existing landslides	Characteriz-ation of potential landslides	Travel distance and velocity	Frequency assessment	Temporal spatial probability	Elements at risk	Vulnerability
Preliminary	Basic (1) (2)	Basic (1) (2)	Basic (1) Intermediate (2)	Basic (1,2)	Basic (1,2)	Basic (1,2)	Basic (1,2)
Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate to Basic
Advanced	Sophisticated	Sophisticated to Intermediate	Intermediate to Sophisticated	Intermediate to Sophisticated	Sophisticated	Sophisticated	Intermediate to Sophisticated

Notes:

(1) For qualitative zoning
(2) For quantitative zoning
(3) See Section 8 for description of the levels of input information. viz basic, intermediate, sophisticated.

Figure 29 - Levels of activity required for susceptibility, hazard and risk zoning levels (Source: AGS, 2007a)

Landslides Susceptibility zoning involves the spatial distribution and rating of the terrain units according to their propensity to produce landslides. This is dependent on the topography, geology, geotechnical properties, climate, vegetation and anthropogenic factors such as development and clearing of vegetation. Usually this investigation involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a potential to experience landsliding in the future. The study area may be susceptible to more than one type of landslide (e.g. rock fall and debris flows) and may have a different degree of susceptibility (and in turn hazard) for each of these. In this case, susceptibility and hazard zoning maps are preparated for each type of landslide and are combined them to obtain the global landslide hazard map of the area. In some situations susceptibility zoning needs to be extended outside the study area being zoned for hazard and risk to cover areas from which landslides may travel on to or regress into the area being zoned. It is generally necessary to assess independently the propensity of the slopes to fail and areas onto which landslides from the source landslides may travel or regress (Cascini, 2008). Landslides susceptibility may be assessed based on qualitative or quantitative methods. In the qualitative approach, the descriptors are defined based on the judgment of the person carrying out the analysis. It can be divided into two types (Aleotti and Chowdhury,1999): field geomorphologic analysis and the combination of index maps with or without weighting. In the geomorphologic approach the assessment is made by the expert in the field, often with the support of aerial photo interpretation. The stability map is derived from the geomorphologic map. The susceptibility descriptors may be expressed as, for instance, the percentage of the landslide deposits per unit area. The Table 11 gives examples of landslide susceptibility mapping descriptors in relation to the potentially affected area.

Susceptibility descriptors	Rock Falls	Small landslides on natural slopes	Large landslides on natural slopes
	Probability rock falls will reach the area given rock falls occur from a cliff[a]	Proportion of area in which small landslides may occur[b]	Proportion of area in which large landslides may occur[b,c]
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.25 to 0.5	>0.25 to 0.5	>0.25 to 0.5
Low susceptibility	>0.01 to 0.25	>0.01 to 0.25	>0.01 to 0.25
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

[a] Spatial probability determined from historic, relative stability indexes, data or analysis taking consideration of the uncertainty in travel distance.
[b] Based on landslide inventory, geology, topography and geomorphology.
[c] Usually this is active, dormant and potentially reactivated slides, not first time slides.

Table 11 - Examples of landslide susceptibility mapping descriptors (Source : Fell et al., 2008)

In the index maps, the expert selects the critical instability parameters, assigns to each of them a weighted value that it is expected be proportionate to the relative contribution to the slope failure. The first steps are subdivide each parameter into a number of relevant classes and assign a weighted value to each class and to each of the parameter map; secondly, weighted maps are overladed and obtained scores of each terrain unit, finally the obtained scores in susceptibility classes are classified.

The quantitative susceptibility assessment may be either relative or absolute. In the relative approach, data treatment techniques evaluate the relative significance of the parameters and then correlate different combinations of parameters with the spatial distribution of the existing landslides in order to obtain the best match. An important step is the conversion of categorical parameters into numerical ones and ranking them according to their contribution to the instability (Carrara, 1983). Susceptibility scores obtained with these techniques are usually reclassified to obtain susceptibility classes (i.e. high, medium and low susceptibility). Absolute susceptibility is usually assessed with deterministic approaches such as slope stability models. The susceptibility may be expressed as the safety factor which calculation requires the knowledge of the geometry of the slope, the soil/rock strength properties and groundwater conditions. The safety factor of each slope or terrain unit is assigned to a susceptibility class. For natural slopes it is not practical to assess factors of safety with any degree of certainty and the susceptibility is likely to be useful in a relative sense, not absolute.

Landslide Hazard Zoning takes the outcomes of landslide susceptibility mapping, and assigns an estimated frequency (annual probability) to the potential landslides. The hazard may be expressed as the frequency of a particular type of landslide of a certain volume, or landslides of a particular volume and velocity (which may vary with distance from the landslide source), or in some cases as the frequency of landslides with a particular intensity, where intensity may be measures in kinetic energy terms. Intensity measures are most useful for rock falls and debris flows (e.g. depth×velocity). Hazard zoning may be quantitative or qualitative. It is generally preferable to determine the frequency of landsliding in quantitative terms so the hazard from different sites can be compared, and the risk estimated consequently also in quantitative terms. However in some situations it may not be practical to assess frequencies sufficiently accurately to use quantitative hazard zoning and a qualitative system of describing hazard classes may be adopted (Fell R. et al., 2008). The spatial distribution of hazard is shown on landslide hazard maps that are used to avoid the development of threatened areas, representing the most efficient and economic way to reduce future damage and loss of lives.

Landslide Risk zoning depends on the elements at risk, their temporal–spatial probability and vulnerability. For new developments, an assessment will have to be made of these factors. For areas with existing development it should be recognized that risks may change with additional development and thus risk maps should be updated on a regular basis. Several risk zoning maps may be developed for a single hazard zoning study to show the effects of different development plans on managing risk. It provide a global view of the expected annual damage due to the potential landslide hazard by identifying the most vulnerable elements that are threatened. Based on the information supplied by such maps and cost-benefit analyses, either protective or reinforcement works can be envisioned to minimize the risk level, whereas alert systems can be established in places in order to protect the human lives. Risk maps are documents that are not intended for direct use in urban planning and development because they generally reflect the current situation of potential damage but not the spatial distribution of the hazardous zones. In that respect, non-urbanized areas are often displayed as having low risk level regardless the level of existing hazard which is not quite appropriate.

There are no internationally accepted risk criteria for landsliding. Criteria should be developed in consultation with all the affected parties, including the affected public. During the risk analysis, is better to be most informed about precedents and understand the analyses and their appropriate limitations, that are involved in this process (Fell R. et al., 2008). Generally it should be possible to define risk zones in individual risk terms. However there may be some situations where a large number of deaths may result from a single landslide event. In these cases consideration of individual risks may not properly reflect societal aversion to such an event and societal risk criteria may require consideration.

Zoning for both landslide hazard and risk mapping introduces the spatial dimension of the landslide hazard management, generally there must be done for each type of landslide which has been identified and characterised as affecting the area being zoned. Moreover, the hazard and risk zoning maps should be at the same scale as the susceptibility zoning map and should show the zoning classification for the area being mapped. Susceptibility, hazard and risk zoning maps can be grouped into three different categories: basic, intermediate and sophisticated and on the basis of the purpose three different zoning levels (preliminary, intermediate and advanced) can be obtained. The selection of the most appropriate zoning method depends on several factors such as: availability, quality and accuracy of data; resolution of zoning; required outcomes; scale of zoning, etc. The guidelines JTC-1 analyzed methods and activities that may be used: to map the existing landslides and to assess the areas with a potential to experience landsliding in the future and to assess the travel distance and velocity, the intensity and the frequency of landslides.

The following tables summarise these suggestions by relating methods, input data and procedures, classified as heuristic, statistical and deterministic. Methods using heuristic or empirical procedures, that process essentially topographic, geological and geomorphological data, are considered basic methods for inventory of existing landslides and characterisation of potential landslides (Table 12). The method can be defined "intermediate" when further details on the input data, and using procedures based on statistical analysis are added. Finally, sophisticated methods necessarily need hydrogeological and geotechnical data, and deterministic or probabilistic procedures. Analogous considerations can be made for the assessment of travel distance and velocity and frequency of landslides (Table 13 and Table 14) (Cascini L.., 2008)

Method	Input / Procedure	Topography, landslide inventory, geology, geomorphology	Adding soil classification and depth, terrain units	Adding hydrogeology and geotechnics
Basic	Heuristic or empirical models	*		
Intermediate	Statistical analyses	*	*	
Sophisticated	Deterministic (physically based or geotechnical) models	*	*	*

Table 12 - Methods required for the inventory of existing landslides and characterization of potential landslides (Source: Cascini L., 2008)

Method	Input / Procedure	Historical info, topography, geology and geomorphology	Adding likely landslide mechanism and soil classification	Adding DTM and geotechnics
Basic	Heuristic or empirical models	*		
Intermediate	Empirical models or simplified analyses	*	*	
Sophisticated	Deterministic	*	*	*

Table 13 - Methods for travel distance and velocity assessment (Source: Cascini L.., 2008)

Method	Input / Procedure	Geomorphology, aerial photographs, incident data	Adding proxy data, satellite images, triggering factors, etc.	Adding geotechnics
Basic	Heuristic	*		
Intermediate	Statistical analysis	*	*	
Sophisticated	Statistical or deterministic	*	*	*

Table 14 - Activities required to assess the frequency of landslides (Source: Cascini L., 2008)

With reference to the scale of zoning maps, it can be observed that: firstly, the maps should be prepared at a scale appropriate for displaying the information needed at a particular planning level and, secondly, the input data used to produce the landslide zoning map must have the appropriate resolution and quality. On the basis of these considerations, landslide zoning scales and their applications are suggested as follows (Soeters and van Westen,1996 and Cascini et al.,2005):

- Small scale (< 1:100,000) can be used for landslide inventory and susceptibility zoning, on a typical area larger than 10,000 km2, to inform policy makers and the general public;

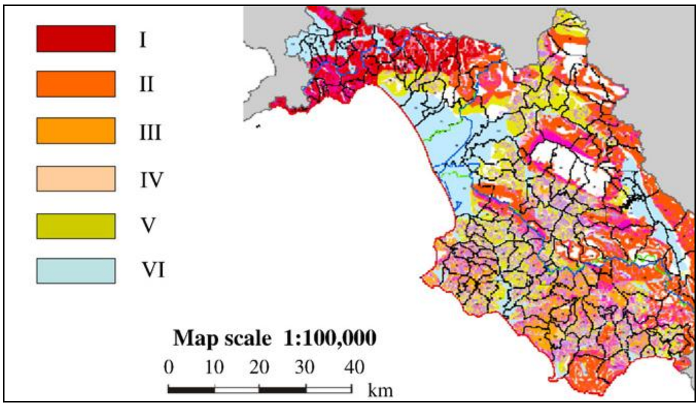


Figure 30 – Example of susceptibility zoning map at small scale (Cascini l., 2008)

- Medium scale (1:100,000 to 1:25,000) should be devoted, on an area of 1000 to 10,000 km2, to develop landslide inventory and susceptibility zoning for regional development or very large-scale engineering projects, and preliminary level hazard zoning for local areas;

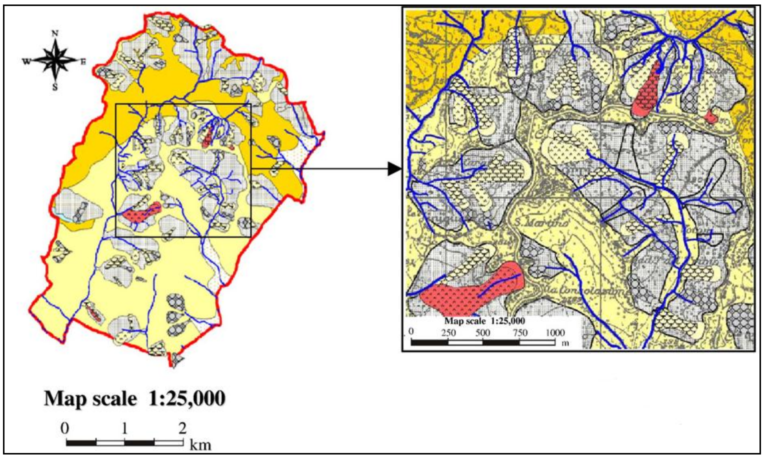


Figure 31 - Analysis of susceptibility zoning at medium scale for the area framed with the black square in the figure. (Cascini, 2008)

- Large scale (1:25,000 to 1:5000) can be directed, over an area of 10 to 1000 km2, towards landslide inventory, susceptibility and hazard zoning for local areas; intermediate to advanced level hazard zoning for regional development; and the advanced stages of planning for large engineering structures, roads, and railways;

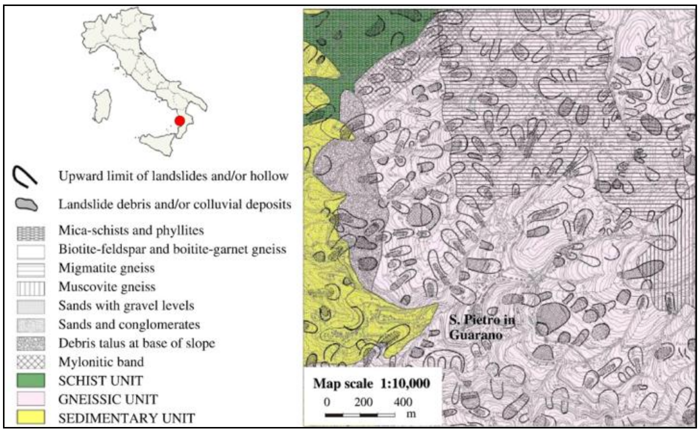


Figure 32 – Example of geological and landslide map of a sample area in the Calabria Region at large scale (Cascini, 2008)

- Detailed scale (> 1:5000) should concern, over an area of several hectares to tens of square km, intermediate and advanced hazard zoning levels for local and site specific areas and for the design phase of large engineering structures, roads and railways.

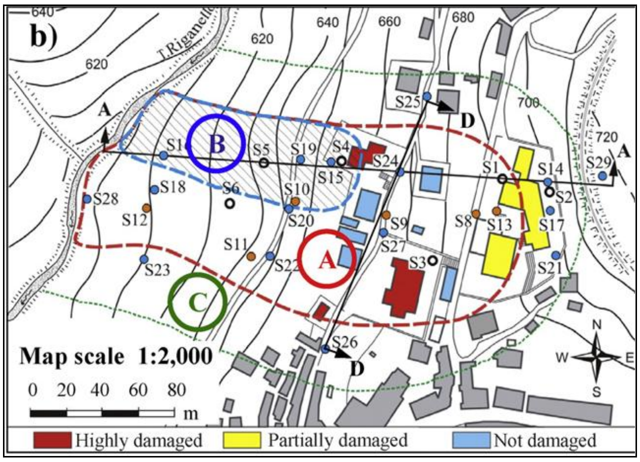


Figure 33 – Example of landslide investigation at detailed scale (Cascini L., 2008)

The types and levels of zoning and zoning map scales provided applicable suggestions to land-use planning for urban development or other uses, such as managing landslide hazard and risks for roads. At small scale, only basic methods (i.e., methods based on geological data and heuristic procedures) can be used, then only a preliminary zoning level can be pursued and obtained. At medium scale, statistical procedures can be used, so two zoning levels may be defined. At large and detailed scales, three zoning levels are possible, respectively based on basic, intermediate and sophisticated methods. However, the type of analysis, level and scale of zoning also depend on the complexity of the landslide features, the homogeneity of the terrain, the spatial variability of the important causal factors, the geotechnical parameters and the amount of available data and expertise.

The Table 15 connects each scale with the purposes of zoning (information, advisory, statutory and design) and, on the basis of previous tables, with the zoning methods, zoning levels and types of zoning. Each scale have a defined meaning and aim (Figure 34).

Scale description	Indicative range of scales	Zoning methods			Zoning levels			Types of zoning		Purpose
		Basic	Intermediate	Sophisticated	Preliminary	Intermediate	Advanced	Susceptibility	Hazard	
Small	<1:100,000	*			*			*		Regional zoning - Information
Medium	1:100,000 to 1:25,000	*	(*)		*	(*)		*	(*)	Regional zoning - Information - Advisory
Large	1:25,000 to 1:5000	*	*	*	*	*	*	*	*	Local zoning - Information - Advisory - Statutory
Detailed	>1:5000	[*]	(*)	*	[*]	(*)	*	(*)	*	Site specific zoning - Information - Advisory - Statutory - Design

Notes: * Applicable; (*) May be applicable; [*] Not recommended or not commonly used.

Table 15 - Methods, levels, and types of zoning at different scales (Source: Cascini L., 2008)

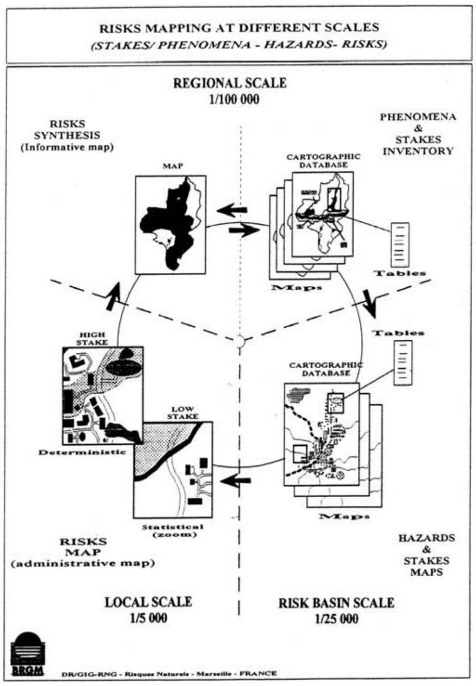


Figure 34 - Risk mapping at different scale (Source: Leroi, 1997)

Two different levels of zoning are almost constantly analyzed: at an intermediate scale (1:25,000 or smaller) and at a large scale (1:5,000 or larger). In the first level (1:25,000), the zoning must be produced using a qualitative approach that could be usefully applied even at the largest scales. On the contrary, at the second level (1:5,000 or larger, as well as at a site scale) the quantitative risk assessment (QRA) must be preferred, above all, where good and extensive knowledge is available.

At the intermediate scale (1: 25,000), landslide susceptible areas would show as input the classification, location, areal extent and, possibly, other geometric characteristics of each landslide, creeping zone and potential sliding; the activity classes of landslides; the areas onto which the potential sliding may travel with qualitative and/or quantitative information on past events. Landslides intensity should be based on simple parameters describing the destructiveness of landslides or potential sliding as, for instance, the potential post-failure velocity. Other information can be useful to improve the landslides characterization as those regarding the volume, the qualitative or the quantitative estimation of the actual rate of movement, the data set on geotechnical aspects, triggering factors. At a large scale (1: 5,000 or larger) the above elements, even if implemented in a qualitative risk procedure, must be considerably improved with quantitative data on volumes, the actual rate of movement, more advanced parameters describing the landslides intensity; moreover, advanced geotechnical, triggering factors and further data sets are necessary. If well related such maps, even those at intermediate scale, may allow mathematical and quantitative risk assessment (QRA).

The danger map can simplify the analysis of sliding frequency and the compilation of the hazard maps that must clearly indicate the likelihood of landslide magnitude (velocity and/or volume). Generally, at 1:25,000 scale, the likelihood is expressed in a qualitatively way on the basis of indicators such as, for instance, some geomorphological factors (i.e. state of activity). While, at 1:5,000 scale, the quantitative hazard estimation requires the use of advanced mathematical models such those relating, for example, the triggering factors to the landslide mobilization. With respect to consequence analysis, that is necessary to produce the risk maps, different procedures must be adopted according to the reference scale. At an intermediate scale, the analysis should be performed by appropriately selecting the reference area, the most relevant elements at risk within, and criteria for an overall qualitative estimation of the consequence. While, at a large scale, each element at risk, its vulnerability, temporal probability and criteria able to transform the individual into an aerial estimation of the consequences, taking potential development programs into account, should be considered. Finally, for risk zoning maps, risk estimation based on a well-known formula is absolutely necessary, whereas the study is carried out at either intermediate or large scale (Cascini et al., 2005).

3.3. Definition of Terms

Definitions for terms used in landslide zoning and risk management are based on IUGS (1997), with some amendments prepared by The International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee 32. These definitions have be used for all zoning, reports and land use planning documents.

Definitions of terms are (AGS, 2007a):

Acceptable Risk – A risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Annual Exceedance Probability (AEP) – The estimated probability that an event of specified magnitude will be exceeded in any year.

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Danger (Threat) – The natural phenomenon that could lead to damage, described in terms of its geometry, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a rock fall). The characterisation of a danger or threat does not include any forecasting.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability.

Hazard – A condition with the potential for causing an undesirable consequence (*the landslide*). The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the likelihood of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide inventory –An inventory of the location, classification, volume, activity and date of occurrence of landsliding

Landslide activity –The stage of development of a landslide; *pre-failure* when the slope is strained throughout but is essentially intact; failure characterized by the formation of a continuous surface of rupture; *post-failure* which includes movement from just after failure to when it essentially stops and *reactivation* when the slope slides along one or several pre-existing surfaces of rupture. Reactivation may be occasional (e.g. seasonal) or continuous (in which case the slide is "active")

Landslide Intensity – A set of spatially distributed parameters related to the destructive power of a landslide. The parameters may be described quantitatively or qualitatively and may include maximum movement velocity, total displacement, differential displacement, depth of the moving mass, peak discharge per unit width, kinetic energy per unit area.

Landslide Susceptibility – A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Likelihood – Used as a qualitative description of probability or frequency.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event.

There are two main interpretations:

- Statistical – frequency or fraction – The outcome of a repetitive experiment of some kind like flipping coins. It includes also the idea of population variability. Such a number is called an "objective" or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.
- Subjective probability (degree of belief) – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Qualitative Risk Analysis – An analysis which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur.

Quantitative Risk Analysis – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

Risk – A measure of the probability and severity of an adverse affect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard

identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (*or risk treatment*).

Societal Risk – The risk of multiple fatalities or injuries in society as a whole: one where society would have to carry the burden of a landslide causing a number of deaths, injuries, financial, environmental and other losses.

Susceptibility – see Landslide Susceptibility

Temporal-Spatial Probability – The probability that the element at risk is in the affected area at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Zoning: The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk.

4. Risk Management Phases

As previous mentioned (par. 1.3 – Risk management for natural disaster) the disaster management includes measures taken before (pre-disaster phase), after (post-disaster phase) and during (disaster phase) the event; it aims to reduce, or avoid, the potential losses from hazards, assure prompt and appropriate assistance to victims of disaster, and achieve rapid and effective recovery.

A disaster management includes phases of prediction, the initiation and planning which are required for the predication phase. After onset of disaster occurrence, executing involves warning, emergency relief, rehabilitation, and reconstruction (Figure 35). The activities conducted in the disaster project management cover scope of prediction, warning, emergency relief, rehabilitation, and reconstruction (Moe T..L. and Pathranarakul P., 2006).

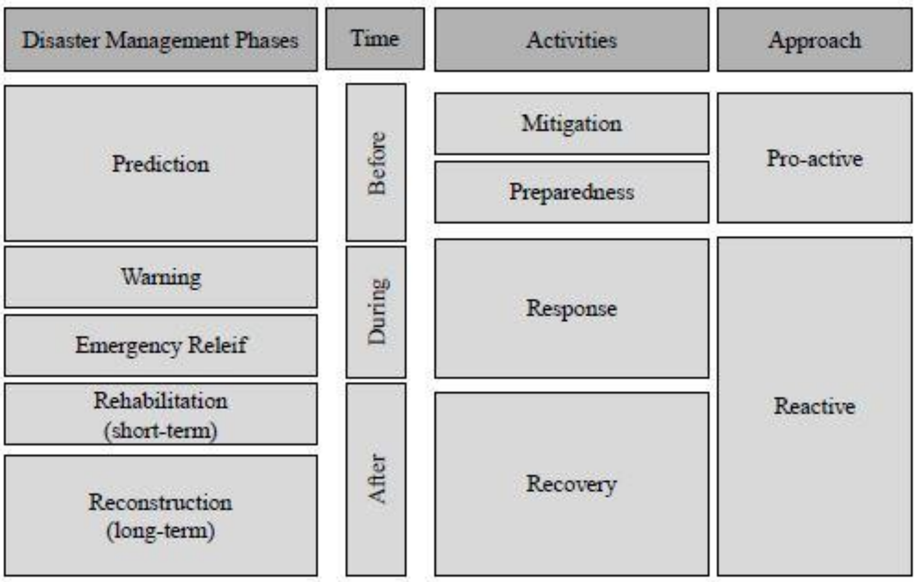


Figure 35 - Activities carried out in the disaster project management (Moe T..L. and Pathranarakul P., 2006)

This chapter considers several aspects of landslide risk assessment, it describes the essential methods can be used in the disaster/risk phases and discussed their applicability in order to forecast and to mitigate the landslide disasters. Reference has been made to the human fatalities as well as the enormous economic consequences of landslides every year. Although landslide-related damage appears to be more extensive in industrialised countries (United States, Japan, Italy, France, etc.), in view of the increasing pressure on the environment, in developing countries it could even lead to economic recession and stagnation. Experts and planners all over the world are therefore becoming increasingly aware of the importance of predicting where, how and why landslides will occur in a given area and numerous approaches to landslide hazard/risk assessment have been developed in recent years.

4.1. Basic concepts and input data

As a basis, there are four fundamental assumptions (Hutchinson, 1995):

- landslides will always occur in the same geological, geomorphological, hydrogeological and climatic conditions as in the past;
- the main conditions that cause movements are controlled by identifiable physical factors;

- the degree of hazard can be evaluated;
- all types of slope failures can be identified and classified.

However, there are some difficulties given by the causes identification, the triggering factors and the cause-effect relationships and by the discontinuous nature (in space and time) of slope failures. While, is an obstacle to the lack of historical data concerning the frequency of geomorphologic process.

Moreover, the work-scale to be adopted for mapping, investigation and assessment of hazard is chosen on the basis of three factors:

- the purpose of the assessment. In land use, for example, planning on a regional scale could be adopted (1 : 100.000–1 : 500.000), whereas for more specific problems such as the implementation of large engineering structures or the definition of a plane of priority measures, the scale should be more detailed (medium scale: 1: 25.000–1 : 50.000). Frequently, these analyses are preliminary to more specific studies to be conducted on perhaps a single slope or small areas where an even larger scale would be appropriate.
- The extent of the studied area.
- Data availability.

For large areas, hazard assessment may be based on the analysis and interpretation of available data, while for smaller areas the assessment of stability and hazard could be facilitated by specific geotechnical investigations. The choice of the work-scale affects the selection of the approach: thus, a statistical approach may not be suitable for studies concerning individual slopes or small areas while a geotechnical engineering approach based on the calculations of safety factor and/or associated failure probability, would not be suitable at the regional scale.

Specific facts and generalised information are required for many components of hazard assessment and risk management of slopes and landslides. These include: the assessment of performance over time, the consequences of failure including environmental impacts and economic aspects.

There are essential pre-requisites to the development or application of any method of hazard assessment. These include an understanding of geology, hydrogeology and geomorphology from available maps, reports and field surveys, preliminary geological and geotechnical investigation, access to historical information on land sliding, rainfall records and historical seismicity. Information on the extent of success or failure of any hazard assessment and management strategies previously undertaken will also prove to be useful. In the use of a method of landslide hazard assessment it is of fundamental importance to identify the causes of potential instability and landslides. Indeed, by determining the factors that have caused landslides in the past it may be possible to forecast where and when future events could occur.

Furthermore, the collection of useful data play an important rule for the assessment through an appropriate cost/benefit analysis. The risk financing includes economic values about loss for public infrastructure and private assets, and also for investments into national and local calamity funds. The strategy consists in arranging the financing of risk prior to actual events so that in case of an event, sufficient financing will come forward. Risk financing and mitigation measures are closely linked: Incentives for mitigation are directly related to insurance and reinsurance schemes and premiums and the perception of being bailed out post-disaster by the government.

4.2. Pre-Event phase

In the pre-disaster phase, the activities are chosen in order to reduce human and property losses caused by a potential hazard, these are mitigation activity, mean identification and reduction of the consequences/effects, and preparedness activity, to plan actions in order to respond at the events. For example, carrying out awareness campaigns, strengthening the existing weak structures, preparation of the disaster management plans at household and community level, etc.

Developmental considerations play a key role in contributing to the mitigation and preparation of a community to effectively confront a disaster. This includes structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards and non-structural measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and temporary evacuation of people and property from threatened locations.

Essential activities include:

- data management: collection, storage and accuracy;
- landslide models: analysis of sliding frequency, risk zoning parameters;
- delineation of mitigation and monitoring plans.

4.2.1. Data collection and selection

The *first step* in every assessment consists of collecting all available information and data on the study area. The importance of accurate collection and storage of information in the database is widely acknowledged, but this is undoubtedly one of the most burdensome operations in the task of hazard assessment, regardless of the particular approach that is being adopted and the extent of the study area (Aleotti P. and Chowdhury R., 1999). Some researchers estimate that the cost of data collection and management accounts for 70–80% of the total cost, including review and updating (Leroi 1996).

The selection of data that could or should be utilised for the assessment of a given area depends essentially on:

- the size of the study area
- the work-scale
- the technique adopted and
- the type of landslide.

Useful in the achievement of the objective is the use of Geographical Information Systems (GIS). Two fundamental rules must be observed when creating a database (Leroi 1996):

- the information must be homogeneous, i.e. it must have the same work-scale and the same geographic projection system;
- the database must be organised into basic monothematic layers, each of which contains homogeneous data.

In addition, a database should include at least the following basic information:

- a census of existing landslides including their nature, size, location and history;
- a reliable site reference code;
- any available information from previous site investigations (aerial photo interpretation, laboratory testing, field analyses including back analyses of failures);
- any remedial or preventive measures installed and their effectiveness;
- data from any installed instrumentation (inclinometers, piezometers).

The reliability and accuracy of data during collection and storage is very important, its reliability and accuracy should subsequently be reviewed from time to time. Moreover, additional information often becomes available with the discovery of new historical sources or as a result of additional investigations. For example, data on frequency and spatial distribution of past land sliding must always remain open to revision. The occurrence of new instabilities or the reactivation of old landslides may provide detailed information on the failure mechanisms or further details of the relationship between rainfall and landsliding may become available.

The target or desirable level of detail and reliability concerning all information (geological details, geotechnical parameters and pore water pressures) will be determined not only by the purpose and importance of the project but also by the availability of the financial and other resources to carry out the relevant tasks.

4.2.2. Landslide models

This activity is focused on the evaluation of sliding models, based on historical data and also on new acquisitions, in order to define an appropriate mitigation or monitoring preparedness plan.

As mentioned in the previous chapter, the methods of model assessment can be qualitative or quantitative. Generally, qualitative approaches are based entirely on the judgement of the person or persons carrying out the susceptibility or hazard assessment. The input data are derived from assessment during field visits, possibly supported by aerial photo interpretation. These methodologies, can be divided into two types: field geomorphological analysis and the combination or overlaying of index maps with or without weighting. The geomorphological map, supplemented by additional data, provides all the information needed to define the conditions of stability or the degree of instability in a given area. In the quantitative/index approach, base or index maps are overlain and suitably weighted and the area is divided into homogeneous zones. The attribution of weighted values on a subjective basis to the numerous factors that govern slope stability represents the main limitation in all the methods described above.

Subsequently, is introduced the statistical approach. This technique is used to evaluate the influence of each contributory factor in producing instability. The statistical approach is defined as a direct comparison technique based on the relationship between various fundamental maps (usually lithology and slope inclination) with landslide distribution maps. The major difficulty consists in establishing the slope failure processes and in systematically identifying and assessing the different factors related to landsliding. One of the principal advantages is that the investigator can validate the importance of each factor and decide on the final input maps in an interactive manner.

Some conceptual differences can be recognized in the distinction between inductive, deductive and geotechnical approaches. The difference between inductive and deductive methods appears that with the deductive approach the selection of parameters and the choice of their relative weighting is determined empirically (post-event), whilst in the deductive approaches such determinations are made on the basis of experience and intuition (pre-event). The geotechnical approach involves analysing specific sites or slopes in engineering terms. The main physical properties are quantified and applied to specific mathematical models and the safety factor is calculated. Moreover, decisions must be made on whether to use peak shear strength values or residual shear strength values (or values in between) for specific parts of the slip surface (Aleotti and Chowdhury, 1999). For these reasons such methods are normally applied only in small areas and at detailed scales.

Generally, in this step, the use of G.I.S. makes these operations much easier and facilitates the simulation of multiple scenarios based on variable factor hypotheses (usually the triggering factors), as well as the construction of reliable hazard maps.

In the phase of sliding models is important the evaluation of essential features: landslides frequency and intensity, identification of susceptible areas, and elements at risk.

The *landslide susceptible areas* are sectors prone to slope failure or that a landslide may travel onto or regress into it. These areas show as input: rate of movements, area into which the slide may and landslide inventory (location, classification, areal extent and volume, creeping zone, state of activity). First of all is the detection of the area where first-failure phenomenon or landslide reactivation can occur, then there is a landslide classification, areal extent (obtained by aerial photo interpretation) and volume estimated (on the basis of in-situ investigations).

It is difficult to standardise descriptions of landslide susceptibility because (AGS, 2007):

- Whether the geological, topographical, geotechnical and climatic conditions are judged to be conducive to landsliding is often subjective and not readily quantified.

- Different descriptors are required for the different types of landslides, e.g. the proportion of the area which may be affected by the landsliding for small scale landslides; the number of landslides/ square km for small landslides; the number of rock falls per kilometre length of cliff etc.
- The difficulty of assessing whether if landsliding occurs, it will travel on to slopes below or retrogress up-slope and the likelihood that a particular area will be affected by the landslide.
- The time frame in which landslides have occurred is not included (it is in hazard).

In some situations it may be sufficient to simply use two susceptibility descriptors; “susceptible” and “not susceptible”. In general however there will be value in conveying to users of the maps the degrees of susceptibility either in quantified or relative terms.

The Table 16 gives examples of susceptibility descriptors for some more common scenarios.

Susceptibility Descriptors	**Rock Falls**	**Small Landslides on Natural Slopes**	**Large Landslides on Natural Slopes**
(a) Quantified susceptibility descriptors			
	Probability rock falls will reach the area given rock falls occur from a cliff (1)	Proportion of area in which small landslides may occur (2)	Proportion of area in which large landslides may occur (2) (3)
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.25 to 0.5	>0.25 to 0.5	>0.25 to 0.5
Low susceptibility	>0.01 to 0.25	>0.01 to 0.25	>0.01 to 0.25
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01
(b) Relative susceptibility descriptors			
Susceptibility Descriptors	**Rock Falls**	**Small Landslides on Natural Slopes**	**Large Landslides on Natural Slopes**
	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.	The proportion of the total landslide population in the study area.
High susceptibility	>0.5	>0.5	>0.5
Moderate Susceptibility	>0.1 to 0.5	>0.1 to 0.5	>0.1 to 0.5
Low susceptibility	>0.01 to 0.1	>0.01 to 0.1	>0.01 to 0.1
Very low susceptibility	0 to 0.01	0 to 0.01	0 to 0.01

Notes

(1) Spatial probability determined from historic, relative stability indexes, data or analysis taking consideration of the uncertainty in travel distance.

(2) Based on landslide inventory, geology, topography and geomorphology.

(3) Usually this is active, dormant and potentially reactivated slides, not first time slides.

(4) By “small” landslides is meant here landslides which are less than about 1000 m^3 volume.

Table 16 - Examples of landslide susceptibility mapping descriptors (Source: AGS, 2007)

Rock fall susceptibility may also be described in terms of the density of scars on a rock slope from which falls have occurred or the number of rocks which have fallen from a slope. For small shallow landslides the susceptibility may also be expressed as the number of slides per square km.

Landslide susceptibility involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding. The Table 17 lists the activities required to characterise, determine the spatial distribution of potential landslides and their relationship to topography, geology and geomorphology. It should be noted that there is a direct relationship between the scale of zoning maps and the level of landslide characterisation, with larger scale zoning maps being required at the intermediate and sophisticated levels. Table 18 lists the activities required to assess the travel distance and velocity of potential landslides.

Moreover, it is an essential part of evaluation the preparation of a landslide inventory. It involves the location, classification, volume, travel distance and state of activity and date of occurrence of landsliding in an area. Table 19 lists the activities which will typically be required at the basic, intermediate and sophisticated level.

Characterisation Method	Activities
Basic	Prepare a geomorphologic map. (1)
	Prepare a landslide inventory as described in Table 8. (1)
	Prepare calculations of the % of the total landslide count for each susceptibility class, the % of the area affected by landslides for each class and the % of each class in comparison to the total study area and classify according to Table 4.
	Correlate the incidence of landsliding with the geology and slope to delineate areas susceptible to landsliding.
	For regional zoning correlate the incidence of landsliding with annual rainfall or snowmelt, and/or seismic loading.
	Prepare the landslide susceptibility zoning map superimposed on the topography with a suitable legend.
	Implement the data and the maps in a GIS (recommended).
Intermediate	**The same activities as basic plus**
	Obtain basic soil classifications and depths in the study area.
	Classify more complex terrain units. Qualitative rating of the landslide susceptible areas based on overlapping techniques.
	Develop quantitative ratings (often relative rating) of landslide susceptible areas based on data treatment techniques.
	Implement the data and the maps in a GIS (recommended).
Sophisticated	**The same activities as Intermediate plus**
	Detailed mapping and geotechnical investigations to develop an understanding of the mechanics of landsliding, hydrogeology and stability analyses.
	Perform data treatment analysis (discriminate; neural networks; fuzzy logic; logistic regression; etc) and develop quantitative ratings to obtain susceptibility classes.
	Perform stability analyses.
	Implement the data and the maps in a GIS (recommended).

Note. (1) The landslide inventory and geomorphologic mapping should be carried out at intermediate and sophisticated levels for intermediate and sophisticated level susceptibility zoning.

Table 17 - activities required to characterise, determine the spatial distribution of potential landslides and their relationship to topography, geology and geomorphology (Source: AGS, 2007).

Travel Distance and Velocity Analysis method	Activities
Basic	Collect and assess historical information on travel distances and velocity.
	Assess limiting travel distances from geomorphologic data and old landslide deposits.
	Assess the likely travel distance and velocity from consideration of the classification of the potential landslides, geology and topography and empirical methods.
	Based on this information assess the limit (greatest) likely travel distance for each classification of potential landslide.
Intermediate	**The same activities as Basic plus**
	Assess likely landslide mechanisms and classification of soils in the landslides.
	Use empirical methods based on travel distance angle or shadow angle to assess travel distance accounting for the uncertainty in the empirical methods and data inputs.
	Assess velocity from potential energy and travel distance using simple sliding block models.
Sophisticated	**The same activities as Intermediate plus**
	Investigate geotechnical properties of the sliding materials as required by numerical models.
	Use numerical models to model travel distance and velocity.

Table 18 - Activities required for assessing the travel distance and velocity of potential landslides (Source: AGS, 2007)

Characterisation Method	Activities
Basic	Prepare an inventory of landslides in the area from aerial photographs and /or satellite imagery, and by mapping and from historic records. The inventory includes the location, classification, volume (or area) and so far as practicable the date of occurrence of landsliding.
	Identify the relationship to topography, geology and geomorphology.
	Show this information on inventory maps along with topographic information including contours, property boundaries, mapping grid, roads and other important features such as streams and water-courses.
Intermediate	**The same activities as Basic plus**
	Distinguish different parts of the landslides.
	Map landslide features and boundaries.
	Collect and assess historical information on the activity of landsliding.
	Analyse the past evolution of the land use to know whether human activities have had an influence on the incidence of landslides.
	Increased time and resources in the research phase of the inventory compilation resulting in more rigorous and extended coverage
Sophisticated	**The same activities as Intermediate plus**
	Prepare an inventory of geotechnical data.
	Implement investigations to better define geotechnical conditions.
	Geotechnical analysis to understand slope instability processes.
	Advanced temporal cataloguing of periodic reactivations of the same hazard and temporal windowing of specific triggering events to provide periodic inventory data sets which can then be used in advanced validation approaches.

Table 19 - Activities required to preparing a landslide inventory (Source: AGS, 2007).

The *landslide intensity* may be assessed as the spatial distribution of:

- The velocity of sliding coupled with slide volume or
- The kinetic energy of the landslide; e.g. rock falls, rock avalanches or
- Total displacement or
- Differential displacement or
- Peak discharge per unit width (m 3 /m/second), e.g. for debris flows.

For basic and intermediate level assessments of intensity only velocity and volume might be assessed. For advanced assessments of rock fall and debris flow hazard the energy might be assessed.

Approaches for intensity assessment are historical info, geology and topography (qualitative methods, assess the relative intensity from the estimated landslide volume and the expected landslide velocity), simple models (estimate expected or observing landslide velocities) or numerical models (calculate the kinetic energy(velocity) by means of numerical models).

The *frequency* is expressed as probability of occurrence or by return period based on hazard acceptability criteria. Frequency of land sliding can be determined from historical data, relation to triggering event frequencies (i.e. rainfall, earthquake) with known annual exceedence probabilities, or relating the indicators or revealing factors of slope stability conditions (i.e. water content, groundwater and/or pore pressure regime) to triggering factors (rainfall) (Table 20 and Table 21).

Frequency Assessment Method	Activities
Basic	Frequency established based on the relative freshness of the morphological features of the scars and landside deposits taking into account the presence of active geomorphic events (e.g. slope undermining by either river or sea erosion).
	Frequency established based on interpretation of numbers of landslides from aerial photographs taken at known time intervals.
	Assess the historic frequency of rock falls, slides from cuts, fills and retaining walls, or small landslides on natural slopes from basic landslide inventories.
	As above and relate to the basic level of frequency of triggering events such as daily rainfall or seismic events.
Intermediate	**The same activities as Basic plus**
	Relate to slope characteristics such as topography (slope angle, elevation, aspect), geology, geomorphology using multi-variate analyses.
	Assess the historic frequency of rock falls, slides from cuts, fills and retaining walls, or small landslides on natural slopes from landslide inventories. Where appropriate, develop and use frequency volume curves.
	Use proxy data such as silent witnesses (e.g. damage to trees and dendrochronology).
	More detailed analysis of rainfall including the effects of antecedent rainfall, rainfall intensity and duration on the incidence of individual landslides (the threshold) or large numbers of landslides.
	For seismically induced landsliding, relate the incidence of sliding to seismic loading including the peak ground acceleration and magnitude of the earthquake using empirical methods.
Sophisticated	**The same activities as Intermediate plus**
	Assess geotechnical parameters of the soils. Model slope factors of safety from geotechnical parameters and rainfall frequency or piezometric data.
	For seismically-induced landslides, analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

Table 20 - Activities required for assessing the frequency of rock falls, slides from cuts, fills and retaining walls and small landslides on natural slopes (Source: AGS, 2007)

Frequency Assessment Method	Activities
Basic	Assess the historic frequency of landsliding from the landslide inventoy including activity indicators such as cracked buildings, displaced fences, bent and tilted trees.
	Assess frequency from geomorphology evidence such as the freshness of slide scarps and other surface features associated with landslide movement using subjective assessment.
Intermediate	**The same activities as Basic plus**
	As above, and use of proxy data such as carbon 14 dating, lichenometry dating, of vegetation buried by sliding, or in raised alluvial terraces in valleys which may have been blocked by landsliding.
	Relate history of landsliding to rainfall intensity and duration and antecedent rainfall or to snow melt.
	Assess the likelihood of seismically-induced sliding from consideration of the mechanics of the landslide. Use empirical and simplified methods to assess likely displacements during earthquakes.
	As an alternative to estimating from historic data, assess frequency by subjective assessment, e.g. by assessing the probability of landsliding given a rainfall or seismic load.
Sophisticated	**The same activities as Intermediate plus**
	As above and relating the history of landsliding or factor of safety to rainfall, slope geometry, piezometric levels (where available), geotechnical properties and factors of safety.
	For seismically-induced landsliding analyse displacements using 'Newmark' type analyses and for liquefiable soils, the likelihood of liquefaction and flow sliding.

Table 21 - Activities required for assessing the frequency of landsliding for large landslides on natural slopes (Source: AGS, 2007)

The *elements at risk* include the persons (country house/few persons, village/ten of persons, city/hundreds of persons) and property (private buildings, public buildings, historical buildings) potentially affected by landsliding on, below and up-slope of the potential landslides. They may include indirect impacts such as reduced economic activity resulting from the landslide. Table 22 lists the activities required to do this. The vulnerability of the elements at risk depends on both the typology of the element and on the intensity of the landslide interacting with it. The vulnerability can be physical, economic, environmental and social, the corresponding exposed elements are structures and infrastructures, population, natural environment and economic activities.

Finally, the consequence scenario is defined, based on different approaches (qualitative, quantitative), on experience and on scenario components. It is available and important that appropriate failure mechanisms are identified and that geotechnical models are selected which correspond as closely as possible to these mechanisms.

Assuming sufficient information on geotechnical parameters, it is possible to simulate the risk scenarios and evaluate an proper damage losses, using index maps. It is also important to consider the selection of the final performance. In many instances, probabilities of failure or non-performance may have to be based on different criteria. For example, there are many applications, such as high speed railways through hilly areas, in which deformations must be kept low. Satisfactory performance in such cases should be specified in terms of lateral and vertical slope deformations below a tolerable limit, a sloping area may nevertheless have a high hazard because of deformation levels which constitute non-performance or failure in terms of that particular application. For a road or highway embankment, the same deformation levels may not constitute a high or even a moderate hazard. Then categories of hazard would correspond to different categories of estimated deformation, the performance function would be formulated in terms of the permanent deformation of a sliding block subjected to a particular ground motion. Based on that performance function, values of the probability of failure, possible scenarios and risk damage are then be calculated.

Method for Assessing Elements at Risk	Activity
Basic	Make an assessment of the population who live, work and travel through the area; property such as houses, buildings, roads, railways and services which are permanently in the area and of property such as vehicles which travel through the area. For existing development base this on the current and proposed land use. For new development estimate from proposed land use and occupancy. Where applicable assess environmental values which may be affected by landsliding.
	Generic classifications based on the main land uses, namely urban, industrial, infrastructure, or agricultural.
Intermediate	As above in greater degree of detail. Economic consequences may be included.
Detailed	As above in detail. Economic consequences will be estimated such as the implications of loss of a road providing access to a town until repairs are carried out.

Table 22 - Activities required for assessing the elements at risk (Source: AGS, 2007)

4.2.3. Monitoring plans

At the end of the previous procedure, the scenarios must be selected and priorities have to be individuated (Fell et al. 2005). The decisions can be made easier by hazard and risk zoning which can direct the urban planning and development, the emergency plans and the monitoring planning.

Concerning the mitigation for urban planning, the most common practice includes the delimitation of zones in which building is either prohibited or restricted to some types of constructions with a low occupation level. The main problem is not the elaboration of local plans, but the long-term applicability of such plans. For instance, in the capital of Honduras, Tegucigalpa, the planning documents elaborated in the seventies excluded any construction on the zone of Berrinche landslide on the left bank of Comayagua River; but after several decades of non-respect of these prescriptions, hundreds of houses built at its toe were destroyed by the sudden reactivation of the slide following Hurricane Mitch (Cascini et al, 2005). Another situation in developing countries may occur when marginal housing is suddenly expanding outside of the planned building areas, even despite of the existence of strict limitations or regulations, and implies a high risk situation due to uncontrolled debris flow hazard.

Therefore, emergency plans and remedial measures must be strongly implemented to limit the consequence of landslides.

Concerning the monitoring systems, at small and large scale, by both the present technology and the mathematical modeling, few considerations are necessary as it concerns: the problem to be faced; the best approach to be used; the test to be systematically carried out in order to improve the confidence on systems devoted to the population safeguard.

Monitoring systems are record several elements: the triggering factors (rainfall, earthquake, anthropogenic factors), the indicators or revealing factors of slope stability conditions (water content, groundwater, pore pressure regime, etc.) and the effect caused by the triggering factors (soil and/or element at risk displacements). Such elements can be qualitatively and/or quantitatively measured and can be or not related to other elements included in the same or other classes. The selected option strictly depends on the size of the study area, the landslide typology and the available instrumentation. Moreover, all procedures, especially those based on an advanced technology and/or modelling, must be systematically tested in sample areas.

At large scale (1:5,000 or higher), monitoring systems can be based on instruments, techniques and interpretative procedures that can notably improve the landslide risk mitigation. In this case, remote sensing begins to furnish significant features in order to confine, inside a large area, zones where an emergency will probably occur. The reduction in area extent allows measurements of physical quantities, at local and site scale, as well as the use of well-known and powerful engineering models to correlate the experimental data. Such models can be used to define alert threshold which can be based, for a certain landslide typology, on displacement rate, groundwater change, rainfall characteristic and so on.

A growing attention is worthy to be put on the use of SAR (Curlander & McDonough 1991) interferometry to measure the superficial displacements, using two interferograms at different time periods (DInSAR) (Van Westen 2004). However, at the present, the application of DInSAR is restricted to the monitoring of a single landslide phenomenon, and such techniques have been utilized to measure ground displacements characterized by a prevailing vertical component (e.g. subsidence phenomena).

An example of monitoring/mitigation system, is the study of rock cliffs hazard analysis based on remote geostructural surveys, in the area Campione del Garda (Lake Garda, Northern Italy) (Ferrero et al., 2011). The Campione del Garda coastal cliff area is subject to frequently rock fall phenomena, this needs to be mitigated by defensive and reinforcing methods for protection of the inhabitants and the structures (Figure 36). The design of the mitigation interventions must be based on the area's risk zonation in order to identify the optimum systems and locations. In this study, the assessment is based on kinematic analysis on rock-mass structure in order to compute the probability of block detections on the slopes. This analysis was conducted by applying the key block method, which allows identification of the types of possible instability and evaluation of the block volumes. Moreover, a block-path probabilistic analysis was then performed on several potentially hazardous sections and a two dimensional analysis was made using the CRSP method.

Several mitigation systems have been examined in order to reduce the hazard zones on the basis of the accomplished results. The following several measures have been proposed: artificial gallery accessing road protections, walls to avoid access to high hazard areas, removal of unstable blocks and monitoring of possible zones of unstable slopes. Designs of these various measures could be based upon the quoted lumped mass analysis in terms of impact energy to be absorbed (for the gallery and the walls) and for the definition of the structural dimensions (e.g., the gallery lengths) (Ferrero et al., 2011). Moreover, a new hazard zonation was completed in consideration of the proposed mitigation measures for quantifying the final hazard potential for the coastal cliff. Therefore, during the geomechanical survey of the cliffs overlooking the town of Campione del Garda, a few potentially unstable blocks of considerable dimensions were observed. These blocks are beyond the scope of this study, as their fall would most probably trigger a wider rockslide. Owing to the dimensions of those blocks, any passive defensive system would not be economically practicable. Nevertheless, monitoring the stability of such blocks should be considered absolutely essential for the safety and protection of the Campione del Garda inhabitants and structures (Figure 37) (Ferrero et al., 2011).

Figure 36 - View of the Campione del Garda inhabited shore on the western coast of Lake Garda (Northern Italy) (Source: Ferrero et al., 2011).

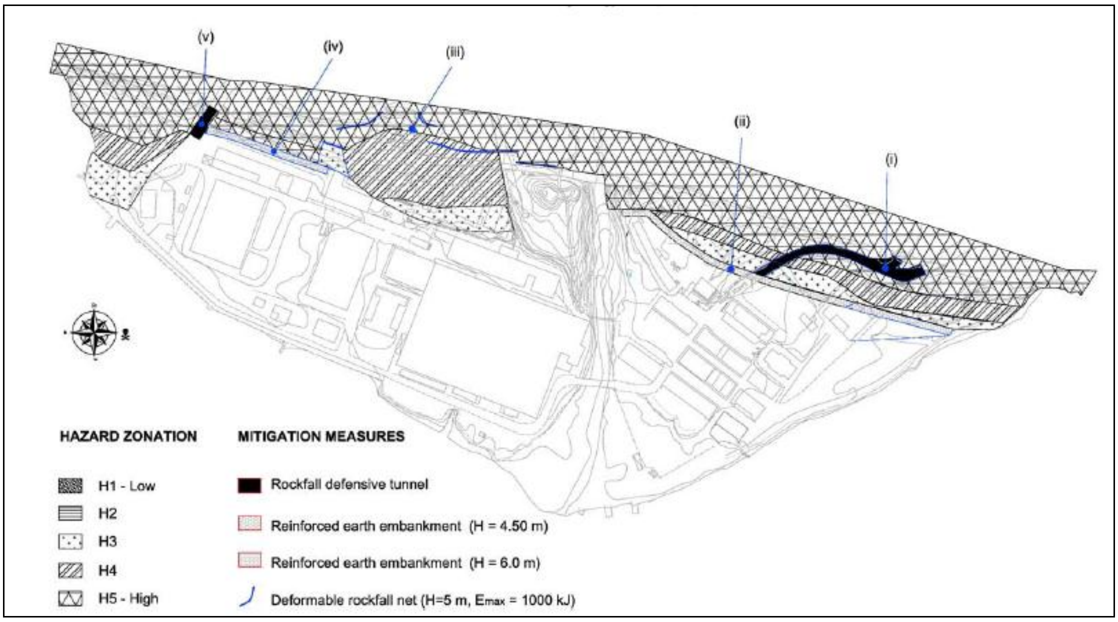


Figure 37 - Final hazard zonation map and indication of remedial works: (i) Gardesana tunnel exit; (ii) earth embankment with height of 4.5 m; (iii) deformable rockfall net; (iv) earth embankment with height of 6.0 m; (v) Gardesana tunnel entrance(Source: Ferrero et al., 2011).

4.3. Event phase

During events, the activity is focused on rescue and relief efforts, the main actions are humanitarian assistance, temporary repair and restoration of service, damage assessment and mobilization for financial resources. The event phase is known as the response activity and can be further elaborated by:

- Warning. This phase refers to the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid or reduce their risk and prepare effective response.
- Emergency relief. The provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. It can be of immediate, short-term, or protracted duration.

Essential activities during the event include:

- emergency response mapping: quickly, to recognize affected areas, to locate and to identify necessary objects (sensitive targets, points of interest, roads, ecc) ;
- Plan action to mitigate the problem and route rescue, distribution of food/medicines to the affected areas;
- Assessment of damages and temporary repair/restoration of service.

In this study, the focus is on the first activity: the emergency rapid mapping.

4.3.1. Emergency Rapid mapping

Emergency response is generally understood as supporting the organized intervention of civil security entities after a catastrophic event either caused by a natural disaster or resulting from human conflict. These emergency responses need to be intelligent and also more customized to the individual sites to manage the emergency situations more efficiently. Moreover, effective counter-measures in such situations will be established only if more accurate and prompt spatial information about the changing areas due to the emergency are available.

Geospatial processing activities in support of emergency response range from the provision of relevant archived map products to dedicated data processing to provide thematic inputs into the different phases of emergency response, e.g., situation assessment, logistical planning, detailed damage assessment and post-disaster reconstruction. Emergency response actions tend to be localized (local or regional scales), thematically specific (classification of individual urban structures, rather than generic land use classes), and have stringent timing requirements for the delivery of the data layers.

A typical sequence of geospatial support activities for emergency response is as follows.

- In the prealert stage, early warning indicators may trigger the search for suitable archive earth observation (EO) data that could be used to establish the pre-event reference situation. This stage is relevant only for events of a probabilistic nature for which adequate early warning mechanisms are in place (tropical cyclones, forest fire risk, and flood forecasts).
- Directly after the event, it is important an immediate access to digital repositories of appropriate EO imagery and geospatial feature data at the required scale and accuracy to establish the reference situation. Data layers derived from these data sets need to be specific to the thematic needs of the response effort (i.e., populated area delineation, infrastructure mapping, vicinity analysis). At this stage, the ability to assemble the contributions from a large number of source is paramount. Concurrently, it is recognized as a needed ingredient in the construction of a value-added information service in support to decision makers during emergencies operations to have available collection of consistent reference geospatial raster and vector datasets, or base cartographic content (transportations, surface hydrology, boundaries, ecc). In this frame, reference data are the “minimum spatial datasets” which assure and support valuable geographic analyses and mapping.

- Directly after the event, high-resolution (airborne or satellite) imagery is tasked to be acquired over the event site. The primary use of this data is for the assessment of the post-event situation compared to the reference situation. At this stage, early post-event collateral information may become available, e.g., the exact impact area, logistics of the relief effort and media reports, that will help guide the geospatial analysis effort.
- After the initial geospatial analysis results are disseminated to emergency response actors, new queries may be formulated that require the data layers to be revisited or the geospatial analysis to be fine-tuned. Depending on the nature of the event, several situation updates may be necessary (e.g., forest fires, extended conflicts). In certain cases, the emergency response may be followed by a reconciliation stage, (reconstruction) where by progress reporting may be supported with further geospatial analysis.

The common requirements at all stages of the emergency response cycle are (Brunner et al., 2009):

- the collation of data resources from different archives and acquisition capabilities,
- the need for customized rapid visualization for each of the actors in the emergency response community,
- the need to communicate, in near real-time, requests for geospatial processing, organize collaborative efforts, and inform decision makers with tailored output.

The aim is to provide timely and accurate information derived from different satellite images sensor data and other geospatial raster and vector data sources. The type of products can be classified in: reference/pre-event maps and post-event maps.

The *reference map* provides knowledge on the territory and assets prior to the emergency. The content consists in topographic features on the area affected by the disaster, in particular information that can assist the rescuers in their specific crisis management tasks. The base layers usually presented in the map are transport networks and related infrastructure (e.g. roads, tracks, trails, railways, bridges, harbours, and airfields), hydrology (rivers, lakes, reservoirs and open water) toponyms, administrative boundaries and settlements. Usually, the reference map is based on pre-event image (Figure 38).

Post-event map provides an assessment of the event impact and extent. they are directly derived from satellite images acquired after the emergency event (optical or radar) or are based on aerial images (optical or radar). Delineation maps include the event type, the impact extent and, when relevant, impact severity grading. Therefore, these maps provide an assessment of the damage grade (extent, type and damage grades specific to the event and eventually of its evolution). They may also provide relevant information that is specific to critical infrastructures, transport systems, aid and reconstruction logistics, government and community buildings, hazard exposure, displaced population, etc.(Figure 39)

Particularly, concerning the landslides, the optimum is the use of optical data that allows the visual identification of the affected areas through a pre-post event comparison. Emergency products are generally derived by visual interpretation of very high resolution images. The best possible data are optical multispectral, very high resolution; the sub-optimum is SAR, very high resolution, the use of SAR data is reasonable if a pre event image is available for interferometric analysis. The main final outputs are defined by landslides delineation, extraction of damage assessment information (infrastructure and population) and trafficability analysis. The identification of the damaged areas allow to identified the safe zone possibly voted to be gathering areas.

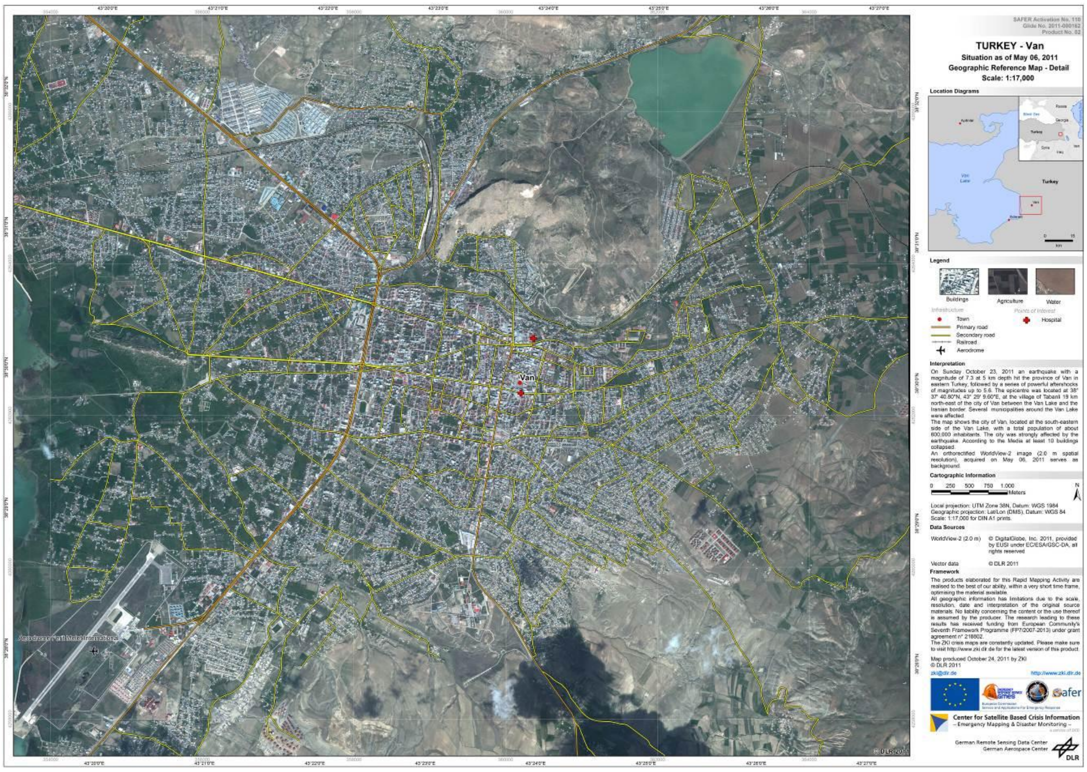


Figure 38 – Example of reference map (Source: Safer www.emergencyresponse.eu/ Earthquake in Turkey, 23 October 2011)

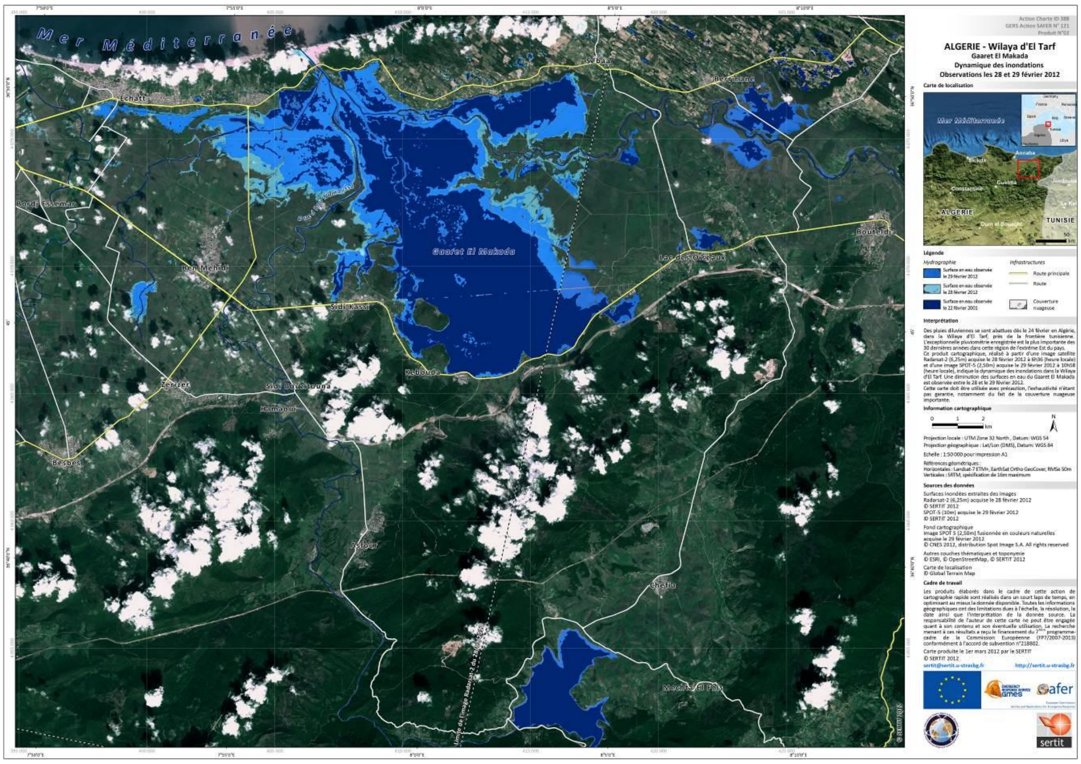


Figure 39 – Example of post disaster map (Source: Safer www.emergencyresponse.eu/ Floods in Algeria 26 February 2012)

Detailed surveys in areas of greatest damage or uncertainty about the extent of the losses are possible using vehicles equipped with video cameras and integrated GPS (Mobile Mapping System). They allow rapid collection of data to allow accurate assessment of conditions on the ground. Moreover, traditional techniques of geo-referencing aerial photography, ground profiling radar, or Lidar are prohibitively expensive, particularly in inaccessible areas, or where the type of data collected makes interpretation of individual features difficult. Image direct georeferencing, simplifies the mapping control for large scale mapping tasks. Mobile mapping is the process of collecting geospatial data from a mobile vehicle, typically fitted with a range of photographic, radar, laser, LiDAR or any number of remote sensing systems. Such systems are composed of an integrated array of time synchronised navigation sensors and imaging sensors mounted on a mobile platform. Objects can be measured and mapped from images that are directly georeferenced by the navigation and positioning sensors. The main aim of the Mobile mapping system is the acquisition of geographical data, these can be movies and/or single georeferenced frames. The primary output from such systems include GIS data, digital maps.

A typical mobile mapping system consists of four components: position/navigation module; imaging/ranging module; system control module; data processing/feature extraction module. The modules can be integrated together to create a multi-task system for handling various concurrent operations in real-time and/or post-processing mode as well as for providing automatic acquisition of directly georeferenced ditigital data for mapping and geospatial data collection. Generally, multiple digital camera are mounted on the top of the land vehicle, permitting stereo imaging and 3D measurements, some system also have down-looking digital cameras to take images of the conditions of the roads surface

An example of mobile mapping is the system developed by ITHACA with the Politecnico di Torino, the Low Cost Mobile Mapping System (Figure 40).

Figure 40 - Low Cost Mobile Mapping System (developed by ITHACA with the Politecnico di Torino)

The device is composed by four webcams, with a total field of view of about 180 degrees, and one GPS receiver that allows to record the webcam position with a high frequency. The number of the webcams and their orientation can be easily customized according to the acquisition needs (vehicle type, survey requirements, etc.). The instruments have been integrated in a compact device, similar to a flashing, easily installable on the top of a vehicle by means of a magnetic base or a suction holder. The direct link with a laptop allows to monitor and record the acquisitions and to tag points of interest and related metatada in real time. The research (Lingua et al., 2009) is focused on the post-processing stage, specifically the GIS software plug-ins is aimed at making easier and quicker the visual interpretation of the data (both imagery and GPS tracks) to identify the features of interest (Figure 41).

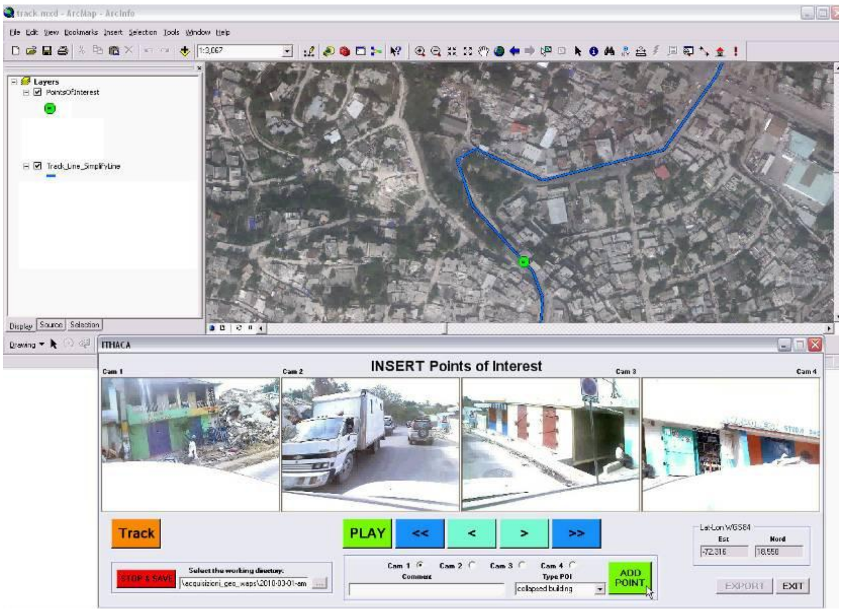


Figure 41 - Data visualization and processing, software GEOWASP GEODB developed by Politecnico di Torino and Ithaca

4.4. Post Event phase

After disaster, the activities are focused on rehabilitation and reconstruction. The recovery phase begins once the post-disaster situation has stabilized enough for activities focused on returning people and the economy to pre-disaster or better levels.

The post-event phase can be further elaborated by:

- Rehabilitation (short-term). This phase includes decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk.
- Reconstruction. This phase includes the essential activities conducted are mitigation, preparedness activities in prediction phase; response activities in warning and emergency relief phases; and recovery activities in rehabilitation and reconstruction phases.

  Mitigation activities include structural and non-structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards.

  Preparedness include activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and properly from threatened locations.

  Response includes the provision of assistance or intervention during or immediately after a disaster to meet the life preservation and basic subsistence needs of those people affected. It can be of an immediate, short-term, or protracted duration.

  Recovery includes decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk.

Then, essential activities include:

- investigative actions focused on the assessment of losses and the reconstruction of damaged buildings and damaged critical infrastructure and private capital;
- the macroeconomic and budget management;

- the revitalization of affected economic sectors, incorporation of disaster mitigation in reconstruction activities;
- adoption of monitoring plans based on the ultimate goal and the results obtained from surveys (reconstruction, recovery environment without rebuilding, etc..).

4.4.1. Disaster Recovery and Vulnerability Reduction

More recent approaches to disaster management and mitigation have focused on the socio-economic and political processes that differentially distribute levels of vulnerability and impact the ability of individuals, groups and communities to resist, respond and recover from disaster events (Joakim E., 2011). This approach recognizes that it is the interaction of both the hazard and vulnerabilities shaped by society that create disaster events (Cannon, 2000). The vulnerability is existing before, during and after a disaster event and incorporates coping capacity and resilience as an inherent part of overall vulnerability.

The conceptualizations of vulnerability provide effective strategies to „build back better" (Joakim E., 2011). Through an assessment of the key processes impacting levels of vulnerability, strategies and policies can be developed for reducing vulnerability and increasing resiliency in the face of future hazards. The recovery is based on the reduction of vulnerability. In order to operationalize a vulnerability reduction framework during the post-disaster period, the following guidelines provide an approach to recovery that seeks to address the underlying issues that created the disaster:

- *Explore root causes of vulnerability*. In this conception of “building back better”, the identification and assessment of most vulnerable areas, groups and infrastructures are essential to ensure that sustainable recovery takes place. This indicates that an exploration of why the community was vulnerable to a disaster in the first place, is required to guide policy development during recovery efforts;
- *Recognize the role of resilience*. The acknowledgement of the role of resilience may counteract the tendency to view individuals impacted by a disaster event as helpless victims who require the assistance of skilled outsiders, particularly when the disaster impacts impoverished regions. Through the incorporation of a resilience approach, individuals and communities are recognized as having capacities on which programs and resources can be built upon. This approach recognizes that all individuals have some form of resilience and capacity to cope and respond to both current and future events and seeks to build upon the strengths that already exist within the community;
- *Focus on long-term outcomes*. Many scholars, governments and NGOs have recognized the need for longer-term programs to recover from and mitigate against future disaster events. Through the recognition that the most successful recovery interventions require long-term commitments and the strategic planning characteristics of development programs, disaster recovery initiatives should incorporate strategies that are mid-to-long term in nature and promote disasterresilient societies by reducing vulnerability (Birkmann and Fernando, 2008);
- *Acknowledge human-environment relationship*. Researchers have increasingly identified how the impacts of human activities on the natural environment may have led to increased susceptibility to, and devastation after, a disaster event. Examples of these impacts include increased risk of landslide events through deforestation and development on hill slopes; lack of natural buffers to storm surge and hurricanes due to destruction of mangrove forests in coastal areas; and the increasing role of human-induced climate change on the frequency and severity of meteorological hazards. Through the recognition of the interconnections between nature and society, recovery initiatives should explore options that promote sustainable human-environment interactions, inhibit further environmental degradation and enhance environmental quality;
- *Local Participation*. Involving the local population in the recovery process will help to ensure that recovery efforts reflect the needs and wants of the local population. The use of community participation encourages bottom-up approaches that recognize the inherent knowledge and capacities of affected populations. As community members examine their own strengths and weaknesses,

participatory approaches may help to empower and motivate them to take appropriate actions (ActionAid, 2004). Participatory approaches also help to provide an understanding of community perceptions of vulnerabilities and resiliencies, leading to more appropriate recovery and preparedness activities that address the specific needs of the community;

- *Continued monitoring and evaluation*. Continued monitoring and evaluation of recovery efforts is required to ensure that vulnerabilities are not intensified or perpetuated throughout the rehabilitation process. In order to achieve the outcome of building back better through vulnerability reduction, long-term monitoring and evaluation methods are required to scrutinize recovery interventions and initiatives, provide direction to improve the success of recovery programs, as well as provide a platform for learning and disseminating information regarding disaster recovery strategies for future events.

4.4.2. Mitigation activities

The activity is focused on the investigation the damage caused by failures in the past and in attempting to forecast the impact that event will have in the future, in a given area.

The following outlines some of the key areas which should be considered during the following activities.

Reference data collection. Collection of all available information and data on the affected area in order to compare the pre and post situation. Moreover, this data set can be used as a tool to assess the magnitude of the damage. The reference data, such as the event phase, provide knowledge on the territory before the disaster. The base layers usually presented in the map are transport networks and related infrastructure (e.g. roads, tracks, trails, railways, bridges, harbours, and airfields), hydrology (rivers, lakes, reservoirs and open water) toponyms, administrative boundaries and settlements.

Waste volume estimations. Estimating the volume of disaster debris is an important step in the wake of a disaster. In order to scope the damage and calibrate the response, it is important that a reasonable estimate of the disaster debris is available to decision makers as quickly as possible. Debris estimates for disasters are rarely computed from ground measurements as that would be time consuming and potentially logistically challenging. Instead, estimates are generally made using satellite imagery or aerial photographs.

Environmental monitoring: It would be appropriate to have a consistent approach to monitoring, specifying the parameters to be monitored, the protocols to be used, the frequency and external reporting requirements. More credibility and consistency could be obtained if the monitoring was undertaken by the government agency responsible for environmental oversight, preferably with the support of research institutes. Monitoring provides real-time information on ongoing programme or project implementation required by management. It is not realistic to expect that any monitoring tool or mechanism will satisfy all needs. It possible to use different tools or also to use the same tools differently. Monitoring of outcomes typically requires a different mix of tools than those traditionally used at the project level. Generally the monitoring is made using ground measurements (ground radar, inclinometer, terrestrial laser scanning, ecc). Where the location is logistically complicated, it is possible to use satellite imagery or aerial photographs or LiDAR flights. In some cases, traditional techniques of geo-referencing aerial photography, ground profiling radar, or Lidar are prohibitively expensive or the site is in inaccessible areas, it is possible using vehicles equipped with video cameras and integrated GPS (Mobile Mapping System). They allow rapid collection of data to allow accurate assessment of conditions on the ground. Mobile mapping is the process of collecting geospatial data from a mobile vehicle, typically fitted with a range of photographic, radar, laser, LiDAR or any number of remote sensing systems. Objects can be measured and mapped from images that are directly georeferenced by the navigation and positioning sensors. The main aim, as mentioned above, of the Mobile mapping system is the acquisition of geographical data, these can be movies and/or single georeferenced frames. The primary output from such systems include GIS data, digital maps.

An example of environmental monitoring is the early warning system (EWS), this is a system of data collection and analysis to monitor people's well-being (including security), in order to provide timely notice when an emergency threatens, and thus to elicit an appropriate response. This definition emphasizes that early warning systems are information systems which is to provide information on occurring hazards that might evolve into disasters unless early response is undertaken. The objective of EWS thus is to monitor the first signs of emerging hazards in order to be able to trigger early and appropriate responses to these first signs and thus reduce or mitigate disaster risk.

Mitigation plans. Mitigation plans form the foundation for a community's long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage in the next disaster. The planning process is as important as the plan itself. It creates a framework for risk-based decision making to reduce damages to lives, property, and the economy from future disasters. Local governments are required to develop a hazard mitigation plan as a condition of receiving certain types of hazard mitigation disaster assistance, emergency and non-emergency.. The mitigation actions are identified into the following groups:

- Prevention, such as planning and zoning, building codes, capital improvement programs, open space preservation, and storm water management regulations;
- Property Protection: modification of existing buildings or infrastructure to protect them from a hazard, or removal from the hazard area. (for example acquisition, elevation, relocation, structural retrofits, flood proofing);
- Public Education & Awareness: actions to inform and educate citizens about potential risks from hazards and potential ways to mitigate them. Such actions include outreach projects, real estate disclosure, hazard information centers, and school-age and adult education programs;
- Natural Resource Protection: actions to preserve or restore the functions of natural systems. These actions include sediment and erosion control, stream corridor restoration, watershed management, forest and vegetation management, and wetland restoration and preservation;
- Structural Projects: actions involve the construction of structures to reduce the impact of a hazard. Such structures include storm water controls, floodwalls, seawalls, retaining walls, and safe rooms.

Mitigation plan is based on data generated through monitoring, including baseline data, information on the programme or project implementation process, and measurements of progress towards the planned results through indicators. The plan should describe the process by which the community decides on particular mitigation actions. This description should include who participated in the analysis and selection of actions. Some of the mitigation actions initially identified may ultimately be eliminated in the community’s action plan due to limited capabilities, prohibitive costs, low benefit/cost ratio, or other concerns.

There is a range of approaches and tools that may be applied to monitoring/mitigation projects. The projects must determine the merge of monitoring tools and approaches for each project, ensuring that the monitoring contains an appropriate balance between: data analysis (obtaining and analysing documentation from projects that provides information on progress), validation (check-in whether or not the reported progress is accurate) and participation (feedback from partners and beneficiaries on progress and proposed actions).

Concerning the landslides, many mitigation measures can be:

- Mapping, Local governments, developers, and residents can make better decisions using maps. Soil types, slope percentage, drainage, or other critical factors are used to identify landslide prone areas.
- Drainage Control Regulations, Drainage regulations are similar to storm water management regulations. By controlling drainage, a community can reduce the risk of landslides resulting from saturated soils.
- Grading Ordinances Grading and Hillside Development Ordinances, ordinances require developers and landowners to obtain permits prior to filling or regrading., moreover they set specific standards for construction on hillsides.
- Geological Hazard Overlay Zones. A geological hazard overlay zone requires a detailed geotechnical analysis prior to any construction activity. Used in association with building codes, this may reduce damage potential by providing clear information about risk.
- Relocation Structures may be moved to less hazardous locations.

- Debris-Flow Measures Debris-flow measures may include stabilization, energy dissipation, and flow control measures, all of which may reduce damage in sloping areas.
- Vegetation Placement and Management Plans. Various types of vegetation increase soil stability through root length and strength and by absorbing precipitation. Management plans are aimed at ensuring long-term maintenance of vegetation appropriate for an area.
- Abatement Districts A special taxing district, such as an abatement district, can be used to pool resources to mitigate common hazards
- Restrictive Covenants A legally binding agreement in a private development can be used to impose restrictions on land use

5. Investigation and monitoring technologies

The issues related to landslides, especially rock fails, are important in the management of the territory, in the definition of risk scenarios and in the preparation of opportune measures of forecasting and prevention. For this reason, it is essential to develop methods based on the collection of survey data and monitoring in order to define scenarios and to implement warning system and/or civil protection plans.

The selection of adequate instruments depends on several factors, such as time to install and get results, instruments vulnerability, site accessibility, weather conditions. Generally, traditional methods include the installation of tools directly in the area and provide information on the type punctual measured variables. This includes exposure to hazardous conditions and long periods for the installation of equipment and high costs of management and maintenance. Many of the limitations can be overcome through the use of advanced technologies for the information acquisition. Geo-information science and earth observation consist of a combination of tools and methods for the collection, storage and processing of geo-spatial data and for the dissemination and use of these data and of services based on these data.

In this chapter, a summary review and a classification of the main approaches of investigation and monitoring are discussed, finally advantages and disadvantages of different methods, relationship between type of approach and scale of work are evaluated.

The investigation and monitoring methods can be divided in two main groups: ground surveys methodologies one and aerial/satellite methods one.

5.1 Ground surveys methodologies

The ground surveys methodologies include:

- traditional surveys;
- terrestrial photogrammetric;
- Terrestrial Laser Scanning;
- ground based SAR;
- thermal IR;
- mobile mapping system;
- wireless sensor network.

Different factors affect the selection of these methods and their applicability, internal factors, typical of the instrument used, and external factors, independent of the instrumentation. In the evaluation of ground surveys methods, each system has been described about internal parameters and, also, external considering the same arguments for each one. These factors are: time available, studied area and its accessibility, exposure to hazardous condition and representation scale.

5.1.1. Traditional surveys

Traditional surveys include different products: geological, geomorphological, topographic survey, ect. Generally, these methods consist in analysis directly on the field in order to provide information on the characteristics and to identify the most dangerous local situations. The identification of features and elements at risk will be done through the comparison of the characteristics local with situations type derived from experiences and studies in the field. Furthermore, the collection of geological, geomorphological and geotechnical available data in the study area is significant for the reconstruction of the preliminary model and the subsequent recognition of the geo-mechanical parameters of the rock types outcrops.

Below some of the traditional surveys are presented.

The *geological survey* should lead to the definition of the geological model of the study area, in particular must be identified and mapped all rock types and the features considered significant for the reconstruction of the stratigraphic and structural area. Indeed, geological map must contain all the formations outcropping and primary and secondary discontinuities (directions layer, faults, etc.). Moreover, researchers must carry out sampling of stratigraphic sections and make appropriate graphical representations to correlate the sections between them. Indeed, the maps must be accompanied by geological sections (traces of which must be marked on all maps made) in number, orientation and scale appropriate to represent in relation to the morphological area situation and to the characteristics of the stratigraphic and structural investigated territory in order to indicate susceptible areas to amplification. Must also be drawn the pattern of stratigraphic relationships and indicated the position of any geognostic present.

The *geomorphologic survey* is capable to identify and mapping the forms and processes associated with the action of gravity, surface water and groundwater, human activity, as well as those affected by the geological structure. The geomorphologic map it must identify the geomorphologic processes current and past.

In the map must in particular be highlighted:

- areas subject to subsidence;
- the kinematics of the landslide phenomena observed and the maximum thickness of layers in landslide;
- the general scheme hydrogeological and permeability for soils and rocks.

The *lithological survey* is derived from all the formations in the geological map in order to group the litho-stratigraphic units in terms of mechanics-technical features. The map must be accompanied by profiles oriented so that they are significant for the reconstruction of dip and dip direction and relations between the litho-units, also in relation to the morphological aspect.

Usually, units are described:

- for litho-units of the substrate layers: the fracturing degree, cementing, intercalation, the lateral variations and all the information necessary to determine the type of geomechanical behavior and the possible lateral and vertical anisotropy;
- for units litho cover: the origin of the material, the shape and size of the clasts or of potential including stone, the presence of fine fraction, the degree of densification and / or consistency, the shims.

In *topographic survey*, measures are taken by instruments, allowing the acquisition of points (Total Station, GPS). This method will exploit the properties of intersections of rays and projective visual, using measures derived from angular values. The topography studies methods, implementation process, calculation models and instruments aimed at the detection of a portion of the earth's surface, small enough to be able to neglect the sphericity or curvature. Topographic operations have as their purpose the measurement of:

- directions
- distances
- altitude gaps

The methodology and the data accuracy are conditioned by several external factor, the main are:

- *the time available*. Usually, these activities are characterized by long period for the acquisition and processing of data, because operators work directly on target area and in most cases, surveys require the installation/use of instrumentation in order to acquire and/or to monitor on the field. Moreover, the instrumentation acquires at regular intervals (as hours, days, etc.) and it is necessary to have available a range of consistent data, in order o have available a range of consistent data in order to make critical assessments of studied area.

- *size of studied area and its accessibility*. The size and accessibility of the area is a important factor that affects the time and, in case of limited accessibility, the accuracy of the data obtained. The optimum is an area of small size (about 5km sq) and easily accessible, so as to carry out the reliefs in a short time and with good accuracy. The intermediate is an area of great size with good accessibility, while the worst-case scenarios are not easily accessible areas of medium / large size (this involves long time for survey and low accuracy).Generally, in this last situation the traditional survey is not an option to be considered.
- *exposure to hazardous conditions*. The exposure to danger during the survey is a critical factor in order to assess the feasibility of the survey itself and to evaluate alternative solutions.
- *representation scale*. The representation scale can be small (<1:100.000), medium (1:100.000 – 1:25.000), large (1:25.000 – 1:5.000) or detailed (> 1:5.000). Concerning the traditional survey, the optimum is large or detailed scale because it allows better accuracy in the data representation and the final map results more itemized. It is possible to use conventional methods to obtain maps at small/medium scale, but in this case the final map will be less detailed in the information provided. Also having to deal with a large area, the time needed to perform the investigations will be greater.

5.1.2. Terrestrial photogrammetry

The purpose of the terrestrial photogrammetric survey is to provide data on shape, size and position of a specific structure or monument, at a given time, for evaluating its actual conditions and/or architectonic aspects. The photogrammetric method is used both in the environmental and in the architectural field. There are two types of surveys: general and detailed surveys. General surveys are performed to represent the shape in a general form, just showing the main lines. Detailed surveys are complete and rigorous, used in the systematic documentation. Its aim is to produce all the geometrical information needed to prepare the planes required for the monitoring/restoration works. These surveys has to be done with high precision.

In the landslide monitoring, the photogrammetry permits to reconstruct the three dimensional landslide shape with great wealth of information and to study its 3D evolution over time. Moreover, the development of digital photogrammetry offers new innovative procedures, like the creation of DSMs in automatic mode for the reconstruction of surfaces and the generation of ortho-images. The accuracy of the acquired points depends on several factors, which must be determined in the planning phase of the relief: calibration of the camera, orientation of the image and return the item. The accuracy depends on the distance between the two stations of the acquisition and the distance of the object; larger the scale of the image is greater the accuracy on image (Ferrero et al., 2012).

The images georeferencing can be performed using known coordinates of GCP (Ground Control Points), visible on images, or by an integrated system between the camera and the GPS receiver. The generation phase of the DTM is based on its image matching algorithms (Grun, 1985; Grun and Baltsavias, 1988).

Moreover, the technological development allows the introduction of appropriate software tools to perform measurements on the digital model. The digital model allows to study without constraints of time, being able to perform new measurements for dip and dip direction and processing in the laboratory.

Executing survey the following operational phase in site are required (Ferrero et al., 2012):

- step of taking pictures;
- execution of the control survey in order to geo-reference the model and to evaluate deformations on the ground;
- determination of image scale through the position of objects of known size in the image.

While, in the elaboration phase the following steps are required (Ferrero et al., 2012):

- slope orientation;
- generation of the point cloud and surface reconstruction with the elimination of errors

- extraction of the planes of discontinuity, using software that select areas of the scanned images (Ferrero et al., 2009)
- extraction of traces (Umili et al., 2012)

Concerning external factors, the terrestrial photogrammetric survey presents several advantages and limitations/disavantages:

- *the time available.* This methodology allows to reduce the time of operation on the field, also the realization of a digital model of the slope permits to perform new measurements and processing at different times in the laboratory. Obviously, more extended the slope to be analyzed more time to carry out the survey.
- *size of studied area and its accessibility*. The terrestrial photogrammetric can be operative from few cm to hundred meters away, allows to make measurements of extended slopes and collect large amounts of data. Moreover, the methodology addresses the issues related to the slope accessibility, also providing a complete description of its morphology.
- *exposure to hazardous conditions.* The terrestrial photogrammetry is adequate about the harzard exposure, the digital model of the slope allows to determine orientation, spacing, and traces of discontinuities in the laboratory without field surveys. Potential exposure to the hazard remains, this depends on the slope conditions and the distance at which the operator decides to make acquisitions.
- *representation scale*. The representation scale can be small (<1:100.000), medium (1:100.000 – 1:25.000), large (1:25.000 – 1:5.000) or detailed (> 1:5.000). Concerning the terrestrial photogrammetry, the optimum is large or detailed scale because it allows better precision in the data representation. It is possible to use this method to obtain maps at small/medium scale, but in this case the representation will be less detailed in the information provided.

5.1.3. Terrestrial Laser Scanning

LIDAR (or laser scanning) provide high-resolution point clouds of the topography and has several applications that range from mapping to monitoring deformation, landslides or rockfall displacements. LIDAR is mainly used to create accurate and precise highresolution digital elevation models (HRDEM) in raster grids or triangulated irregular networks (TINs), with a high density of information. This density mainly depends on the position of the sensor: metric to decimetric resolution for airborne laser scanning (ALS) and centimetric to millimetric resolution for terrestrial laser scanning (TLS) (Shan and Toth 2008).

The ground based LIDAR massively captures coordinates of ground points in 3D with high velocity and accuracy. This consists of an instrument for measuring distance (laser) and a scanner. The range depends on the reflectivity of the materials on the slope and on the angle of incidence. The maximum range for natural slopes is in the order of 1000 m owing to the low reflectivity of the ground. The user can define the necessary parameters for data acquisition (spacing between points, dimensions of the area to be scanned, etc.) in a PDA (Personal Digital Assistant) connected to the instrument. A comparison between the existing TLSs on the market (manufacturers: Cyra, Mensi, Optech, Riegl, Z and F) can be found in Staiger (2003).

Applications in the investigation and monitoring of rock/slope system are numerous. The investigation concerns the implementation of 3D detailed models for reconstruction of risk scenarios, the extraction of quantitative detail, the calculation using software in order to obtain information about orientation and curvature of the surface obtained from the point cloud. While the monitoring includes study of landslides and volumetric changes comparing models 3D obtained at different times.

Moreover, laser scanning is a common tool for displacement monitoring. To obtain the complete field of displacements for the whole landslide is of great help to understand landslide kinematics and failure mechanism. The basic principle requires at least two epochs of HRDEM acquisition. A great improvement in the rockfall hazard assessment is the monitoring using a terrestrial laser scanning of fallen blocks from a cliff between two epochs or more. Indeed, such approaches allow for the quantification of the magnitude and activity of rockfalls in a cliff. In addition, new methods of mobile terrestrial LIDAR along road cuts already produce detailed 3D models that provide data for structural analysis. If such acquisitions are repeated over time, they can be used to detect the most active areas (Jaboyedoff et al., 2010).

The standard deviation of the measurements can be quite high, depending on multiple factors, such as the quality of the TLS data sets, the density of points, the existence of vegetation, the roughness of the relief, the quality of the alignment between the scans, the relative or absolute positions of the TLS and the variation of the surface of the terrain between the two epochs (Jaboyedoff et al., 2010).

The executing survey and the elaboration phase have steps similar to terrestrial photogrammetry, in brief:

- step of scanning the area;
- evaluation of Ground Control Points in order to geo-reference the model and to estimate deformations on the ground;
- determination of image scale through the position of objects of known size in the image.
- generation of the point cloud and surface reconstruction with the elimination of errors
- extraction of the planes of discontinuity, using software that select areas

The Terrestrial Laser Scanning application is conditioned alike terrestrial photogrammetry:

- *the time available.* This methodology allows to reduce the time of operation on the field, also the realization of a digital model of the slope permits to perform new measurements and processing at different times than the acquisition. Obviously, more extended the slope to be analyzed more time to carry out the survey.
- *size of studied area and its accessibility*. This method, operative from few cm to hundred meters away, allows to make measurements of extended slopes and collect large amounts of data. Moreover, the methodology addresses the issues related to the slope accessibility, also providing a complete description of its morphology. The vegetation is one of the main disturbance to the technique.
- *exposure to hazardous conditions.* The TLS is adequate about the harzard exposure, the digital model of the slope allows to determine orientation, spacing, and traces of discontinuities in the laboratory without field surveys. Potential exposure to the hazard remains, this depends on the slope conditions and the distance at which the operator decides to make acquisitions.
- *representation scale*. The representation scale can be small (<1:100.000), medium (1:100.000 – 1:25.000), large (1:25.000 – 1:5.000) or detailed (> 1:5.000). Concerning the terrestrial photogrammetry, the optimum is large or detailed scale because it allows better precision in the data representation. It is possible to use this method to obtain maps at small/medium scale, but in this case the representation will be less detailed in the information provided.

5.1.4. Ground based SAR

Synthetic aperture radar (SAR) technique was invented to overcome resolution restrictions encountered in radar observations from space and generally to improve the spatial resolution of radar images. Similarly to space-borne radar application, also for ground-based radar images it is possible to use interferometric techniques (InSAR). InSAR is based on the quantitative comparison of the phase information between two radar acquisitions of the same scenario, using a pair of complex SAR images, where the former and the latter are referred to as master (m) and slave (s) images.

Ground based differential interferometry (GBInSAR) became diffused, in particular for monitoring landslides and slopes, through high flexibility in terms of spatial resolution, temporal coverage, observation geometry, frequency acquisition and ease of implementation. A GB-InSAR exploits the same principle used in spaceborne InSAR but can provide images of a single slope in much shorter time intervals (about every 10 min), overcoming some of the limitations of satellite data acquisition. With respect to space-borne system, GB-InSAR offers a significantly higher image acquisition rate, coupled with the ability to provide displacement measurements over a limited area (up to a few square kilometers) with an optimal viewing geometry and a very high spatial resolution. Moreover, the GB-InSAR can operate in presence of steep slopes when satellite images perform unsuccessfully.

In the general case, for satellite observations, the two acquisitions are taken from slightly different positions and in different moments of time, the phase of each pixel of the interferogram, referred to as interferometric phase, contains different contributions as follows: topographic effect (the height of the portion of terrain corresponding to a pixel in the interferogram), dielectric effect (phase shift induced both by the propagation through the atmosphere and by the dielectric properties of the reflecting targets) and displacements of the mapped terrain (phase of each pixel of the single SAR image contains information about the absolute distance along the line of sight (LOS) of the system between the sensor and the portion of terrain corresponding to the pixel) (Tarchi D., et al., 2003). With a ground-based platform, the ideal condition of zero baseline can usually be achieved and a couple of images are sufficient to generate a topography-free interferogram and to derive information on displacements. As for spaceborne interferometry, the attained displacement maps provide the component of the displacement along the line-of-sight (LOS) of the SAR system (Casagli et al., 2010).

The final displacement map having the following characteristics (Tarchi D., et al., 2003):

- measured displacements refer to the component of the real displacement along the line of sight of the SAR system and to the time span between the acquisitions of the SAR images;
- spatial resolutions equal to those of the original SAR images; the resolution could degrade if spatial averaging is applied at some step of the processing chain.

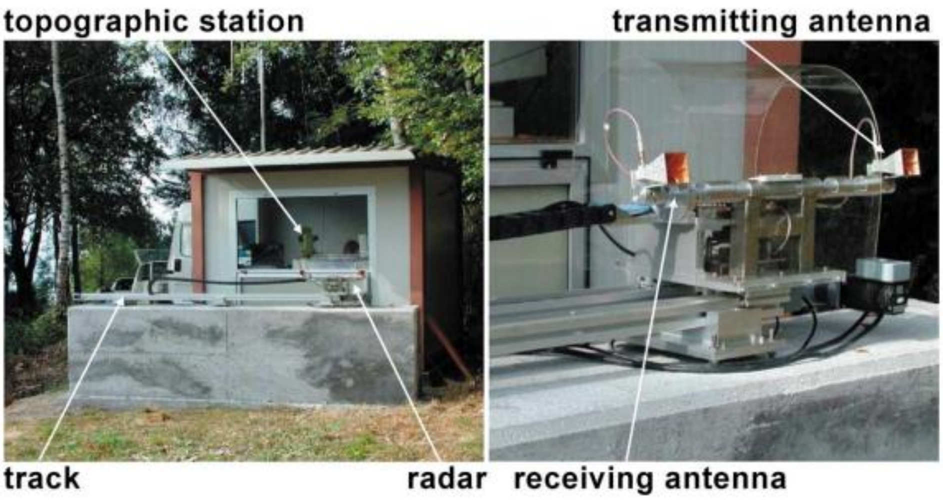


Figure 42 - Field set-up of the instrumentation and detail of the motorized sled with the antennas. The topographic station can be used for validating radar measures on a selected benchmarks. (Source: Tarchi D., et al., 2003).

It is possible to acquire SAR images through a portable SAR to be installed in stable area. The motion for synthesizing the SAR image is obtained through a linear rail where a microwave transceiver moves regularly. Most of the instruments are based on a continuous-wave step-frequency radar as microwave transceiver. A 2–3-m-long linear rail on which two antennas move with mm steps is used to form a synthetic aperture. The microwave transmitter produces continuous waves around a center frequency. The transceiver moves along the rail, observing a portion of the slope determined by the field of view of the real antenna (Figure 42) (Figure 43) (Casagli et al., 2010). The receiver can provide the amplitude and the phase of the microwave signal backscattered by the target. Range and cross-range synthesis of complex images are obtained by coherently summing signal contributions relative to different antenna positions and different microwave frequencies.

Figure 43 – Example of GB-InSAR apparatus. The radar moves along the rail (x axis) to perform synthetic aperture

The use of a ground-based radar allows to provide the flexibility in order to accomplish the variability, about size, movement mechanism, displacement rate, water content, state and distribution of activity, which intrinsically characterizes slope processes. Indeed, ground-based system makes possible to change the observation parameters (such as the distance from the target, the frequency of observation, the length of synthetic aperture, the angle of incidence, the revisiting time) in order to adapt them to every situation.

However, a ground-based system suffers from several limitations, such as to cover only areas of limited extension (about 100,000m^2 from a mean distance of 1 km) and the necessity of a location having a suitable visibility of the area under test. In addition, due to the fact that the system should be fixed in a stable position during the acquisition and to the limited extension of the synthetic aperture, the spatial resolution in azimuth depends both on the distance from the sensor and on the lateral displacement with respect to the sensor location.

Considering the behavior of ground based SAR with respect to external parameters, it is noted that:

- *the time available*. The main advantages of the method are versatility and adaptability of the measurement parameters that can be modified according to the rapidity with which it is possible to install the system and get the first measurement data. Furthermore, this method has the ability to perform continuous data acquisition or with reduced time interval between two successive acquisitions. Then, it is possible the assessment of rapid movements. This instrument makes the tool useful in case of early warning. The limits can be given, in the case of prolonged surveys, by costs for maintenance of the instrument and for connection to the electricity network.
- *size of studied area and its accessibility*. Ground-based radar installations are usually at their best when monitoring small scale phenomena like buildings, small urban area or single hillsides, while imaging from satellite radar is able to monitor a very large area. The presence of vegetation may be a disturbing element, another element of limitation is that the location must have a suitable visibility of the area under test. The spatial resolution is dependent on the distance and then a few km away, the loss of resolution can nullify a major advantage (the study area should not exceed few km sq).
- *exposure to hazardous conditions*. The ground based SAR is adequate about the harzard exposure. Obviously, potential exposure to the hazard remains, this depends on the slope conditions and the distance at which the operator decides to make acquisitions. Currently, technological developments are trying to make the instrument easier to remedy at hazardous conditions in the difficult installations.
- *representation scale*. Concerning this method, the optimum is large or detailed scale because it allows better precision in the data representation. It is possible to obtain maps at medium scale, but in this case the representation will be less detailed in the information provided. Indeed, as above mentioned, the spatial resolution is dependent on the distance and then a few km away, the loss of

resolution can nullify a major advantage (cover only areas of limited extension, about 100,000m^2 from a mean distance of 1 km).

5.1.5. Thermo IR

In recent years, the Infrared thermography (IRT), with the development of ground-based thermal sensors, has increased its use in the characterization and monitoring of landslides. Infrared thermography allows measurement without contact using the infrared radiation coming from the area investigated. This method has its potential in relative low cost of the thermographic cameras, in high spatial resolution, in the ease of acquisition and processing images.

The dependence on thermal parameters, such as the thermal inertia, linked to density and geological composition of materials, allows its use in order to typify miscellaneous deposits such as those landslides. Moreover, the ability to remotely investigate the surface temperature of the scenario studied, in full safety for the operator, allows the IRT to provide an important contribution in order to a detailed characterization of landslides (Casagli et al., 2012).

The IRT is based on the physical principle that all objects above absolute zero emit an electromagnetic radiation in the infrared band, according to the black body radiation law. Thermal imaging cameras detect radiation in the infrared range of the electromagnetic spectrum (roughly 9,000–14,000 nanometers or 9–14 µm) and produce images of that radiation (thermograms). Thermography makes it possible to see the environment with or without visible illumination. The amount of radiation emitted by an object increases with temperature; therefore, thermography allows one to see variations in temperature. Measuring the pattern of radiation emitted it is possible to obtain information on temperature and physical surface properties and structure.

The instrument used in Infrared thermography is a camera susceptible to radiation, formed by an optical and an electronic component. The infrared radiation is converged by the objective towards a sensor, which generates an amplified pulse. This is converted from analog signal to digital in order to be processed of the electronic processor. Moreover, through calibration procedures and compensation of the atmospheric effects, the electronic processor converts the pattern of thermal radiation surface in thermal images (thermograms). These images are false-color maps of the surface temperature and are formed by a grid of pixels where the gray level indicates the value of radiant temperature corresponding to the point investigated (Casagli et al., 2012).

The Infrared thermography presents several advantages and limitations/disavantages, concerning external factors:

- *the time available.* The main advantages of the method are adaptability rapid installation of the instrument. Furthermore, this method has the ability to perform continuous data acquisition. It is capable of catching moving targets in real time, then it is possible the assessment of movements and to make the tool useful for monitoring system and/or in case of early warning.
- *studied area and its accessibility*. The method enables to compare thermal images over a wide area, also it can be used to detect objects in dark areas. It is a non-destructive and an indirect method, because it does not operate directly on the examined area but from the opposite side. Accurate temperature measurements are hindered by differing emissivities and reflections from other surfaces, most cameras have ±2% accuracy or worse in measurement of temperature and are not as accurate as contact methods. Moreover, the infrared thermography is only able to directly detect surface temperatures. Condition of work, depending of the case, also can be drastic: 10°C of difference between internal/external, 10km/h of wind maximum, no direct sun, no recent rain, ect.
- *exposure to hazardous conditions.* The IRT is adequate about the harzard exposure. Indeed, it can be used to measure or observe in areas inaccessible or hazardous for other methods. Being an indirect method, this allows to make assessments from opposite sides and in conditions of safety. Obviously, potential exposure to the hazard remains, these concern in particular the conditions during installation and monitoring plans.

- *representation scale.* The optimum is large or detailed scale because it allows better precision in the data representation. It is possible to obtain maps at medium scale, but in this case the representation will be less detailed in the information provided (the study area should not exceed few km sq).

5.1.6. Mobile Mapping System

Advances in resolution and accuracy of multi-platform (satellites, aircrafts or helicopters) have rendered suitable for the generation of 3D models; however, these can only capture “building roofs” not the “facades”. Terrestrial mobile mapping system have been invented and used to acquire ground level data, to collect damage information, to support on-site investigation and emergency response and disaster management in urban areas (Li J. and Chapman M.A., 2008). The mobile mapping system can be defined as a kinematic platform, with multiple sensors integrated and synchronized to a common time base, to provide a 3D near-continuous and automatic positioning of both the platform and simultaneously collected geospatial data (Grejner-Brzezinska, 2001). Such systems are composed of an integrated array of time synchronised navigation sensors and imaging sensors mounted on a mobile platform. The primary output from such systems include GIS data, digital maps, and georeferenced images and video.

Mobile mapping systems are useful used for various mapping applications, the availability of mobile mapping internet facilitates the extension of the operational environments to real time, enabling change detection, emergency response and real time decision making.

The system consists of four main components: position/navigation module, imaging module, system control module and data processing/feature extraction module (Figure 44). The modules can be integrated together to create a multi-task system for management operations in real-time or post-processing mode and for providing automatic acquisition of directly georeferenced digital data. Digital camera are mounted on the top of the land vehicle, permitting stereo imaging and 3D measurements, some system also have down-looking digital cameras to take images of the conditions of the roads surface. The position and orientation of the cameras are constant, so 3D spatial coordinates can be computed in a local coordinate system. The final object coordinates can be determined by integrating this system with the GPS/IMU navigation subsystem (Li J. and Chapman M.A., 2008). Features are identified in the images and their position are derived from the spatial information of the vehicle. The Table 23 shows the main sensors of a typical mobile mapping system and their functionality.

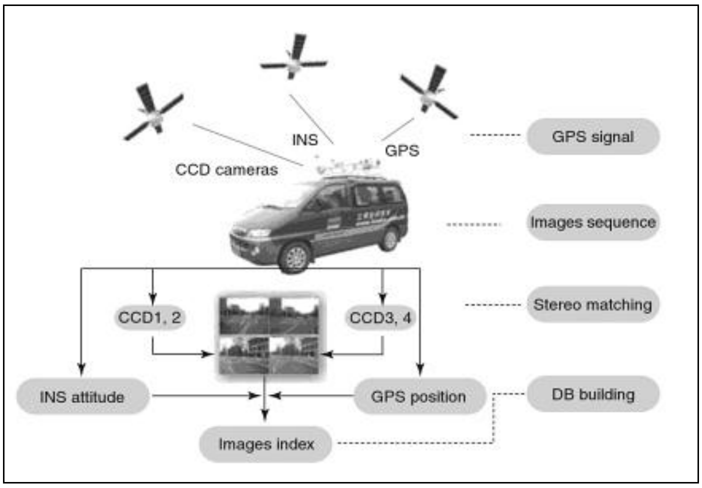


Figure 44 - The operational principle and major components of a terrestrial mobile mapping system (Source: www.leador.com.cn)

Georeferencing of digital image is accomplished by the multi-sensor navigation and positioning techniques. In order to improve the accuracy and robustness of georeferencing, multiple positioning sensors, GPS, Inertial Navigation System (INS) and dead-reckoning (DR) can be combined for data processing. The system can achieve cm accuracy of vehicle positioning an meter or sub-meter 3D coordinate accuracy of objects measured from the georeferenced image sequences. Moreover, the data link to a geospatial database is easy, so the collection geometric and attribute information can be used to build or update a database. With the development of internet and images compression technologies,real time image data link from a field mobile mapping system to an office GIS can be realized (Li J. and Chapman M.A., 2008).

Sensor type	Sensor functionality
GPS receiver	• Image geopositioning in 3D • Time synchronization between GPS and IMU • Image time-tagging • IMU error control • Furnishes access to the 3D mapping frame through WGS84
Inertial Measurement Unit (IMU)	• Image orientation in 3D • Support image georeferencing • Provide bridging of GPS gaps • Provide continuous, up to 256 Hz, trajectory between GPS measurement epochs • Support ambiguity resolution after losses of lock, and cycle slip detection and fixing
CCD digital camera	• Collect images to derive object positions • Two or more cameras provide 3D coordinates in space
Laser range finder	• Support feature extraction from the imagery by providing precise distance measurements
Laser scanner or Lidar	• Collect 3D point clouds to derive 3D object models • Collect both object's geometry and surface texture information
Voice recording, touch screen, Barometers, Gravity gauges	• Document attribute information

Table 23 - - Main sensors of typical mobile mapping system and their functionality (Source: Li J. and Chapman M.A., 2008).

The image sequences acquired are tagged with their position and orientation information determined by the GPS/INS component. These images are used for video-logging, photo-logging application, and GIS base map applications.

The GPS-based video-logging or photo-logging systems offer a fast and low-cost approach. Visual inventory and feature documenting along road corridors remain the major purpose of these kinds of systems. The collected video/photo images are georeferenced with respect to a global coordinate system by using continuous GPS navigation and positioning information; the interpretation of data is through the use of image processing software. Finally, the resolution of camera is important, indeed the low resolution of video images limits quantitative measurements from these images.

An advantage is that the data link to a geospatial database is easy and straightforward. The collected data, position and attribute of features are stored in a simple format that can be used in standard GIS systems. The data are displayed in map format, analyzed and manipulated using GIS database query functions. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through widely distributed Internet and even wireless networks. The base map or view image data is developed from an operator directly in the vehicle or in the office.

Finally, the use of the mobile mapping system presents advantages and limitations conditioned by:

- *the time available*. Advantage of the method is the rapid collection of high-quality spatial information. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks. This method has the ability to perform continuous data acquisition. This instrument makes the tool useful in case of early warning.
- *studied area and its accessibility*. Mobile mapping systems allow rapid collection of data to allow accurate assessment of conditions on the ground. The sensor used for the data acquisition is positioned on a vehicle, that can be a car, a bike, etc; this allows to move quickly in the studied area

and to acquire large amounts of data in a short time. Obviously the data acquisition is functional to area accessibility, this method cannot be used if the vehicle does not have the possibility of movement.

- *exposure to hazardous conditions.* Exposure to risk is subject to the context in which the mobile mapping system is used, in the mapping of roads and railways for asset management and engineering planning, there isn't a concrete exposure to hazard. While in the infrastructure mapping for emerging responses, dangerous situations may occur due to the conditions of roads network.
- *representation scale.* Optimum is large or detailed scale because it allows better precision in the data representation. It is possible to obtain maps at medium scale, but it is possible in this case that the representation will be less detailed in the information provided.

5.1.7. Wireless Sensor Network

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity.

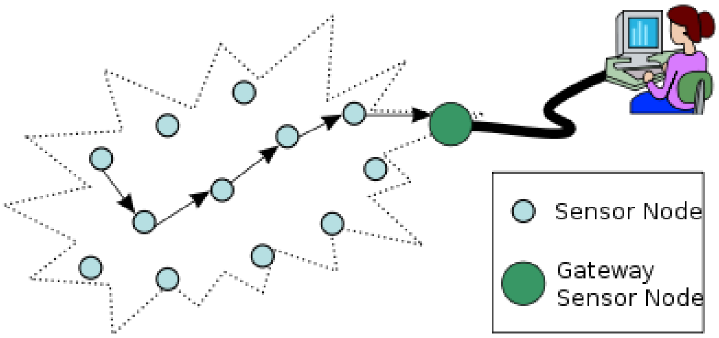


Figure 45 - Example of typical multi-hop wireless sensor network architecture

The WSN is built of "nodes", where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting (Figure 45). A sensor node might vary in size from that of a shoebox down to the size of a grain of dust. The cost of sensor nodes is similarly variable, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth.

The main characteristics of a WSN include: power consumption constrains for nodes using batteries or energy harvesting; ability to cope with node failures; mobility of nodes; communication failures; heterogeneity of nodes; scalability to large scale of deployment, ability to withstand harsh environmental conditions; ease of use.

Sensor nodes can be imagined as small computers, extremely basic in terms of their interfaces and their components. They usually consist of a processing unit with limited computational power and limited memory, sensors or MEMS (including specific conditioning circuitry), a communication device (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery.

The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many applications, they are required that are fast and easy to install and maintain. In recent years, this method has evolved to cover many applications of earth science research, such as volcanoes, forests fire detection, landslide detection, natural disaster prevention.

The Table 24 shows which physical principles may be used to measure various quantities (Lewis F.L., 2004). These sensors, indeed, are formed by components capable of detecting physical parameters (position, temperature, humidity) to process the data, to communicate between them and to transmit the acquired data to the central storage collection.

Some uses of the WSN in monitoring landslides have produced good outputs, results from simulated landslides indicate that it can achieve high degree of accuracy (in the order of cm) in the landslide detection. Generally, it proposes a network of sensor columns deployed at hills with landslide potential with the purpose of detecting the early signals preceding a catastrophic event. Detection is performed through an algorithm, this can be a threshold based algorithm, that influence the sampling rate of the geological sensors and the transmission of data to higher layers using rainfall and pore pressure based alert levels (Maneesha V.R., 2009), or an algorithm to estimate the slipping surface, a Finite Element Model that predicts whether and when a landslide will occur. (Terzis et al., 2006). However, concerning the rock fails or, it is necessary to reduce installation time and focus sensors that acquire parameters such as fractures dimension, tilt or weather parameters.

Moreover, the WSN presents advantages and limitations, concerning external parameters:

- *the time available.* Wireless sensor network(WSN) technology has the capability of quick capturing, processing, and transmission of critical data in real-time with high resolution. With the development of fast communication, such data can be disseminated and accessed through Internet. This method has the ability to perform continuous data acquisition. This instrument makes the tool useful in case of early warning. However, it has its own limitations such as relatively low amounts of battery power and low memory availability compared to many existing technologies.
- *studied area and its accessibility*. WSN systems allow collection of data to allow accurate assessment of conditions. It is a non-destructive method and a real time monitoring system. this method is based on a field deployment of a wireless sensor network based landslide detection system. This system uses a heterogeneous network composed of wireless sensor nodes, Wi-Fi, and satellite terminals for efficient delivery of real time data to the data management centre, to enable sophisticated analysis of the data and to provide landslide warnings and risk assessments to the inhabitants of the region. The optimum is an area of small/medium size.
- *exposure to hazardous conditions* These sensors have the advantage of deploying sensors in hostile environments with a bare minimum of maintenance. This fulfills a very important need for any real time monitoring, especially in hazardous or remote scenarios.
- *representation scale.* Optimum is large or detailed scale because it allows better precision in the data representation.

Measurements for Wireless Sensor Networks		
	Measurand	**Transduction Principle**
Physical Properties	Pressure	Piezoresistive, capacitive
	Temperature	Thermistor, thermo-mechanical, thermocouple
	Humidity	Resistive, capacitive
	Flow	Pressure change, thermistor
Motion Properties	Position	E-mag, GPS, contact sensor
	Velocity	Doppler, Hall effect, optoelectronic
	Angular velocity	Optical encoder
	Acceleration	Piezoresistive, piezoelectric, optical fiber
Contact Properties	Strain	Piezoresistive
	Force	Piezoelectric, piezoresistive
	Torque	Piezoresistive, optoelectronic
	Slip	Dual torque
	Vibration	Piezoresistive, piezoelectric, optical fiber, Sound, ultrasound
Presence	Tactile/contact	Contact switch, capacitive
	Proximity	Hall effect, capacitive, magnetic, seismic, acoustic, RF
	Distance/range	E-mag (sonar, radar, lidar), magnetic, tunneling
	Motion	E-mag, IR, acoustic, seismic (vibration)
Biochemical	Biochemical agents	Biochemical transduction
Identification	Personal features	Vision
	Personal ID	Fingerprints, retinal scan, voice, heat plume, vision motion analysis

Table 24 - Measurements for Wireless Sensor Networks (Source: Lewis F.L., 2004)

5.2 Remote sensing methodologies

The remote sensing generally refers to the use of aerial sensor technologies to detect and classify objects on Earth (both on the surface, and in the atmosphere and oceans) by means of propagated signals emitted from aircraft or satellites. There are two main types of remote sensing: passive remote sensing and active remote sensing. Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding areas. Reflected sunlight is the most common source of radiation measured by passive sensors. Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. radar and LiDAR are examples of active remote sensing where the time delay between emission and return is measured, establishing the location, speed and direction of an object.

By satellite, aircraft, spacecraft and helicopter images, data is created to analyze and compare things like vegetation rates, erosion, pollution, forestry, weather, and land use. These things can be mapped, imaged, tracked and observed. These instruments are useful not only in the planning processes, and also in to detection and mapping of many types of natural hazards, in the vulnerability assessment area and in the monitoring of events which could cause a disaster and the assessment of the damages.

Generally, the main applications of remote sensing technologies devote to natural disaster management deal with:

- pre-disaster phase: collection and analysis of relevant data and of information useful to identify causal factors (both natural and human) which contribute to the hazard; development of a sufficient knowledge of the processes and of the causal factors leading to the hazard. Moreover, remote sensing instruments can provide very useful input data for early warning systems dedicated to the evaluation of the impacts of natural components variability (e.g. the climate) on natural disasters occurrences, constituting natural disaster predictions systems;

- response and post-disaster phases: systematic observation of the state of the environment in order to monitor the effects of a natural disaster on the territory (estimate of the changes possibly occurred) and to identify the affected population. In this case, the extracted information is used to produce suitable cartographic outputs.

The remote sensing methodology include:

- Satellite system;
- Aircraft system.

Different conditions have an effect on the selection/use of these methods, internal factors, typical of the instrument, and external factors. Each system has been described about both internal parameters and external considering the same factors for each one. These are: time available, studied area and its accessibility, exposure to hazardous condition and representation scale.

5.2.1. Satellite Systems

The factors that determine the effectiveness of a remote sensing system for thematic map production activities are:

- sensor features: spatial and spectral resolution of the sensor and area of coverage;
- system features: temporal resolution (or revisit time) of the system, data cost and data availability (this is the data suppliers capability of planning a new satellite acquisition to respond to an emergency need and of providing fast and reliable delivery services).

Collecting information on landslide occurrence and activity over wide areas is a crucial task for landslide hazard assessment. Because their synoptic view and their capability for repetitive observations, optical (visible-infrared) and radar remotely sensed imagery acquired at different dates and at high spatial resolution can be considered as an effective complementary tool for field techniques to derive information on landslide occurrence and activity over wide areas. Since land-surface properties change through time, remote sensing of such changes yields critical temporal control on landscape evolution. Data have to provide information on land cover and the geomorphology of slopes, to inventory and characterize landslide potential in high relief areas (Singhroy et al., 1998), and to monitor post-slide motion and characterize debris size and distribution (Singhroy, 1995).

The following tables show the main parameters of high and very high resolution optical satellites (Table 26) and microwave systems. (Table 25).

RADAR					
Satellite	**Spatial resolution (m)**	**Band**	**Polarization**	**Repeat cycle (days)**	**Operational Since**
ERS 1-2	20x5 m	C	VV	35	1991 (ERS1) 1995 (ERS2)
ENVISAT	20x5 m	C	HH/VV	35	2002
RADARSAT-1	10x5 m	C	HH	24	1995
RADARSAT-2	3x3 m	C	QUAD Pol	24	2005
TerraSAR-X	1x1 m	X	All	11	2006
TanDEM-X	1x1 m	X	All	11	2010
Cosmo SkyMed	1x1 m	X	HH/VV	8	2005

Table 25 - Main characteristics of current microwave satellites (Source: ITC's database of satellites and sensors) QUAD Pol mode (all four polarizations HH, HV, VV, VH)

OPTICAL				
Satellite	**Spatial resolution (m)**	**Sensor**	**Repeat cycle (days)**	**Operational Since**
EROS A	1.9m	CCD (Charge Coupled Device)		2000
EROS B	0.7m	CCD-TDI		2006
Formosat 2	PAN 2m MS 8m	RSI	1	2004
Komposat 2	PAN 1m MS 4m	MSC	14	2006
GeoEye 1	PAN 0.41m MS 1.65m	MSC		2008
Ikonos	PAN 1m, MS 4m	OSA	3	1999
Quickbird	PAN 0.6m MS: 2.44 m	BGIS2000	3	2001
RadipEye	PAN 6.5m MS: 6.5m	Multi-spectral push broom imager	1	2008
WorldWiev1	0.55m	Panchromatic	1.7	2007
WorldWiev2	4.3m	IRU	1.1	2009
Spot4	PAN 10m, MS 20m SWI 20m	HRVIR	26	1998
Spot 5	PAN 2.5/5m, MS 10m SWI 20m	HRG	26	2002
DMC-UK (and Beijing-1, Nigeriasat-2)	ESIS	MS 32m	3	2003
Resourcesat -1 IRS-P6	PAN 6m, MS 23.5m SWI 23.5M MS 56m SWI 56m	LISS-4 LISS-3 AWiFS	5 24	2003
Landsat7	PAN 15m, MS 30m SWI 30m	ETM+	16	1999
ALOS	PAN 2.5m	PRISM	46	2005

IRS-P5/Cartosat ALOS	PAN 2.5m MS 10m	PAN-F AVNIR-2	5 46	2005 2005

Table 26 - Main characteristics of current optical satellites of high to very high resolution.

Optical sensors. The use of these sensors can be limited by weather conditions (they are unable to pass through cloud, rain or fog). Moreover, some systems have pointing capabilities which enable imagery of specified areas to be acquired more frequently. Some high resolution instruments can also provide stereo images by using data collected on a single orbit (along track). Stereo images allow 3D feature extraction. Common applications of high and very high resolution satellite data are map generation and updating and generation of digital elevation models.

Several approaches for locating landslides using band ratios of multi-temporal satellite images to detect changes on land use preand post-landslide occurrence are developed. Basically these approach proposes the use of very high resolution images (e.g., Ikonos or Quickbird type) acquired at different dates. The method consists on image orthorectification, relative radiometric normalisation, change detection using image difference, thresholding and spatial filtering to eliminate pixel clusters that could correspond to man-made land use changes (Metternicht et al., 2005). Other approaches present techniques based on optical correlation of aerial photographs and satellite images, using improved spatial resolution can help landslide mapping and monitoring tasks. Analytical and digital photogrammetry techniques are highly suitable for monitoring geometric changes, such as terrain displacement. Furthermore, optical data have the potential to determine surface information, whereas it has no access to depth information that has to be obtained from geophysical approaches or in combination with physical or numerical models.

Radars instruments. Radars operating in a variety of wavelengths (usually L-, C- and X- bands) are available. X-band radar systems are the most commonly offered by the commercial sector. Radars have the capability to pass through clouds providing data in any weather condition, day/night basis.

Data acquired by satellite-borne Synthetic Aperture Radar (SAR) systems can be profitably used for the detection and quantification of slow mass movements, provided that the interferometric analysis and data interpretation is guided by field knowledge and comprehension of slope failure/ground deformation mechanisms. The interferometry approach is based on the phase comparison of synthetic aperture radar (SAR) images, gathered at different times with slightly different looking angles. The basic principle of interferometry relies on the fact that the phase of SAR images is an ambiguous (modulo-2π) measure of the sensor-target distance. Distance variations are determined by computing on a pixel by pixel basis the phase difference (interferometric phase) relative to two SAR images acquired over the same area during successive satellite passes. This is performed as pixel by pixel product of the reference image (master) times the complex conjugated secondary (slave) image. SAR interferometric data can be used for generating 3D images of the Earth surface (interferometric digital elevation models, DEM).

Moreover, by compensating for the topographic contribution to the interferometric phase (differential SAR interferometry - DInSAR), ground deformation can be isolated in single or in series of interferograms. These applications are possible as long as the phase contribution introduced by electromagnetic scattering on the various objects within the test area remains nearly constant (coherence condition) between the two acquisitions involved in each interferogram (Colesanti C. and Wasowski J., 2004). However, DInSAR has not become an operational tool for landslide monitoring. The loss of coherence, typically related to the presence of vegetation cover, is a major problem for monitoring applications that need to rely on long-term sequential SAR observations. The presence of atmospheric distortion affecting the interferometric phase is another serious drawback (Colesanti C. and Wasowski J., 2004).

Several limitations to the practical applicability of the conventional DInSAR to landslide monitoring are overcome by using the Permanent Scatterers (PS) technique. This technique combines the wide-area coverage typical of satellite imagery with the capability of providing displacement data relative to individual image pixels. Concerning the landslides, even though slow ground surface displacements can be measured with millimetric precision by PS SAR interferometry, at present, the most attractive and proved contribution provided by this remote sensing technique lies in the possibility of qualitative distinction between unstable and stable slopes and qualitative or relative hazard zonation of landslides based on the identification of segments characterised by different movement rates (Colesanti C. and Wasowski J., 2004). In general, the number and the spatial distribution of potential PS is difficult to anticipated a priori, i.e. before acquisition and initial processing of several SAR images. The main reason is that the exact nature and physical principles of scatterers behaviour are still insufficiently known, even though remarkable progresses have been recently reported at least for urban PS (Ferretti et al., 2005).

In slope specific investigations the PS data can represent a very useful complementary data source with respect to the information acquired through ground based observations and in situ surveying. However, the difficulties associated with the feasibility assessments of the applicability of SAR data to local scale problems, as well as with their subsequent interpretation will require a close collaboration between landslide experts and specialists in advanced processing of radar satellite data (Colesanti C. and Wasowski J., 2006).

In general, ground control will always be needed because, in addition to landslide processes, there are several other more or less localised ground deformation phenomena that have to be taken into account to interpret correctly the significance of deformations detected from radar and or optical sensors. These include subsidence (whether caused by natural processes such as compaction, thawing, or man-made), settlement of engineering structures, and shrink and swell of some geological materials.

There are specific geological aspects that constrain the applicability of satellite system, both optical and radar:

- phases of landslide movements (pre-failure, during failure and post-failure).
- gravity and continuous creep
- weathering and shallow seasonal creep

Regarding the pre-failure movements, the displacements can accelerate quickly at the onset of failure and will not be suitable for these applications. However, in more plastic materials with flat-topped stress-strain curves and with a correspondingly slower onset to failure the movements might be more easily detected by remote sensing techniques.
During a first-time movements slide occur quickly in comparison to pre- and post-failure deformation phases. The rate of displacement largely depend on the shape of the stress curve of the materials involved. The deformation takes place over a comparatively short timescale in a landslides history and hence it seems unlikely that the displacements will be easily detected and monitored by periodic space-borne remote sensing.
Post-failure movements involve many naturally degraded slopes, especially in clays, where pre-existing shear surfaces are often present and can become reactivated. A common feature of these subsequent movements is their low speed, regardless of whether they are brought about by seasonal water pressure changes or by an alteration in loading on a slipped mass These movements may continue over long time periods. This phase in a landslides movement history is thus probably the easiest to detect through periodic remote imagery.

Concerning the scale representation, scale of 1: 25,000 should be considered as the smallest scale to analyse slope instability phenomena. Using smaller scale imagery, a slope failure may be recognised if size and contrast are sufficiently large, though previous studies have concluded that the amount of analytical information enabling to make conclusions on type and causes of a mass movement are very limited at scales smaller than 1:25,000.

Moreover, using multi-temporal DEMs derived from remotely data measuring it is possible to make a volumetric estimation of sediment eroded and deposited by debris flows. Volumetric analysis is undertaken by calculating elevation differences between successive sets of cross-sections or DEM measurements. The technique provides an efficient means to obtain spatial data from an entire area of interest, as compared to boundary and cross-sectional data characterizing field surveys. The accuracy of the method is controlled by pre-events photographs, as post-events photographs can be flown at any desired scale. The satellite data will be especially valuable where no other data sources are available by providing initial (potentially wide-area) assessments of ground deformation susceptibility. Then this information can be used to focus on those slopes where there is a potential hazard and where more detailed geotechnical investigations or in situ monitoring may ultimately be required.

Concerning external parameters:

- *the time available.* Advantage of using satellite images (radar and optical) is the rapid collection of spatial information, at different scale of resolution. The limitation is mainly related to acquiring new images, process them in order to make them usable by operators.
- *studied area and its accessibility*. The satellite systems (optical and radar) represent a very useful complementary data source with respect to the information acquired through ground based observations. They can be used in order to identify, in large and complex area, slopes potentially subject to collapse through aerial view. They provide an overview of the adjacent sectors, not only study area.
- *exposure to hazardous conditions*. The satellite data will be especially valuable where no other data sources are available. Then this information can be used to focus on those slopes where there is a potential hazard and where more detailed geotechnical investigations or in situ monitoring may ultimately be required.
- *representation scale.* Considering the size of most landslides, which is in the order of several tens to a few hundreds of meters, the most useful scale is a large/detailed scale. At this scale the phenomenon can be identified as a slope instability feature, and a analysis of the feature is also possible, as the elements of the landslide can be recognized and analyzed. Using small scale, a slope failure may be recognized as such, if size and contrast are sufficiently large. However, the amount of analytical information will be very limited at scale smaller than 1:25.000. Using optical images it is preferable to make use of images with high/very high resolution in order to identify in a correct and accurate way the slope condition. In the other hand, the Permanent Scatterers technique provide information about the slope movement.

5.2.2. Aircraft Systems

Aircraft systems are used for systematic surveys of portions of land. Usually, platforms for aerial surveys include fixed-wing aircraft, helicopters, Unmanned Aircraft Vehicle (UAV), balloons, blimps and dirigibles. The ability to place several sensors makes these flight instruments useful in urban areas, for analysis of risk environment and for the estimation of changes land use. Also have a low cost solution for the creation of cognitive frameworks shared. The use of these technologies allows for very high resolution data in near real-time at very low cost.

The *aerial photography* is the most common technique, the term usually refers to images in which the camera is not supported by a ground-based structure. There are several types of aerial photography, oblique, vertical, combined. Mainly used in photogrammetry and image interpretation are vertical photographs. Pictures that will be used in photogrammetry are traditionally taken with special large format cameras with calibrated and documented geometric properties. Vertical photographs are often used to create orthophotos, which have been geometrically "corrected" so as to be usable as a map. Perspective must obviously be removed, but variations in terrain should also be corrected for. Orthophotos are commonly used in geographic information systems, such as are used by mapping agencies (e.g. Ordnance Survey) to create maps. Large sets of orthophotos, typically derived from multiple sources and divided into "tiles" (each typically 256 x 256 pixels in size), are widely used in online map systems such as Google Maps. OpenStreetMap offers the use of similar orthophotos for deriving new map data. Google Earth overlays orthophotos or satellite imagery onto a digital elevation model to simulate 3D landscapes.

These basic elements can aid in identifying objects on aerial photographs:

- Tone -- Tone refers to the relative brightness or color of elements on a photograph. It is, perhaps, the most basic of the interpretive elements because without tonal differences none of the other elements could be discerned.

- Size -- The size of objects must be considered in the context of the scale of a photograph. Size may refer to the area of an object or to a single dimension such as the length of a road.
- Shape – shape is the geometric outline of an object. Regular geometric shapes are usually indicators of human presence and use. Some objects can be identified almost solely on the basis of their shapes.
- Texture – texture describes the structure of the variation in brightness within an object. The impression of "smoothness" or "roughness" of image features is caused by the frequency of change of tone in photographs. It is produced by a set of features too small to identify individually. Grass, cement, and water generally appear "smooth", while a forest canopy may appear "rough".
- Pattern (spatial arrangement) - The patterns are shapes with identifiable geometric or periodic attributes. Consider the difference between (1) the random pattern formed by an unmanaged area of trees and (2) the evenly spaced rows formed by an orchard.
- Shadow -- Shadows aid interpreters in determining the height of objects in aerial photographs. However, they also obscure objects lying within them.
- Site -- refers to topographic or geographic location. This characteristic of photographs is especially important in identifying vegetation types and landforms.
- Association -- Some objects are always found in association with other objects. The context of an object can provide insight into what it is. For instance, a nuclear power plant is not (generally) going to be found in the midst of single-family housing.

Traditionally, landslide inventories are based on air photo interpretation. This process involves the interpretation of characteristics of the landslide, such as color, contrast, size, shape, and shadow, as well as contextual indicators such as position, and direction (Liu et al., 2002). A further requirement in landslide monitoring is the qualitative interpretation of ground features associated with slope failure such as ground cracks, slopes, depressions and discontinuities in vegetation and soil moisture. Then for clear recognition of such processes, an air photo scale of 1:5000 is an optimal scale, however in some cases the air photo scale of 1:10 000 has been used.

LIDAR (or laser scanning) provide high-resolution point clouds of the topography and has several applications that range from mapping to monitoring deformation, landslides or rock fall displacements. LiDAR (e.g., Light Detection and Ranging) is an active sensor using electromagnetic energy in the visible and near infrared wavelengths that provide data in a nadir-looking mode, at discrete points across a swath (Mather, 2004).

LIDAR is mainly used to create accurate and precise high-resolution digital elevation models (HRDEM) in raster grids or triangulated irregular networks (TINs), with a high density of information. This density mainly depends on the position of the sensor: metric to decimetric resolution for airborne laser scanning (ALS) and centimetric to millimetric resolution for terrestrial laser scanning (TLS) (Shan and Toth 2008). Helicopter-based ALS can give a higher resolution than aircraft-based ALS and especially allows orientating the scanner in all directions (Jaboyedoff et al., 2010). Most LiDAR sensors are flown on board of aircrafts, and can be subdivided on Fsmall footprints_ (5–30 cm), commonly used for detailed local mapping of surface elevations, and Flarge footprint_ (e.g., 10–25 m), collecting an average value for a greater surface area.

ALS can be used for different types of investigation in landslide studies, the main are: support for mapping of geomorphic features, creation of accurate landslide modeling by improving geometrical characterization of slope, monitoring of surface displacement and detection of mobilizable volumes, monitoring of morphologic changes in channel (debris flow), monitoring of surface displacement, rock face imaging and characterization (rock fall), calculate discontinuity orientation (rock fall), quantification of rock fall activity (volumes).

The morphological features of the landslides (e.g. scarps, mobilized material, foot) are easy to delineate based on hill shades of the produced HRDEM. This approach does not replace field investigations, but it changes the fieldwork methods, which become part of the validation processes of a landslide inventory produced by HRDEM analysis (Jaboyedoff et al., 2010). However, the interpretation of the results and the presence of vegetation may degrade the DEM quality, but the detailed morphology provided by HRDEM coupled with geologic information can allow a precise delineation of the limits. Indeed, ALS-derived DEM gives an accurate topography and permits to identify morphologies that are significant in order to characterize the past activity. This method allows a detailed delimitation of the landslides on the topographical surface and it is possible to infer the failure surface in 3D. Moreover, the ALS-DEM is useful in order to improve the traditional hazard mapping by field investigation, especially for inventories but also for characterizing the susceptibility using morphometric indicators. Morphometric indicators such as roughness, and curvature of the slope are used.

Concerning the process-based modeling of debris-flows, is a difficult task because of the complexity of the phenomenon and the variability of controlling factors. The critical parameters are detailed topography (slope angle of channels as well as the channel profile) and channel material can be critical parameters. The ALS-DEM can be used to assess properly the volumes that can be mobilized. Based on the topography curvature of ALSDEM and other properties, it is also possible to extract potential source areas for debris flows (Horton et al. 2008). Moreover, another improvement provided by ALS-DEM is the possibility to improve the modeling of propagation, despite the fact that computing time is very high if a full resolution ALS-DEM is used to compute the models on large areas.

Concerning rockfall the use of ALS-DEM is not yet implemented as a routine, The issue is to locate the source areas. This is often performed at regional scale using slope angle thresholds and slope angle distribution. The threshold depends on the type of bedrock, the presence or absence of a soil cover and the DEM resolution (Loye et al. 2009). This method makes it possible to discriminate efficiently the true cliffs from the one drawn on topographic maps. This method makes it possible to discriminate efficiently the true cliffs from the one drawn on topographic maps. In addition, it is possible to perform structural analysis using ALS-DEM for kinematic test and for trajectographic modeling in order to delineate the propagation area. In addition, the kinetic energy profile is greatly modified when the resolution of the DEM is increased.

Laser scanning is a common tool for displacement monitoring. Obtain the complete field of displacements for the whole landslide is of great help to understand landslide kinematics and failure mechanism. The basic principle requires at least two epochs of HRDEM acquisition. Nevertheless, as monitoring requires both high resolution and high precision data sets, for this reason most of the works have been done up to now using TLS-derived HRDEMs. The low number of monitored landslides using ALS-derived HRDEM is due to the lower precision of ALS compared to TLS. As a result, comparison of such HRDEM requires a longer period between two acquisitions to obtain reliable results. Nevertheless, it is possible to obtain displacement maps simply comparing objects locations on the pictures and on the ALS-DEM (Jaboyedoff et al., 2010).

Main advantages of the technique are the acquisition of real 3D information, the fast data acquisition and its high resolution, . Reversely, the main limitations of the technique are the existence of shadow areas caused by rugged topography, the huge quantity of acquired information and the needed post-processing techniques for filtering and alignment of the data sets, i.e. when a large area is scanned, several data sets must be merged and due to error propagation the alignment started to be more complicated and time-consuming to obtain reliable results.

Another application of aircraft sensors collecting information is the *airborne radar instrumentation*. Basic principles are the same for both satellite and airborne sensors: SAR interferometry uses mainly the phase measurements of two or more SAR images of the same scene, acquired at two different times and/or slightly different locations, the inteferogram resulting as output represent very small slant range changes which can be related to topography and/or surface deformation.

For motion mapping (e.g., multitemporal velocity field measurement of landslides, slope instability) it is necessary to separate the motion-related and the topographic phase contributions. This can be done by differential processing, using multi-pass interferograms which can map small time-sequential relative topographic displacements on the order of one centimetre although field calibration is usually needed to define absolute movements. The data processing technique known as differential SAR interferometry (DInSAR), enables the removal of the topographic component (Metternicht et al., 2005).

InSAR is mainly suitable for monitoring very slow movements of slopes and individual objects. The main advantage over other conventional techniques is the possibility of very precise displacement measurements over large, sparsely vegetated areas at reasonable costs.

To sum up, the potentials and opportunities of SAR sensors for monitoring slope instability are:

- The availability of high resolution images from sensors increase the geomorphologic information on slopes, generating more reliable landslide inventory maps;
- Detailed motion maps produced using techniques such as Permanent Scatterers (PS), DInSAR or InSAR can assist in more accuracy slope stability studies. When the conditions are correct, SAR interferometry is a useful tool for mapping and monitoring mass movements;
- If SAR time series are available, accurate analysis of displacement is possible using PS technique.

However, this technique to monitor slope motion highlight some constraints, as reported by several studies. InSAR only measures displacement in slant range (e.g., the displacement in direction of the radar illumination),the component of velocity vector in the flight direction cannot be measured. Moreover, Really large displacements cannot be detected with InSAR. There is a limit with respect to the displacement gradient between adjacent pixels, which must be less than half the radar wavelength. Another limitation is density and change in vegetation.

Lastly, some advantages of airborne LIDAR over SAR imagery and radar interferometry for the study of landslide in steep, rugged terrain: firstly, LIDAR data are gathered over a narrow vertical swath angle (usually less then 20 degrees off nadir), being usually not affected by topographic shadowing, unlike SAR; secondly, LIDAR data are much easier to process than SAR information and the data can be obtained with a density of around one meter, and vertical accuracy of around 10 cm (Metternicht et al., 2005).

The airborne systems present advantages and limitations, concerning external parameters:

- *the time available.* Advantage of the method is the rapid collection of spatial information. The limitation is mainly related to acquiring new images, process them in order to make them usable by operators. The same for the retrieval of archival images.
- *studied area and its accessibility*. It can identify several requirements for the practical applicability of the technique to landslide monitoring, in relation to slope failure size, surface cover, slope inclination: sensor; bare surface or with little vegetation; low to moderate slope inclination and suitable; orientation with respect to the viewing angle. Moreover, the aircraft systems, such as satellite systems, represent a very useful complementary data source with respect to the information acquired through ground based observations and in situ surveying.
- *exposure to hazardous conditions*. The remote sensing will be especially valuable where no other data sources are available. Then this information can be used to focus on those slopes where there is a potential hazard and where more detailed geotechnical investigations or in situ monitoring may ultimately be required.
- *representation scale.* Considering the size of most landslides, which is in the order of several tens to a few hundreds of meters, the most useful scale is a large/medium scale. At this scale the phenomenon cannot only be identified as a slope instability feature, but a preliminary analysis of the feature is also possible, as the elements of the landslide can be recognized and analyzed. Using smaller scale, a slope failure may be recognized as such, if size and contrast are sufficiently large. However, the amount of analytical information will be very limited at scale smaller than 1:25.000.

The literature reviewed shows that the contribution of remote sensing to the mapping, monitoring, spatial analysis and hazard prediction of mass movements (e.g., landslides, debris flows) has largely been in the form of stereo airphoto and satellite image interpretations of landslide characteristics (e.g., distribution and classification) and factors (e.g., slope, lithology, geostructure, landuse/land cover, rock anomalies). The 1: 15,000 or larger scale is said the best for detecting individual elements related to landslides.

The following table (Table 27) shows the feasibility and usefulness of applying remote techniques for landslide hazard zonation in three working scales (Mantovani et al., 1996). This table was produced before the launch of high resolution satellite sensors and the reporting of successful applications of InSAR, DInSAR, PS, however observations about feasibility and usefulness are still present. In the table the first number indicates the feasibility of obtaining the information using remote sensing techniques (1=low: it would take too much time and money to gather sufficient information in relation to the expected output; 2=moderate: a considerable investment would be needed, which only moderately justifies the output; 3=good: the necessary input data can be gathered with a reasonable investment related to the expected output). The second number indicates the usefulness (1=of no use: the method doe not result in very useful maps at the particular scale; 2=of limited use: other techniques would be better; 3=useful) (Mantovani et al., 1996).

Landslide hazard mapping based on landslide inventory maps benefits most from information collected using remotely sensed data, followed by heuristic approaches at regional and medium scales, statistical and landslide frequency analysis using indirect methods (for medium and large scale studies). Hazard analyses at large scale based on deterministic approaches benefit from the incorporation of remote sensing information, though such models require a considerable investment in terms of money; whereas the process-based models at regional and medium scale are the least feasible of benefiting from the incorporation of parameters derived from remotely sensed data.

Type of landslide analysis	Main characteristics	Regional scale	Medium scale	Large scale
Distribution analysis (landslide inventory approach)	Direct mapping of mass movement features resulting in a map that gives information only for those sites where landslides have occurred in the past.	2-3	3-3	3-3
Qualitative analysis (heuristic approach)	Direct or semi-direct methods in which the geomorphologic map is reclassed to a hazard map, or in which several maps are combined into one using subjective decision rules based expert-knowledge.	3-3	3-2	3-1
Statistical approach (stochastic approach)	Indirect methods in which statistical analysis are used to obtain predictions of mass movement from a number of parameter maps.	1-1-	3-3	3-2
Deterministic approach (process-based	Indirect methods in which parameter are combined in slope stability calculations.	1-1	1-2	2-3
Landslide frequency analysis	Indirect methods in which earthquakes and/or rainfall records or hydrological models are used for correlation with known landslide dates to obtain threshold values with a certain frequency.	2-2	3-3	3-2

Table 27 - Summary of the feasibility and usefulness of applying remote techniques for landslide hazard zonation in three working scales (Source: Mantovani et al., 1996)

The availability of satellite imagery with higher spatial and spectral resolutions in the thermal range of the spectrum (e.g., Terra ASTER) may develop some interest for research on its potential for landslide hazard applications. Monitoring of landslide activity or motion mapping has been mostly undertaken applying satellite InSAR and DInSAR techniques. For alpine areas current limitations relate to their inability to provide information in steep slope areas, vegetated and/or snow covered areas, in addition to problems of data availability.

6. Case study, landslide management - post event phase

The natural disaster and their consequences are intimately connected to human development processes. The loss of human beings and the destruction of economic and social infrastructure are expected to worsen as climate change increases the frequency and magnitude of extreme meteorological events, such as heat, waves, storms and heavy rains. The Cinque Terre National Park was selected for two principal reason: the high value of landscape and environment, then the severity of the flood event happened on the 25th October 2011 and the severe damages occurred after that. This Park was recognised by UNESCO on its ‘World Heritage’ list, on the basis of cultural landscape criteria and its out-standing value, representing the harmonious interaction between people and nature (World Heritage Report 1997).

The selection of the Cinque Terre National Park as test area is directed to provide specific contributions to improve the attention for the natural and cultural heritage, environmental protection and enhancement, through the safeguard of the landscape and of the architectural and archaeological heritage, damaged or under risk (Spanò and Costamagna, 2010). Indeed, some organizations in the world (UNESCO, ICOMOS, ICCROM, ecc.) emphasize the importance of the protection of cultural heritage as a priority of our society. The heritage conservation field places great importance on the use of principles in guiding practitioners to appropriate interventions for heritage properties.

This chapter aims to show how an approach based on geomatics techniques may improve the effectiveness of emergency response/post disaster analysis of natural disaster.

6.1 General description

The Cinque Terre area (Monterosso, Vernazza, Riomaggiore, Corniglia e Manarola) covers approximately 15 km along the extreme eastern end of the Ligurian coastline, between Levanto and La Spezia. The position of the five small towns and the shaping of the surrounding land-scape, characterised by steep and uneven terrains, encapsulate the continuous history of human settlements in this region over the past millennium (Dongiovanni and Valle, 2007; RSA Parco Nazionale delle Cinque Terre, 2004) In the Cinque Terre area, slope instability is mainly due to the presence of land-slide-hill and lithological composition of the substrate to which has been added, over the last decades, the gradual loss of maintenance and defence of the territory operated by human activity. The surveys have been focused in the area of Vernazza, which reported extensive damages since the flood event of 25th October 2011 that has been caused by the overflow of the Vernazzola stream (Figure 46).

Figure 46 - Location of the study area. The grey area is the Vernazza catchment

6.1.1. Geological and geomorphological setting

The coastline is one of the four zones of the province of La Spezia, morphologically indistinguishable (Federici et al. 2001). There are two major lithological and structural units: *Tuscan unit* and *Ligurian unit*. The Ligurian unit is represented by the *Canetolo subunit* and the *Marra subunit*, while the Tuscan unit by the *Falda Toscana* (Figure 47).

In the investigated area, the bedrock outcrops extensively almost throughout the axis of the channel and can be distinguished (Figure 48):

- Falda Toscana, only represented by the formation of *Macigno*. Turbidites made from layers arenaceous from medium to very thick (up over 2 to 3 m) with base coarse, followed by intervals rolled finer granulometry and then by an interval of pelitic thickness almost always less than 3 - 4 cm; turbidites thin layers formed by arenaceous (maximum thickness of 30 to 40 cm), fine-grained, which go up to a interval pelitic often not more than 10 cm;
- Canetolo subunit represented by *Ponte Bratica sandstones*, turbidites consist of sandstones for gray-greenish in thin layers (on average 10 to 15 cm) thick laminates, alternating with layers of silty marl-power almost equivalent; *Gruppo del Vescovo limestones*, limestones and marly limestones in thick and massive beds of gray to white, alternating with calcareous marl gray darker; *Canetolo clay and limestone*, dark-gray shales with limestone layers and sections of cylinder banks marly limestone-based arenitica; limestone and limestone-marl with alteration are compact and fine-grained with conchoidal fracture, have a thickness varying from a few cm to about 50 cm and are considerably deformed.

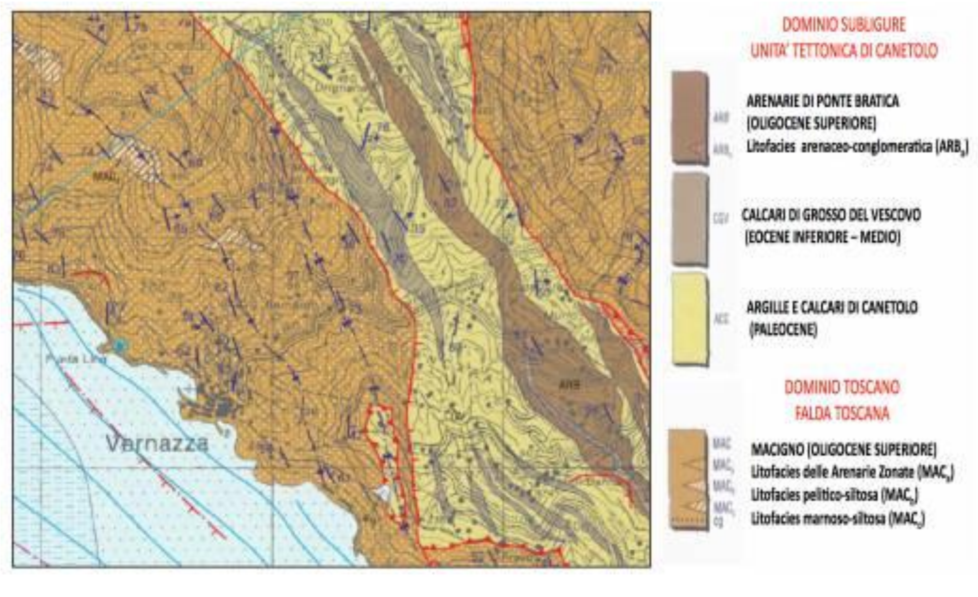


Figure 47 – Extract of geological map 1:25000, Project CARG, F. 248, La Spezia (2003).

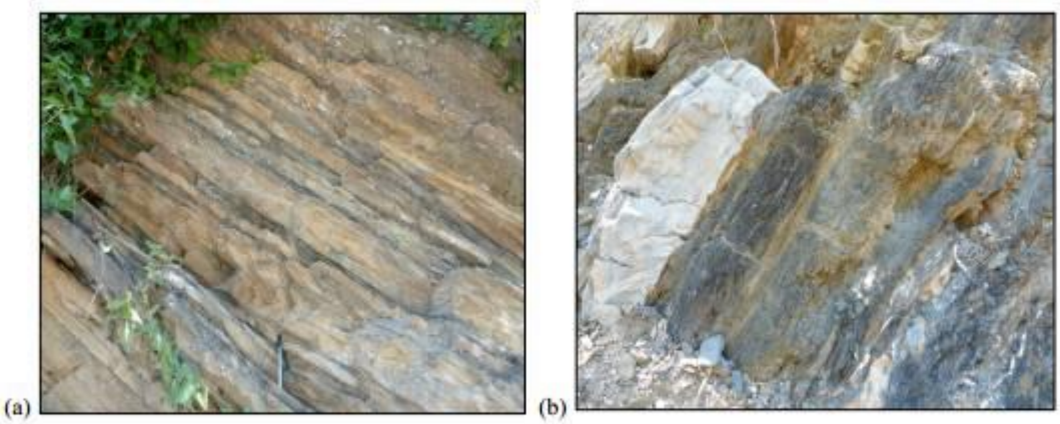


Figure 48 - Detail of the formation of the Macigno (a) and Canetolo clay and Limestone (b).

The coastal morphology is related to the variable lithology of different formations, their schistosity/layering, their geological structures and areas of overlap of tectonic units. External factors influence the morphology in different ways, according the different lithological nature of the substrate. In particular, the schist clayey-marly formations are eroded easily, providing the slopes less steep and full of loose surface debris layers. The carbonate formations and the ophiolites massive provide, instead, slopes harsh, giving rise to extremely rough sea walls to collapse and in general sub-vertical cliffs of considerable height. Also the formations arenaceous, for structural reasons, can have steep slopes. Figure 49 shows the susceptibility map to landslide of the province of La Spezia.

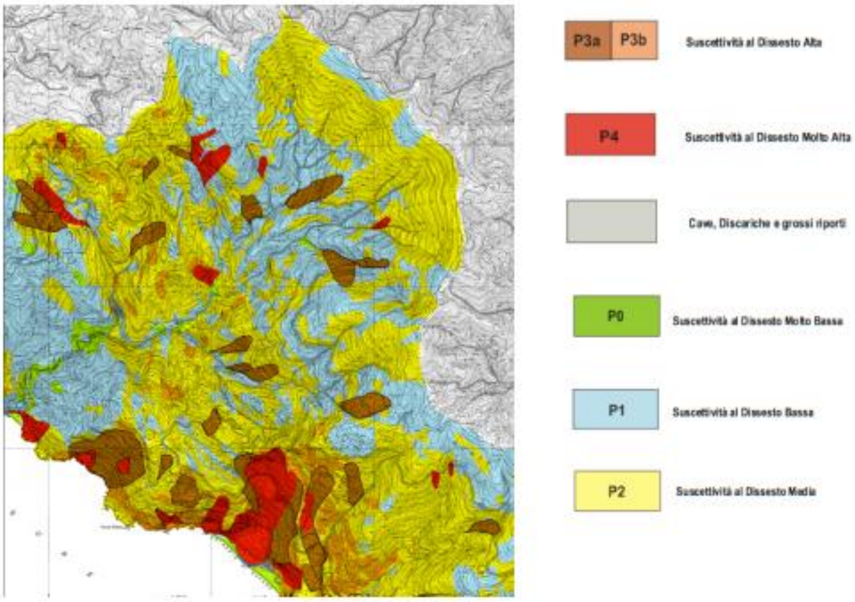


Figure 49 - Susceptibility map to landslide of the province of La Spezia (Source: http://www.provincia.sp.it)

In the coastal area, the main mass movement is that occurs for erosion to the foot, followed by collapses or slipping of failure surfaces, both on the coast to moderate acclivity that of coasts overhanging. In the inland, there are, instead, slopes with less pronounced acclivity, although these formations are still strongly prone to instability, both translational and/or rotational slide. It 's interesting to note that the old landslides have become areas of agricultural settlement and housing, thanks to their lower than acclivity of the slopes. Moreover, landslides larger, however, are again at risk of activation due to erosion torrential. The general steep slope and morphology, however, favoured the degradation processes with a strong areal and/or linear erosive activity.

The drainage network is poorly developed and consists almost exclusively of canals, ditches and channels. These are rivers, with a very limited scope, which, in some cases, may remain almost dry during the dry season. The activity of the water channelled has also led to the deposition of alluvial materials, as shown by the small but numerous torrential floods.

6.1.2. Flood event (25th October 2011)

The heavy precipitation event, occurred in autumn 2011 over the Ligurian Sea,affected an area of about 10x40 km, extending from the Tyrrhenian coastline to the Apennine watershed. The exceptional rainfalls were notably linked to the development of a V-shape Mesoscale Convective System (MCS) that remained over the same area for more than 6 hours, producing an impressive amount of accumulated precipitation over a relatively small area. In particular, the heavy precipitation event, occurred over over the area of Vernazza, exceeded 500 mm in 12 hours, with peaks above 100 mm/hour, leading to a real hydrogeological disaster over the zone by the most organized convective systems (Figure 50) (Turato et al., 2011).

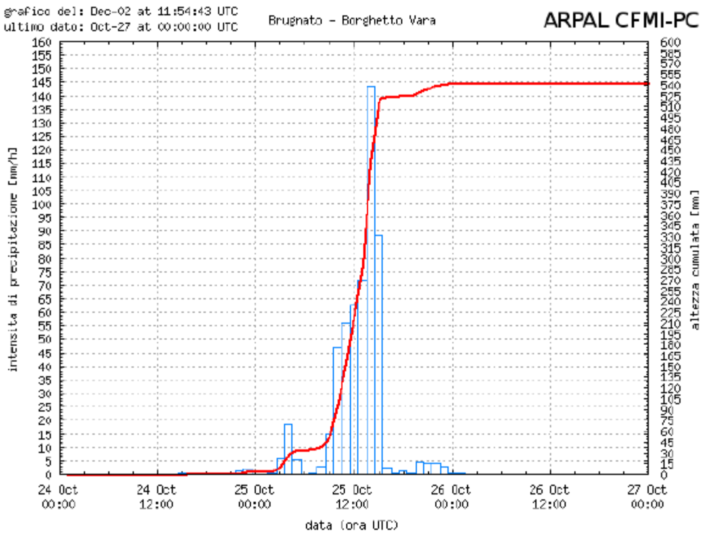


Figure 50 – Ietogram and complete: Brugnato station (Source: Turato et al., 2011)

The rainfalls have caused several landslides involving soil, vegetation cover and the altered portion of the substrate. The surface runoff, due to the inclination of the terrain and the presence of altered ground caused a big amount amount of detritus resulting from landslides and soil cover and in few hours the centre of the town (Figure 51) was reached and partially flooded (Ortolani, 2011).

Figure 51 - Vernazza and its harbour before (a) and after (b) the flood event (Source: Boccardo et al., 2012)

The area has been affected by debris flows, these occur when clusters granules are mobilized as a result of the contribution of large quantities of water. The moving mass is composed of a mixture of air, water and sediments of different sizes, ranging from a few meters to blocks of clays. The flows were activated by small shallow landslides, then the phenomenon can be transformed both in rapid flow, under the action of gravity with the contribution of sudden large amount of water that mobilize further unstable mass. These phenomena are dangerous because, after activation, they can increase velocity, incorporating on the way eroded material by the same flow. During the descent, the sediments of greater size are concentrated in the front, while in the queue prevail finer fractions. This is precisely one of the factors that justifies the high impact strength of the casting on obstacles.

The Vernazzola watercourse and the provincial road along the river, which were seriously damaged by the flood, were the main objective of ground documentation of the calamities. The deposition in the city of a layer of more than 2 - 3 m of mud and debris was favored by urban planning. In fact, the primary road covers the old bed of the river, only a few tens of meters before the town is channeled into the tunnel that leads to the sea. The sudden clogging the entrance to the tunnel by sediments, trees and cars and the inadequacy of the hydraulic flows in disposing of such powerful led quickly the debris flow to slide along the road instead of under it, causing considerable damage to the manufactured products. Moreover, along the stream of water, several artefacts, including bridges, stone masonries opposing the slope pressures, gardens, houses, terraces and other built structures have been heavily damaged or completely destroyed (Figure 52).

Figure 52 - Examples of damages to buildings (Source: Boccardo et al., 2012).

In the affected area by the flood there were about 1000 landslides of which almost 300 only in Vernazza, where the density of landslides was 25 events/km sq.

6.2 Methods

This area has been considered as an example of post event situation. Activities have focused on the assessment of environment. In particular, surveys of slope conditions, production of new watercourse model, surveys in the city center and report on the state of conservation of the paths network have been researched in order to collect information and data on the affected area and in order to propose advices for monitoring and reconstruction plans. For this purpose, different methodologies have been considered. Finally it is shown the feasibility and usefulness of applying methods for post event management in working scale.

The usual first step is the collection of information and data on the studied area. The Liguria Region has provided several geodatabase: the basic maps (Carta Regionale 1:25.000 ed 1994/95; CTR 1:10000 ed 2007; CTR 1:5000 ed. 2007), the Regional Geological Map 1:25000, the Inventory of landslides 1:10000 (IFFI project), the monitoring network of the slopes 1:10000 (Remover) and post flood erosion/accumulation maps, performed by the difference of LiDAR data acquired in 2008 and2011. Even this last products have been achieved by the Friuli Venezia Giulia Region.

6.2.1. Satellite and aerial data

Since the area is large and complex, the most suitable strategy for assessing impacts and damages caused by the flood, is the analysis of images acquired by satellite or aerial platform (pre and post event), conveniently integrated by ground surveys. Remote sensing data, specifically optical data, medium and high resolution have been considered and compared.

As medium resolution data have been evaluated Landsat satellite images, pre and post event; they are archive images, downloadable free of charge from the site USGS Global Visualization Viewer. Specifically, Landsat 7 satellite images have been chosen. The satellite is in a polar, sun-synchronous orbit, meaning it scans across the entire earth's surface. With an altitude of 705 km +/- 5 km, it takes 16 days. The main instrument on board Landsat 7 is the Enhanced Thematic Mapper Plus (ETM+). Main features are:

- Panchromatic band with 15m spatial resolution;
- Visible (reflected light) bands in the spectrum of blue, green, red, near-infrared (NIR), and mid-infrared (MIR) with 30m spatial resolution;
- Thermal infrared channel with 60 m spatial resolution.

Pre event image is 14th September 2011, cloud coverage 0%; post event image is 19th December 2011, cloud coverage 26%. The most appropriate scales of cartographic restitution for a spatial resolution of 30m is 1:100.000, a scale too small for a proper interpretation of the affected area. For this reason images with a resolution of 30 m were sampled at 15m, whit a scales of cartographic restitution of 1:50.000. However, in the following figures it can be noted also as a ground resolution of 15m is not enough to perform an analysis focused on the assessment of losses and direct mapping of small mass movements. For this reason, a scale of 1: 25,000 should be considered as the smallest scale to analyse slope instability phenomena. A slope failure may be recognised if size and contrast are sufficiently large, but the amount of analytical information enabling to make conclusions on type and causes of a mass movement are very limited at scales smaller than 1:25,000 (Figure 53; Figure 54).

Figure 53 - Landsat7 satellite image, pre event (date 14/09/2011), sampled at 15m, representation scale 1:25.000

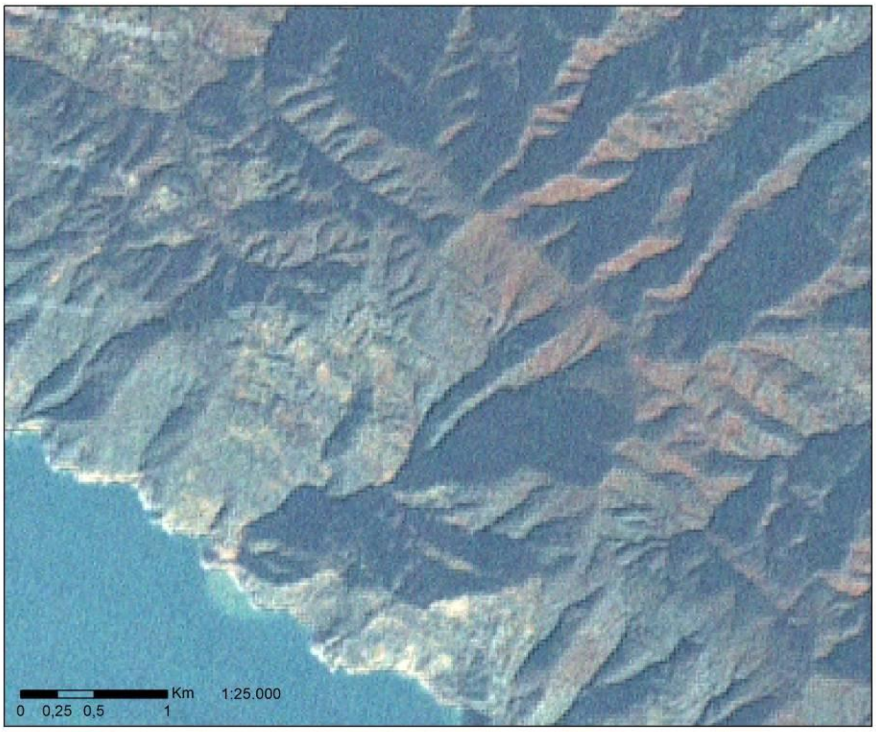


Figure 54 – Landsat 7 satellite image, post event (date 19/12/2011), sampled at 15m, representation scale 1:25.000

The aerial orthophotos and LiDAR flights were provided by Blom CGR Parma and Helica for the Friuli Venezia Giulia Region. Concerning BLOM CGR Ortophotos: pre-event images with GSD (ground sampling distance) 0.50m date August 2010, post–event images with GSD 0.20m in date 28th October 2011; LIDAR flights only post event (28th October 2011) .

Concerning Helica, only one flight performed on the dates 11th -12th -13th November 2011 to 700m AGL (above ground level), and a speed of 130km / h, using Pulse Repetition Frame 100KHz laser, 5:45 theoretical density of ground points per square meter and using for aerial images RolleiMetric AIC-pro (39 megapixel Phase One P45 digital back, CCD sensor with 7228 x 5428 pixel and 6,8 μm pixel size) with GSD 0.15m.

Figure 55 - Ortophoto pre-event August 2010 and post event November 2011 (Source: BLOM-CGR Parma).

Using these images, the scales of cartographic restitution is a detailed scale (> 5.000) and it is possible to perform advanced analysis recognizing affected buildings and roads. Moreover it is possible to identify the most affected areas in order to operated by ground surveys (Figure 56; Figure 57).

The use of remote sensing method allows the rapid collection of spatial data. Then, high/very high resolution data are useful for obtaining information for direct mapping of mass movement features, of flooded area and first damage assessment. Moreover, using remote sensing data and DEM data (extract from LIDAR flight), there is the feasibility of obtain information about geometrical characterization of slope (such as exposure and inclination) and slope model, also using GIS tools it is possible to define surface area and volume involved. The previous parameters can be combined in slope stability calculations and also using rainfall records or hydrological models they can be used for correlation with landslide dates to obtain threshold values.

All these procedures and analysis can be performed separately and/or before a field surveys. However, ground control will always be needed because there are several other ground phenomena that have to be taken into account to interpret correctly the studied area.

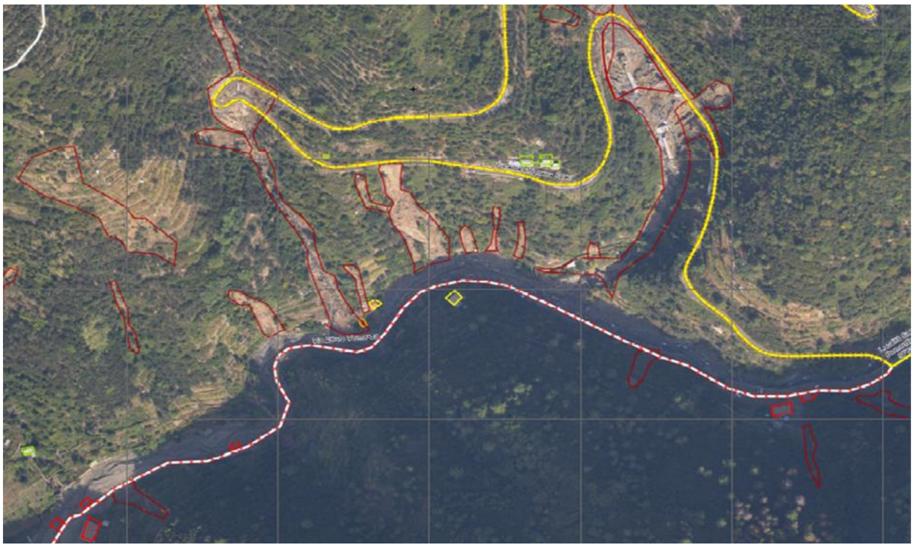


Figure 56 - – Detail of aerial photo post event with delineation of damages (buildings, roads, lasndlisdes)(resolution scale 1:1.000)

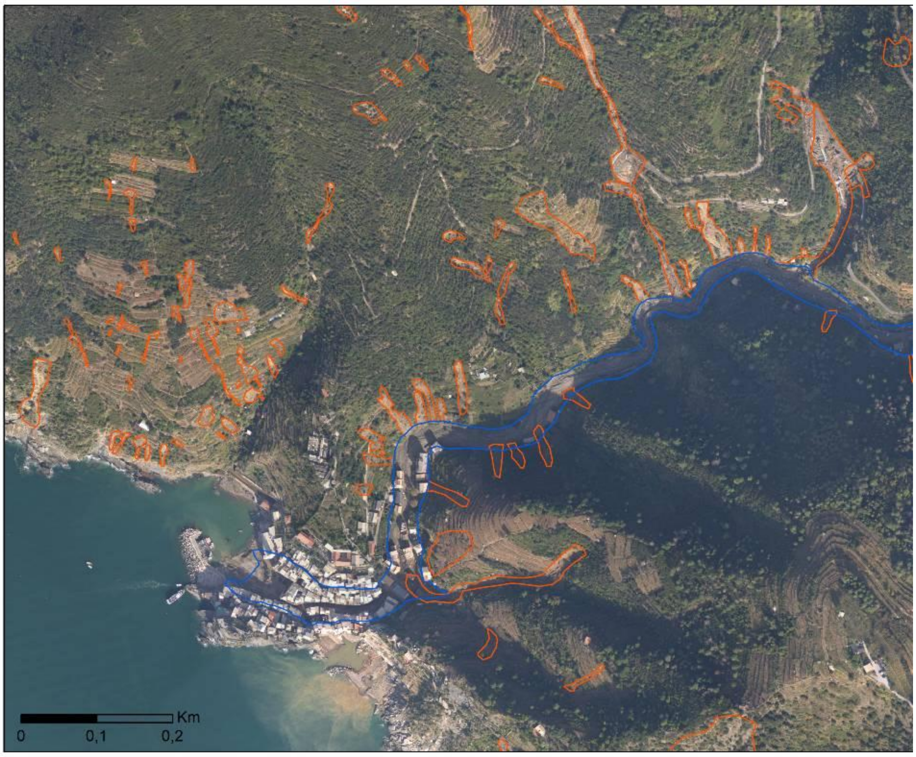


Figure 57 – Aerial photo post event with delineation of damages (landslides and flooded areas)(resolution scale 1:5.000)

6.2.2. Geodetic network

The geodetic network of the area (Figure 58) has been defined by the GPS/GNNS method, it was connected to the permanent ITALPOS stations of BRUGNATO (11 km from Vernazza) and LA SPEZIA (15 km from Vernazza). The vertex situated on the school has was used as local master station. The vertex coordinates was calculated using Leica Geo Office obtaining a good accuracy for the application (RMS: 5 mm in 2D, 10 mm in height). Inside the centre of Vernazza, 3 vertexes were surveyed using total station with a redundant network schema.
The ellipsoidal heights was converted in geoidal heights using a local model of geoid (ITALGEO95) furnished from IGM (Istituto Geografico Militare, the national military geographic institute).

The network represent the basis for the next maps updates and for the multi-scale integration that will support the recovery and rehabilitation projects of the land.

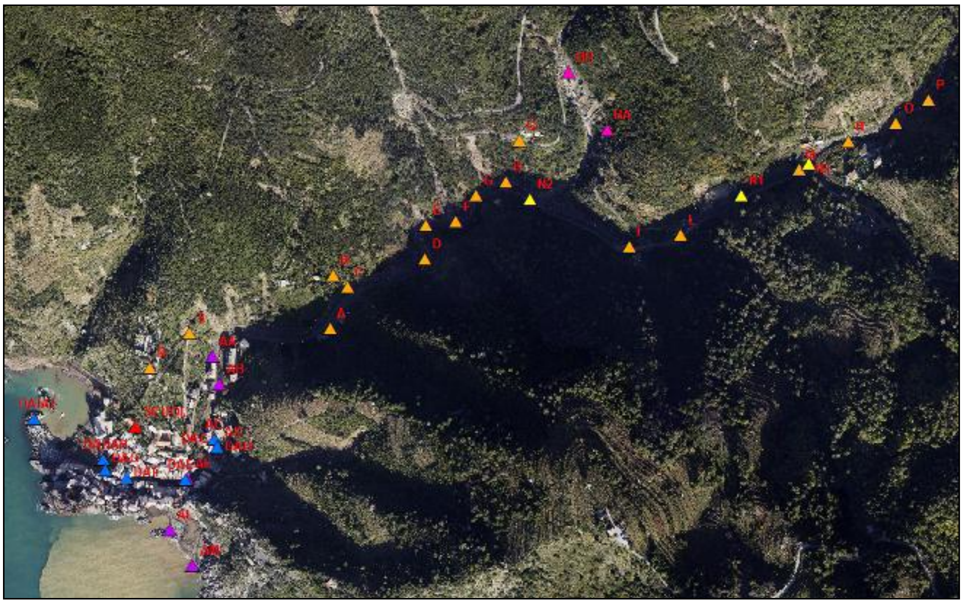


Figure 58 - The geodetic network frame

6.2.3. Traditional surveys: geological field

The traditional survey involves the presence of operators who work directly on target area and in most cases, surveys require the installation/use of instrumentation in order to acquire and/or to monitor on the field Moreover, the acquisition of data on discontinuity occurs in contact with the rock surface and this involves a series of issues related to the achievement of the points of interest, often located on fractured surfaces and therefore dangerous, or at heights without the proper equipment and skills necessary to trace along the slope. On a slope in which there are a large number of joints, therefore, is often difficult to detect even a small part, a factor that makes it difficult an accurate estimation of stability.

The slopes instability has been initially investigated through a geological survey on the field, which has been followed by a geo-structural investigation using traditional method (along scanlines). After an initial photo-interpretation analysis, the study areas were chosen based on localisation of instability phenomena, the most surveys have been concentrated on the primary road (SP 51) (Figure 59). In the figure red stars represent scanlines locations along the primary road (SP51) and along the main geological contact, while blue star represents the survey conducted on the beach formed by the deposition of debris after the flood event.

Geological survey stressed the areas where structural aspects influence instability of the slopes; landslides are more concentrated in the area near the contact of the two different outcropping geological units: in the area represented by the Macigno formation and the Canetolo sub-unit.

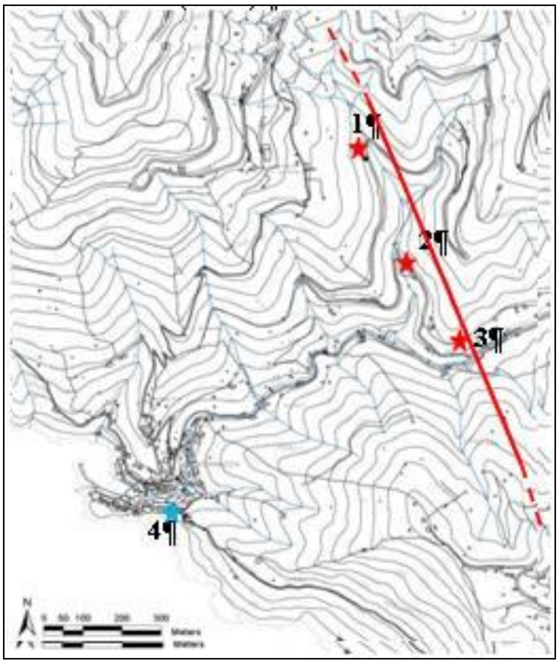


Figure 59 - Location of geo-structural surveys on the Vernazza topographic map (1:5000), red line represents the major geological structure, the contact between the two formations Macigno and the Canetolo formations.

The phenomena have been catalogued using the detection tabs for landslides prepared for the IFFI project (ISPRA) and they are of different types: mainly falls in rock, flows in rock and flows in soil (after Cruden and Varnes, 1996 classification). Rock and soil flows have been caused by internal factors (wide portions of relaxed and altered rocks) triggered by an external factor: the high amount of water infiltrated during the flood event. The rock fall starts with the detachment of rock from a steep slope along a surface on which little or no shear displacement takes place, they are among those phenomena still in progress after the event, due to the main cause of the movement that is an internal factor: the factors (structural characteristics of the slope) have on the movement.

Figure 60 - Pictures of slopes where geo-mechanical surveys have been conducted, the #4 is referred to survey conducted on the new beach.

On the road (SP 51) three different investigations have been performed, with the order to verify the possibility of kinematic movements in reference to phenomena of falling on the individual portions of the rock mass, isolated families of discontinuity (Figure 60).

Basically 3 joint sets are constantly presents on the slopes: two sub vertical sets and one sub horizontal (Figure 61). Table 28 reports the joint set orientation data.

set.	Dip direction [°]	Dip [°]
1	(356.0 ± 180) ± 20	70 -90
2	(246.±180)±20	70.0 -80
3	105.0±20	25.0-30

Table 28 - Joint sets parameters.

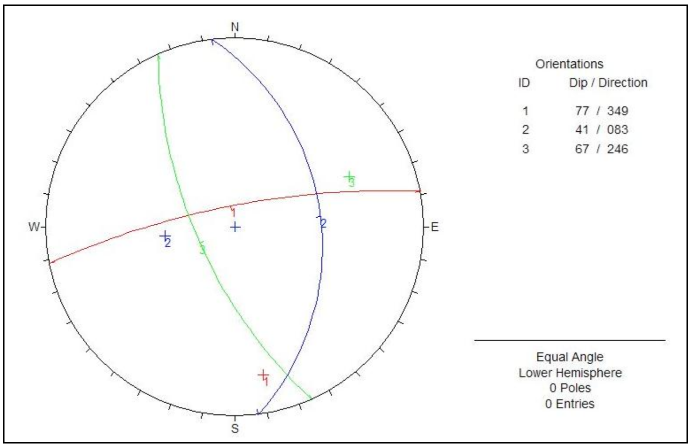


Figure 61 - Stereogram for the three main families identified

Using this method, therefore, it has been possible to identify precisely the pseudo vertical joints, which are those that intersect in a greater number indicated by the horizontal line rib metric during the investigation (Figure 62).

The validity of the results of traditional method of analysis has been integrated acquiring other data through different methodologies, in order to reconstruct a detailed geometric model, where has been possible to identify planes of discontinuity. For this purpose has been used the laser scanning technique.

Figure 62 - Detail of a stringing used for surveying in the field.

6.2.4. Terrestrial Laser Scanning (TLS) survey: slope assessment

The survey with terrestrial laser scanning has been concerned only one of the three investigations along the primary road (Figure 63). The survey of the slopes was carried out with a Riegl LMS-Z420i with a calibrated Nikon D70 digital camera mounted on it. Point clouds of rock faces, (operating ranges of lasers are from 100 to 800 m and more), with accuracies of the 3D coordinates in the range 5 10-3 ÷3 10-2 m and a scanning role from 2000 to 12000 pts/s have been obtained. Angular scanning resolutions are in the order of 100 mrad and allow for a very high sampling density on the object in relatively short acquisition times, resulting in millions of points measured on the object surface. The laser scanner supplies the coordinates of points in space. The next step to realise a geometrical model of the rock mass is the determination of the discontinuity planes.

Figure 63 - Photos of the slope on the side of SP 51 on which the survey was performed geomechanical of interest.

Laser scanner was placed along the road SP 51, in order to have a complete and front view of the rock mass; the mean distance from laser scanner to rock mass is about 50 m. A GPS survey allowed us to georeference the point cloud according to the local geographic system. The DSM (Figure 64) was created triangulating the point cloud; it represents an area which is about 39 m large and 9 m high. DSM is composed by 2’967’901 points, with a density of about 8500 pts/m2.

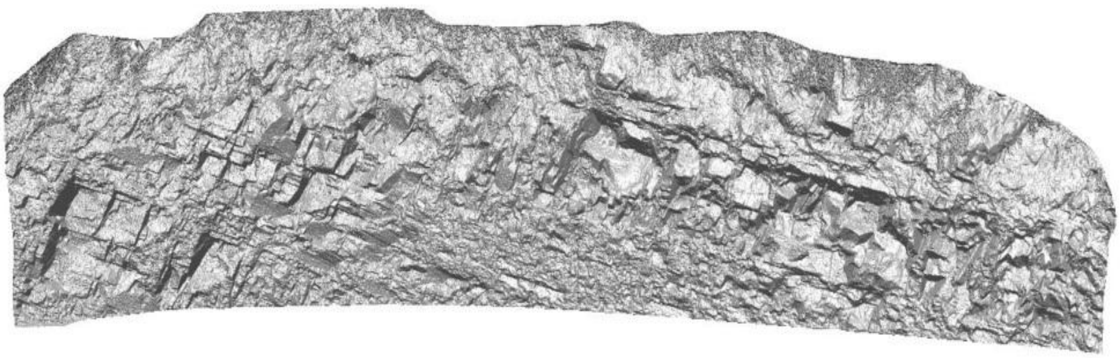
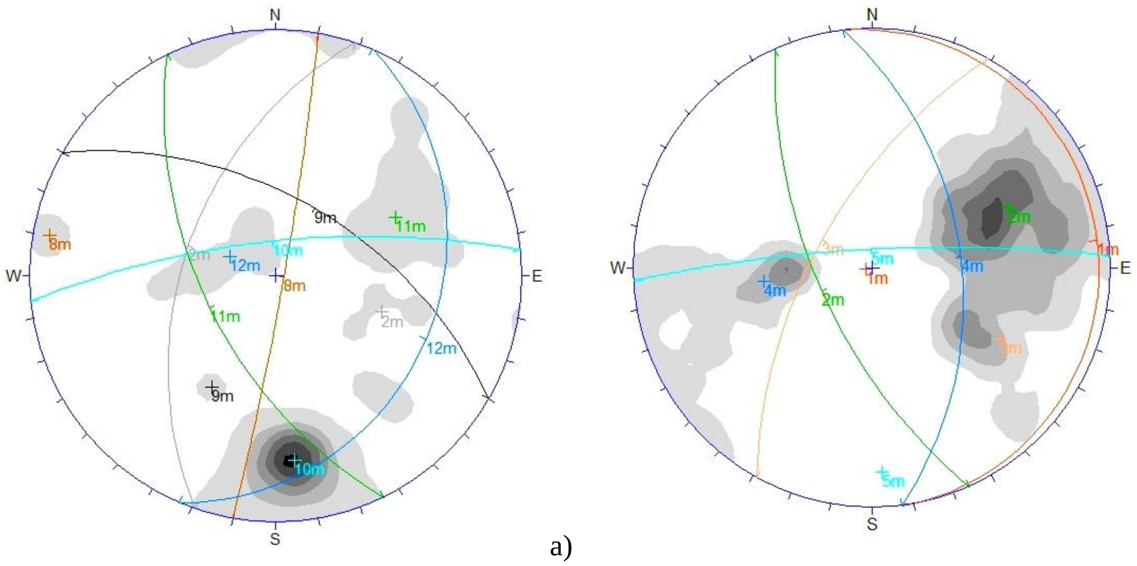


Figure 64 - DSM obtained with the laser scanner (39 m x 9 m, 2967901 points).

DSM data have been used as a starting point for a geostructural automatic detailed survey of discontinuities. In the present case this has been carried out through the use of software Rockscan (Ferrero et al., 2009), developed at the University of Parma, which allows, from a DSM georeferito of the slope and at least a digital image-oriented, automatic identification of the orientation and position of surfaces discontinuity appropriately selected. The image of the slope represents an interface to support the visual recognition and selection of the discontinuities present. Selecting a rock mass portion directly on the image, the software allows the user to determine automatically the planes contained in the selected surface, in number and orientation established a priori by the operator, by defining threshold values of precision with which to identify the points belonging to a same plane. The code computes each equation orientation and other relevant geometrical data of the plane. Moreover, data of arrangement plans can be expressed uniquely through two characteristic angles, the inclination (Dip) and the dip direction of the line of maximum slope. The outputs obtained by this technique allowed the deterministic treatment of the stability both with conventional methods of dynamic analysis of the limit equilibrium, both with separate elements to make a numerical simulation of the entire slope, which is based on the geometry of the systems of discontinuity, on boundary conditions, on the stress state and on the behaviour of the integrate rock and discontinuities.

All stereograms made on the basis of the data obtained with Rockscan are quite similar, while it detects a difference when comparing with that obtained by traditional data analysis. There is a high density of poles in an area of the graph that it is practically empty in all other; with the relief in site, in fact, are carried out several readings also of planes of discontinuity entrants into the hillside, while the analysis on the photograph are much more obvious those parallel to the rock face, which are also those represented more precisely on the digital model of the surface (Figure 65).



a) b)

Figure 65 - Stereograms obtained with traditional survey (a) and using Rockscan (b)

The most significant limitation of this method is therefore linked to the impossibility to find a single picture of all those plans occluded due to not favourable angle between the joint and socket line / scan, especially if you do not apply the corrections necessary to reduce minimum the damage. In this case, the problem has been limited by the availability of the data collected with the traditional survey. Combining these techniques together was, therefore, possible to obtain a estimate of the families of discontinuity and to calculate the volume of the blocks.

The orientation of the discontinuities in relation to that of the slope determines the kinetic and volume potential of the rock blocks to move along the discontinuity planes of their intersections. In all analyzed areas, the blocky system is determined by the inter-section between the 3 sets where one of the plane is sub parallel to the slope. The blocks are supported by the sub horizontal plane and they are cut laterally by the sub vertical planes. The kinematics can then evolve into sliding along the horizontal plane or block toppling on the same plane. In such a geometrical configuration water under pressure plays a key role in triggering the block movements since the sliding plane is dipping with an angle that is smaller than the joint friction angle so the failure must be induced by an extra acting force.

6.2.5. Terrestrial Laser Scanning (TLS) survey: watercourse and new beach

The scanner Focus 3D (Faro Cam2) effectively fitted to the needs of damages documentation due to the portable, the handy characteristics and the simple use. The range of scan distances is variable from 0.6 to 120 m for reflective surfaces (> 90%), the error in linear distances is equal to ± 2 mm at 10 m and 25 m for reflectivity of 10% and 90%; the scan speed is up to 900 000 points per second. In addition, the noise is low and it is possible to acquire radiometric in-formation thanks to the included digital camera with the optical axis coaxial to the laser beam.

The Faro instrument was used for surveying the Vernazzola watercourse (about 2 km from the beginning of the overflow to the sea estuary), and the area of the village where we planned to document the state of built heritage (the main street, the square with the harbour and the castle built on the top of the little hill dominating the town); moreover it has been surveyed a little new beach created by the accumulation of debris due to the flood event (Figure 66).

Figure 66 - A view from the sea of the new beach.

The scans resolution has been chosen medium-high in order to be suitable for both natural and man-made land elements (the scan density was set to obtain 1 point for each 6 mm at distances of 10 meters). During a first step of elaboration a regular set of cross sections at the distance of about 10 m have been briefly extracted, without performing accurate clouds filtering and colouring procedures.

The availability of automated tools in terrestrial laser data management software, allow the use of recording techniques that are endowed with procedures of automatic recognition of geometric correspondences (best fitting).

However, the detected object features, characterized by very few geometric elements easily identifiable and the abundance of repetitive and similar elements (the stones of the river) have advised the use of procedures strictly controlled by measured targets. By means of these control points we achieved the transformation in a single coordinate system based on the reference system WGS84-ETRF2000. Other targets, with a spherical shape and unknown position, have been acquired during points clouds collection with the sole function of tie points, aimed to the registration of adjacent scans. The presented workflow together with a good distribution of tie points and control points enabled rapid registration and recording of scans, obtaining a contextual georeferencing of data and an accurate control of the residuals. The Table 29 shows some information about raw data and results of the performed processing. Figure 67 shows a single coloured points model, the mesh surfaces and an overview of recorded clouds representing the entire section of Vernazzola.

Total Scans	50
Used GCPs/CPs	94
Total raw points	≈ 1 Billion
Dimension (.xyz file format)	≈ 50 Gb
Total points after the post processing (cleaning, noise reduction, decimation etc.)	≈ 260 Million
Dimension (.xyz file format)	≈ 13 Gb

Table 29 - Data showing large size of LiDAR ground collection.

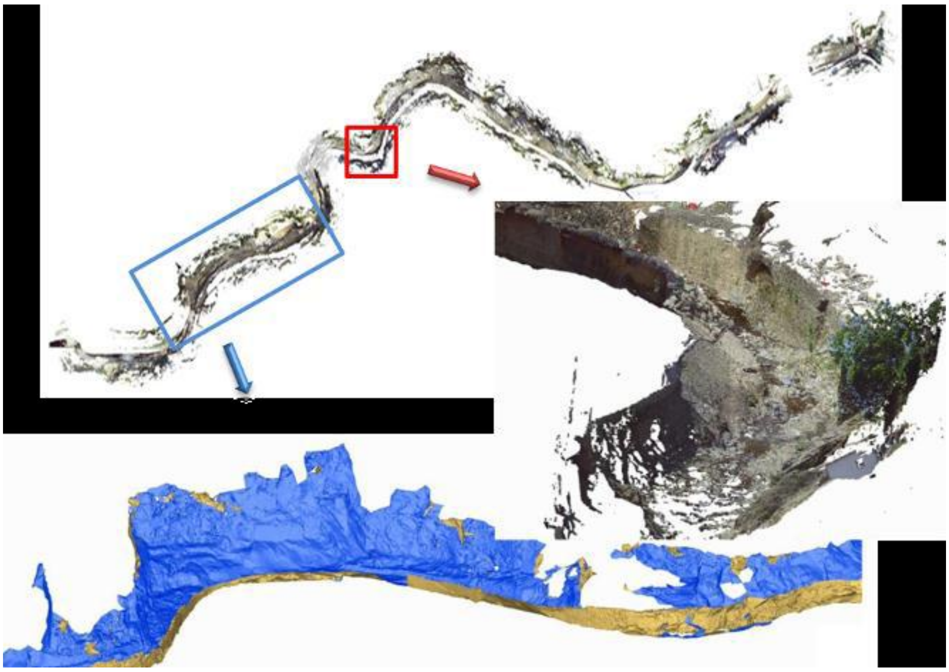


Figure 67 - A collection of images showing TLS data processing results. Coloured models, mesh models and (top) overview of recorded clouds representing the entire section of Vernazzola (Source: Boccardo et al., 2012).

Hydraulic model

The large set of cross sections extracted from the recorded point clouds along the Vernazzola stream (Figure 68) has been used to develop an hydraulic model, using HEC-RAS software, aimed to simulate and design the appropriate safety and restoration measures. The simulations implemented intend to evaluate the stream cross sections more vulnerable to flood events.

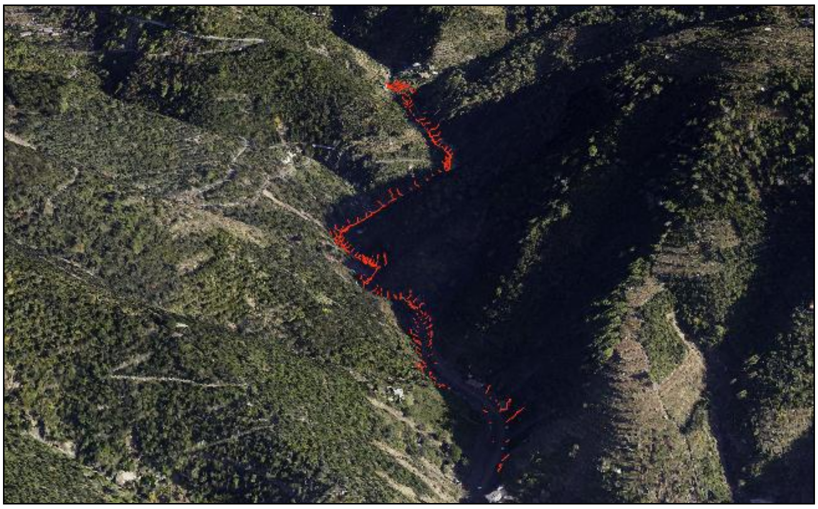


Figure 68 - The extracted cross sections of Vernazzola stream

HEC-RAS has been used to produce a simulation of uniform motion permanent one-dimensional flow. In the calculation it used the same flow data and coefficients roughness used in the previously hydraulic model. It is assumed, in fact, that these parameters have remained the same, unlike the morphology, as amended by the event of flood. An important factor for the model is the coefficient of roughness of the surface, this depends on the coating of the riverbed and the type of vegetation present. For its determination it refers to the Manning coefficients, chosen as a result of inspections carried out along the watercourse analyzed. In this case it is selected the value corresponding to Watercourses and beds of Lower Mountain, with the bottom consisting of gravel, pebbles and boulders sparse. This corresponds to a coefficient n = 0.04, which is used for the right side, the left and the river bed.

The coefficient of expansion and contraction are to same proposed for the previously model developed, they are respectively 0.1 and 0.3. As flow rates are considered those proposed by the Piano di Bacino Area 19 - Cinque Terre, for return periods T = 50 and T = 200 years, and they are respectively 103 m^3/s and 150 m^3 /s.

Concerning the reach boundary conditions, these are a function of the type of current, in this case it refers to mixed stream, with the definition of the conditions upstream and downstream. In both cases, the parameter entered is the critical depth. Finally, the flow profile of each section has been obtained, useful for assessing the flooded areas. for different return periods considered (TR50 and TR200). The following figure are some sections of the study area. Figure 69 shows the section 957.6968 m, where it can be note that the flow for high return period (> T = 50) can flood the left margin, causing damage to the primary road (SP51). The behavior of the flow in the next figure shows that for high return periods (T = 50 and T = 200) the channel does not invade the road section. However, the flow could overwhelm the embankment on the left bank (Figure 70). Simulations show that some sections of the river may be affected by of flooding with the return period of 50 years.

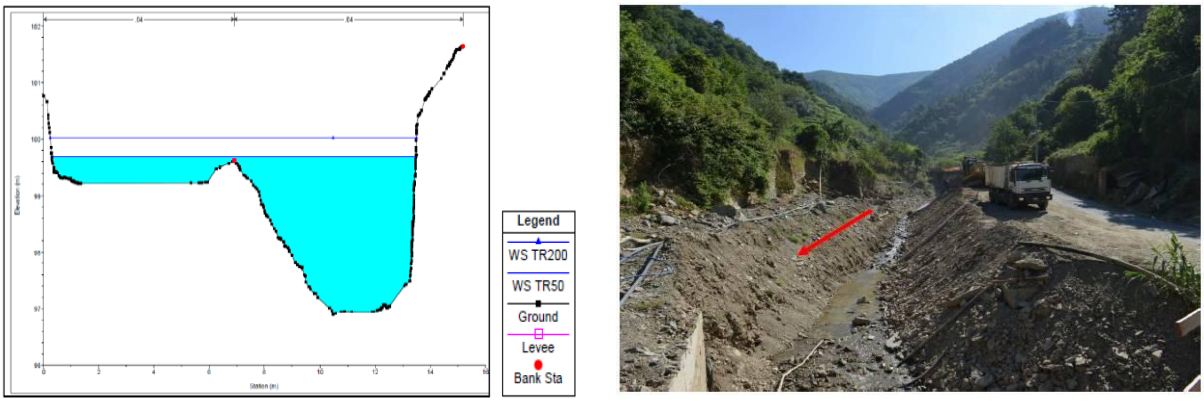


Figure 69 – Output of the hydraulic model for the section 957.6968 m. Next, Vernazzola stream, sector at the section 957.6968 m. (The arrow indicates the direction of flow from upstream to downstream).

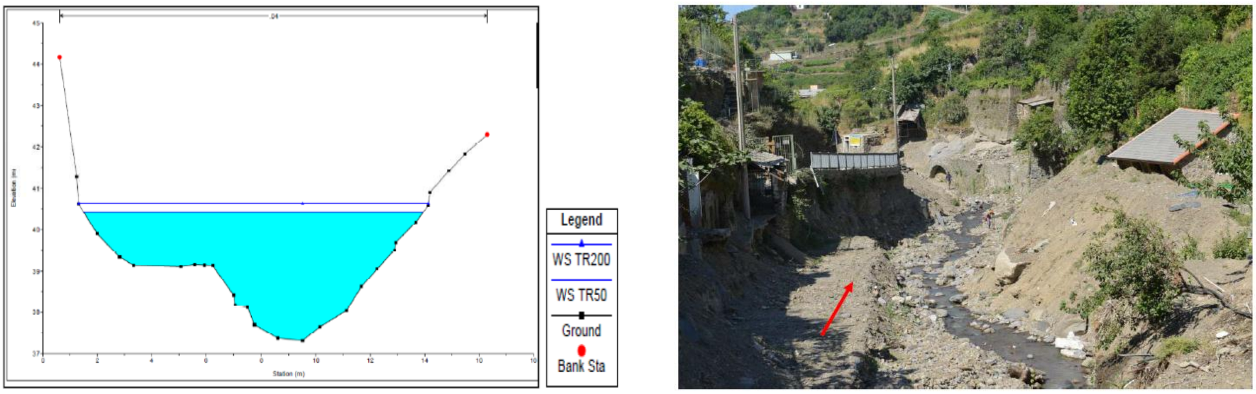


Figure 70 - Output of the hydraulic model for the section 282.3555 m. Next, Vernazzola stream, sector at the section (The arrow indicates the direction of flow from upstream to downstream).

New beach analysis

The heavy precipitation event, occurred in autumn 2011, caused the surface run-off upstream the Vernazza village; a big amount of detritus resulting from landslides filled the little creek, generating a new beach. Using the TLS method, it has been possible to realize a complete survey of this new beach and to achieve an high resolution model (Figure 71).

Figure 71 - Example of TLS acquisition

After the flood, this area have been under careful attention because the uneven coastline of the region offer little place to accommodate people, and a large stony beach, easily and rapidly approachable from the train station, is a very interesting place for the local administration. After the needful stability controls of the rocky slope and safety conditions of the area, this place can emerge as a cultural and tourist resource for the village. TLS points were used to generate a surface of the beach area and near rock faces. Figure 72 is a semi-nadiral view to emphasize the different directions of the tunnels. The contour lines were extracted by planar sections and the coastal line was collected using the limit of TLS data (Figure 73).

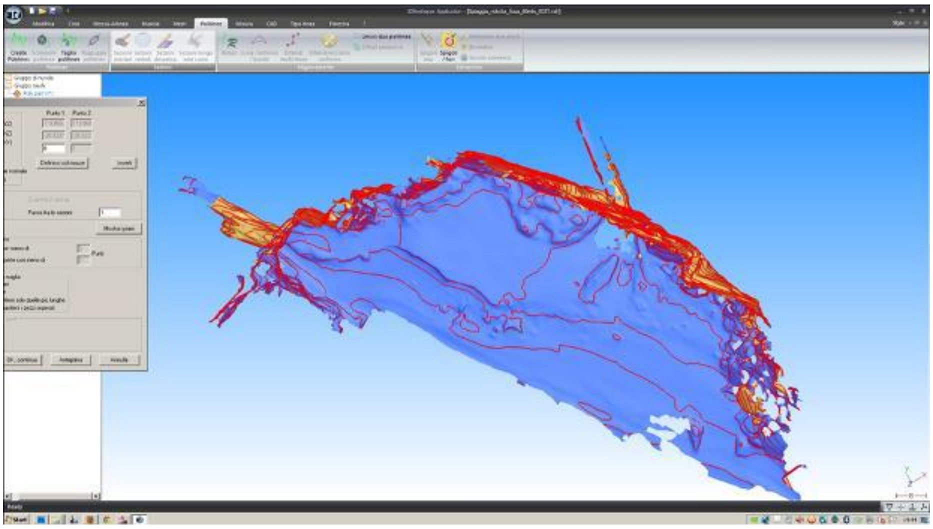


Figure 72 - The beach surface

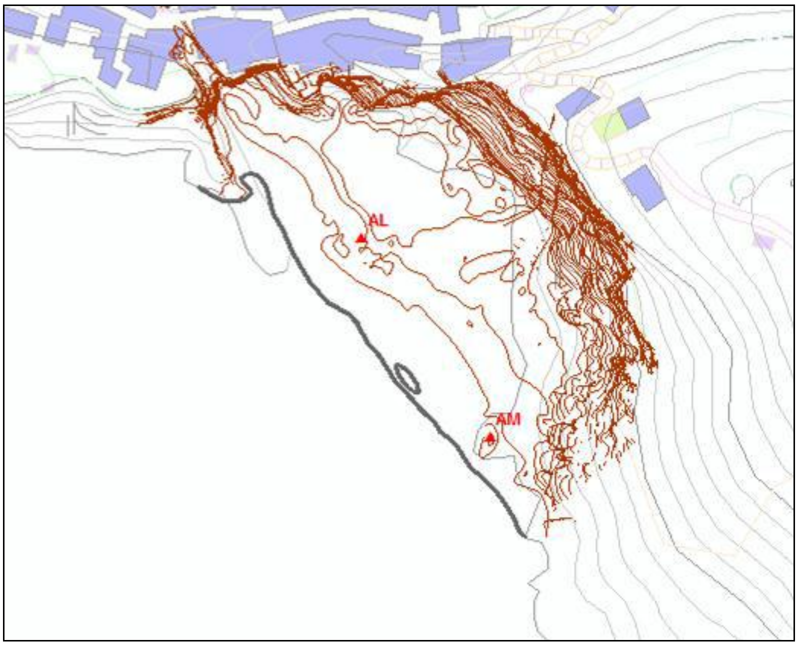


Figure 73 - Contour lines with new sea border line.

6.2.6. Mobile mapping system: paths network

Typical slopes planted with vines by terraces systems, are a unique testimony of the transformation of the area by human activity as well as local areas of interest. Difficult access, due to the land features of the area is made possible by a network of paths, sometimes overlooking the sea, which represents an important component of the landscape and for hiking the Cinque Terre National Park. In this case, because of several factors including the accessibility to the site, for the post-event assessment it was decided to test a mobile mapping system using a bike as vehicle. Indeed, mobile mapping systems allow rapid collection of data to allow accurate assessment of conditions on the ground. The sensor used for the data acquisition is positioned on a vehicle, a bike; this allows to move quickly in the studied area and to acquire large amounts of data in a short time. Obviously the data acquisition is functional to area accessibility, this method cannot be used if the vehicle does not have the possibility of movement.

However, the most advantage of the method is the rapid collection of high-quality spatial information. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks. This method has the ability to perform continuous data acquisition.

Surveys have been performed using GO-PRO stereo cameras with GPS receivers (Figure 74) by a team of experienced cyclists. They have covered almost all of the tracks on mountain bikes in order to collect and to georeference important data on the state of the paths (Figure 75; Figure 76), which are afflicted by several interruptions due to landslides, or simply slipping tracts of dry stone walls after the last flood.

Figure 74 - Mountain bike fitted with the stereo 3D Go-Pro cameras and GPS receiver

Figure 75 – Example of the cartographic representation with GIS data

Figure 76 - Example of a pair of images taken from video and 3D geographical location

6.3 Summary

To sum up, the flood occurred in the area of national park of the Cinque Terre has been used as a test for geomatics techniques that may improve the effectiveness of emergency response/post disaster analysis of natural disaster. In particular, the activities have been focused on the phase of damages assessment and mitigation in prediction phase concerning the landslide management and, also, the watercourse accommodation. Different methodologies have been considered:

- Reference data collection;
- Satellite survey;
- Aerial survey;
- Traditional survey;
- Terrestrial Laser Scanning (TLS) survey;
- Mobile mapping system.

The following table shows the feasibility and the usefulness of applying methods for post event management in working scale, in this case it is medium and large scale (Table 30). In the table the first number indicates the feasibility of obtaining the information (1=low: it would take too much time and money to gather sufficient information in relation to the expected output; 2=moderate: a considerable investment would be needed, which only moderately justifies the output; 3=good: the necessary input data can be gathered with a reasonable investment related to the expected output). the second number indicates the usefulness (1=not very useful: the method doe not result in very useful maps at the particular scale; 2=useful, but it is often necessary the integration with other techniques; 3= very useful, anyway the integration with other techniques it is possible, but not necessary). The value of parameters, usefulness and feasibility, are designed from those proposed by Mantovani (Mantovani et al., 1996).

Type of methods	Advantages	Disavantages	Medium scale	Large scale
Remote sensing (satellite / aerial data)	-Direct mapping of mass movement and/or damaged features resulting in a map -Rapid collection of spatial information -Useful on the slopes where there is a potential hazard and the accessibility is difficult - Possibility to assess the extent of material involved and identify the	- Cartographic scale, a scale of 1: 25,000 should be considered as the smallest scale to analyze phenomena - Difficult to monitor specific geological aspects (such as gravity and continuous creep, quick movements of the slope) - Weather conditions	3-2	3-3

	characteristic features of a landslide, by comparing changes over time and programs for calculating estimates of areas and volumes. - Identification of several requirements for the applicability of the technique to landslide monitoring.	-Possible through software processing construct a model of the slope, but not highlight the main discontinuities - Instrumental/operator errors and accuracy assessment of sensors		
Traditional survey	- Detailed information -Operators work directly on target area	- Long period for the acquisition and processing of data - The size and accessibility of the area is a important factor that affects the time for the survey - Possibility of exposure to hazardous conditions	1-1	3-2
Terrestrial laser scanning	- Rapid execution of the survey - Reduction of the time of operation on the field - Realization of a digital model of the slope permits to perform measurements and processing in the laboratory -Economical survey method - Ability to run the survey both day and night -Possibility to perform the alignment of multiple scans partially overlapped without the need of having to lay references in the scene -Operative method, from few cm to hundred meters, so it is possible to make measurements of extended slopes and collect large amounts of data	-Weather conditions -Dependence of the quality of work the reflectivity of the material from which is formed the wall - Instrumental/operator errors and accuracy assessment of sensors - Possibility of exposure to hazardous conditions	2-3	3-3
Mobile mapping system	- The sensor used for the data acquisition is positioned on a vehicle, so it is possible to acquire large amounts of data in a short time. - Real-time image data link from a field mobile mapping system to an office GIS - Ability to perform continuous data acquisition - Economical survey method	- Instrumental error and accuracy assessment of sensors - Possibility of exposure to hazardous conditions	2-2	3-2

Table 30 - Summary of the feasibility and usefulness of applying in specific working scales

Concerning both the large scale and medium scale, the remote sensing and terrestrial laser scanning (TLS) are the better methods used in this assessment. The mobile mapping system is a new method, developed in recent years through advances in resolution and accuracy of navigation sensors and imaging sensors, but it is useful used for various mapping applications.

The last one, traditional survey is useful in detailed area, because it performs a very detailed information, but the several disadvantages (such as, exposure to hazardous conditions, operator errors, long period for the acquisition and processing of data) imply that the method is usable only if supported by other techniques

7. Discussion

Depending on the characteristics of landslides is considered useful to apply one of different instruments of measurement of the morphology and its movement that technology makes available to us, compared to other tools. Analyses of satellite, airborne or ground determine with precision measuring instruments, accuracies and possible acquisition frequencies very different the application has to be assessed from case to case.

In this chapter it propose to evaluate the most appropriate instruments in each family of cases identified, based on surveys carried out in the case study of Vernazza, state of the art and research support emergency. An attempt was made to develop a compendium of methods used in risk management, carried out in the emergency phase and in which they can fuse together traditional methods with newer methods. A compendium focused to better the quality of information obtained from measurement activities / surveys and optimize data and speed to deliver the same to the relevant bodies in both phases of emergency in pre-or post-event. Careful consideration being given to the varying strengths, weaknesses and limitations inherent in each methodology.

7.1 Comparison between different methodologies: advantages and disadvantages

The selection of adequate methods depends on several factors (such as time to install and get results, instruments vulnerability, site accessibility, exposure to hazards conditions, weather conditions). Traditional methods provide conventional activities directly in the studied area. But also, these include exposure to hazardous conditions, long periods for the acquisition data and high costs of management and maintenance for the instruments. Many of the limitations can be overcome through the use of advanced technologies for the information acquisition (terrestrial laser scanning, remote sensing system).

The following tables summarize and compare the main advantages and disadvantages of applied methodologies, for general situations (Table 31; Table 32; Table 33).

According to the main characteristics of the proposed methodologies, it is possible to evaluate the feasibility and the usefulness of applying these methods during the different disaster management phases and for working scale.

The Table 34 shows the values of feasibility and the usefulness of applying methods. The parameters agree those evaluated in the table 34, designed from those proposed by Mantovani (Mantovani et al., 1996). The first parameter indicates the feasibility of obtaining the information (L=low: it would take too much time and money to gather sufficient information in relation to the expected output; M=moderate: a considerable investment would be needed, which only moderately justifies the output; G=good: the necessary input data can be gathered with a reasonable investment related to the expected output). The second one indicates the usefulness (N=not very useful: the method doe not result in very useful maps at the particular scale; U=useful, but it is often necessary the integration with other techniques; VU= very useful, anyway the integration with other techniques it is possible, but not necessary)

GROUND SURVEYS METHODOLOGIES					
TRADITIONAL SURVEY		**TERRESTRIAL PHOTOGRAMMETRY**		**TERRESTRIAL LASER SCANNING**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Ability to collect detailed information on the field	Limited to the area of observation, does not provide an overview of the adjacent sectors	Ability to collect detailed information, also the realization of a digital model permits to perform measurements and processing in the laboratory	Limited to the area of observation, does not provide an overview of the adjacent sectors	Ability to collect detailed information, also the realization of a digital model permits to perform measurements and processing in the laboratory	Limited to the area of observation, does not provide an overview of the adjacent sectors
Operators work directly on target area	Possibility of exposure to hazardous conditions	Rapid execution of the survey and reduction of the time of operation on the field	Possibility of exposure to hazardous conditions	Rapid execution of the survey and reduction of the time of operation on the field	Possibility (low) of exposure to hazardous conditions
	Size and accessibility of the area are key factors, cannot be used easily in any context		Size of the area is an important factor	Operative method, from few cm to hundred meters	Size of the area is an important factor
	Weather conditions	Economical survey method	Weather conditions	Ability to run the survey both day and night	Weather conditions
Ability to formulate hypotheses about the structure, evaluating the possible mechanisms.	Long period for the acquisition and processing of data	Ability to formulate hypotheses about the structure, evaluating the possible mechanisms.		Ability to formulate hypotheses about the structure, evaluating the possible mechanisms.	Dependence of the quality of work the reflectivity of the material from which is formed the analysed area
Possibility to hypothesize movements of individual blocks.		Possibility to hypothesize movements of individual blocks.		Possibility to hypothesize movements of individual blocks.	
	Operator errors		Instrumental/operator errors and accuracy assessment of sensors		Instrumental/operator errors and accuracy assessment of sensors

Table 31 – Summary of main advantages and disadvantages for the proposed methodologies

GROUND SURVEYS METHODOLOGIES					
GROUND BASED RADAR		MOBILE MAPPING SYSTEM		THERMO IR	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Ability to collect detailed information, also it is possible to perform measurements and processing in the laboratory	Limited to the area of observation, does not provide an overview of the adjacent sectors	Ability to move quickly in the studied area and to acquire large amounts of data in a short time.		Ability to collect detailed information	Limited to the area of observation, does not provide an overview of the adjacent sectors
Rapid execution of the survey and reduction of the time of operation on the field	In the case of prolonged surveys, high costs for maintenance of the instrument and for connection to the electricity network	Rapid execution of the survey and reduction of the time of operation on the field Economical survey method	Possibility of exposure to hazardous conditions	Rapid installation of the instrumentation and reduction of the time of operation on the field Economical survey method	
Ability to run the survey both day and night			Weather conditions		Weather conditions
Usually used in order to monitoring small scale phenomena	Size of the area is an important factor		Size of the area is an important factor	Ability to compare thermal images over a wide area, also to	
Ability to formulate hypotheses about the structure, evaluating the possible mechanisms.	The spatial resolution is dependent on the distance	Real-time image data link from a field mobile mapping system to an office GIS		Ability to detect objects in dark areas	
Ability to perform continuous data acquisition	Disturbing elements are the presence of vegetation and location of instrument, which must have a suitable visibility of the target area.	Ability to perform continuous data acquisition		Ability to perform continuous data acquisition	
	Instrumental/operator errors and accuracy assessment of sensors		Instrumental/operator errors and accuracy assessment of sensors		Instrumental/operator errors and accuracy assessment of sensors

Table 32 – Summary of main advantages and disadvantages for the proposed methodologies

GROUND SURVEYS METHODOLOGIES		REMOTE SENSING METHODOLOGIES			
WIRELESS SENSOR NETWORK		**Satellite system**		**Aircraft system**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
Heterogeneous network composed of wireless sensor nodes, Wi-Fi, and satellite terminals. They transmit the data to the central storage collection.	Limited to the area of observation, does not provide an overview of the adjacent sectors	Ability to assess conditions in adjacent sectors	Detailed geotechnical investigations in situ may be required.	Ability to assess conditions in adjacent sectors	Detailed geotechnical investigations in situ may be required.
Rapid capturing, processing, and transmission of critical data with high resolution		Rapid collection of spatial information, different scale of resolution		Rapid collection of spatial information with high/very high resolution	
	Size and cost for the sensors depend on battery power, memory, computational speed and communications bandwidth.	Used in order to study areas where there is a possibility of exposure to hazardous conditions	Amount of analytical information enabling to make conclusions on type and causes of a mass movement are very limited at scales smaller than 1:25,000.	Used in order to study areas where there is a possibility of exposure to hazardous conditions	
		Ability to run the survey both day and night (for radar sensors)	Weather conditions(for optical sensors)	Ability to run the survey both day and night (for radar sensors)	Weather conditions(for optical sensors)
Ability to detect physical parameters (position, temperature, humidity) and to process the data	Exposure to connection Wi-Fi problem	Using multi-temporal images it is possible to make an evaluation of changes (volume, features) in the time.	Possible to realize a model of the movements, but not to speculate on the movement of individual blocks	Using multi-temporal images it is possible to make an evaluation of changes (volume, features) in the time	Possible to realize a model of the movements, but not to speculate on the movement of individual blocks
Ability to delivery in real time the data to management centre	.	Ability to detect areas potentially affected by events, leading to a first filter in the hazard zoning map	The main limitation is the spatial resolution of images	Ability to detect areas potentially affected by events, leading to a first filter in the hazard zoning map	

Ability to perform continuous data acquisition	Low amounts of battery power and low memory availability compared to many existing technologies Instrumental/operator errors and accuracy assessment of sensors	Very useful complementary data source respect to the information acquired through ground based observations and in situ surveying	Instrumental/operator errors and accuracy assessment of sensors	Very useful complementary data source respect to the information acquired through ground based observations and in situ surveying	Instrumental/operator errors and accuracy assessment of sensors

Table 33 – Summary of main advantages and disadvantages for the proposed methodologies

METHODS	PRE EVENT			DURING EVENT			POST EVENT		
	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale
Traditional survey	L-N	M-U	G-U	L-N	L-N	L-U	L-N	M-U	G-U
Terrestrial photogrammetry	L-N	M-U	G-VU	L-N	L-N	L-N	M-N	M-U	G-VU
Terrestrial laser scanning	L-U	M-U	G-VU	L-N	L-N	L-N	M-N	M-U	G-VU
Ground based RADAR	L-U	M-U	G-U	L-N	L-N	L-N	L-N	M-U	G-VU
Mobile mapping system	L-N	L-N	L-N	M-U	G-U	G-VU	M-U	M-VU	G-VU
Thermo IR	L-N	L-U	M-U	L-N	L-N	L-N	L-N	M-U	M-U
Wireless sensor network	L-N	L-N	M-U	L-N	L-N	L-N	L-N	M-U	M-U
Remote sensing (satellite system)	M-U	G-U	G-VU	M-U	G-U	G-VU	M-U	G-U	G-VU
Remote sensing (aircraft system)	G-U	G-U	G-VU	G-U	G-U	G-VU	G-U	G-U	G-VU

Table 34 - Summary of the feasibility and usefulness of applying in specific disaster management phase and working scales (modified by Mantovani et al., 1996)

7.2 Summary of slope movements

The landslides have different characteristics (geographical geological and morphological), involving materials ranging from rocks of high resistance to cohesive soils inconsistent, and involving volume which can vary from a few to hundreds of millions of m^3 and develop at speeds between a few mm / year and m/s. The great variability of the types of phenomena determines morphological characters and kinematic therefore require very different measuring instruments suitable depending on some key characters and in particular by: extension of the phenomenon, and separate directions of displacement, speed of evolution.

According to chapter 2, traditional classifications suggest a subdivision on basis of the movement, the type of material involved and the velocity. The velocity classes are related with the type of movement (i.e. slides, falls, topples, flow) and the material involved (rock, soil, earth) in order to o classify each event with its characteristic velocity and define the degree of hazard.

Indeed, the instance of risk of hazard is closely related to velocity of movement, for each class is given a destructive potential:

- Extremely Rapid: catastrophe of major violence; buildings destroyed by impact of displaced material and many deaths;
- Very Rapid: some live lost, velocity too much to permit to the person to escape;
- Rapid: escape evacuation possible, structures, possessions and equipment destroyed;
- Moderate: some temporary or little damageable structures can be temporarily maintained;
- Slow: remedial construction can be undertaken during movement, intensive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase ;
- Very Slow : some permanent structures cannot be damaged from the movement;
- Extremely Slow: imperceptible without monitoring instruments, construction possible with precaution

Usually, the flow slides are always extremely rapid events both at initiation, retrogression and during flow-like travel. Soils susceptible to spontaneous liquefaction and extremely rapid flow sliding span a very wide range of gradations in the silt, sand and gravel classes. Most slides nearly always begin during heavy rain, ensuring perched saturation of the loose layer. When debris avalanches enter established steep stream channels or gullies, they become channelized, incorporate further material as well as water and turn into surging, extremely rapid debris flows. Also the slides in rock, usually with high degree of structural control, are extremely rapid due to sudden loss of cohesion. Many become fragmented and flow-like, forming extremely rapid rock avalanches. Of these, rock collapses are especially sudden and rapid, and involve failure of strong rock controlled by a combination of non systematic joints and intact rock bridges. Often they involve large slopes in weak, highly anisotropic foliated rocks, rely on their stability through interlayer friction and tend to be slow.

In order to investigate the potential failure mechanisms and/or the monitoring measures in the different phase of disaster management, it is necessary the choice of correct analysis technique. Indeed, not all site investigations are applicable to all classes of slopes, or to all stages of investigation. This depends on site conditions and potential mode of failure/type of movement. The different types of slope movements have been divided in macro-groups: rock falls/slides in rock; slides in soil; flow landslides.

The following tables shows the feasibility and the usefulness of methods previous mentioned for all the macro-groups of slopes (Table 35; Table 36; Table 37).

The first parameter indicates the feasibility of obtaining the information (L=low: it would take too much time and money to gather sufficient information in relation to the expected output; M=moderate: a considerable investment would be needed, which only moderately justifies the output; G=good: the necessary input data can be gathered with a reasonable investment related to the expected output). The second one indicates the usefulness (N=not very useful: the method doe not result in very useful maps at the particular scale;

U=useful, but it is often necessary the integration with other techniques; VU= very useful, anyway the integration with other techniques it is possible, but not necessary).

METHODS	PRE EVENT			DURING EVENT			POST EVENT		
	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale
Traditional survey	L-N	L-U	G-U	L-N	L-N	L-N	L-N	L-U	G-U
Terrestrial photogrammetry	L-N	M-U	G-VU	L-N	L-N	L-N	L-N	M-U	G-VU
Terrestrial laser scanning	L-U	M-VU	G-VU	L-N	L-N	L-N	M-N	M-VU	G-VU
Ground based RADAR	L-N	M-VU	G-VU	L-N	M-N	M-U	M-N	M-U	G-VU
Mobile mapping system	L-N	L-N	L-N	L-N	M-U	M-VU	L-N	G-U	M-U
Thermo IR	L-N	M-N	M-VU	L-N	L-N	L-N	L-N	M-N	M-U
Wireless sensor network	L-N	M-N	M-U	L-N	L-N	L-N	L-N	M-N	M-U
Remote sensing (satellite system)	L-N	M-N	M-U	L-N	M-U	M-VU	L-N	M-U	M-U
Remote sensing (aircraft system)	L-N	M-U	G-U	L-N	M-U	G-VU	L-N	M-U	G-U

Table 35 - Application of investigation methods to rock falls type of landslide (modified by Mantovani et al., 1996)

L=low: it would take too much time and money to gather sufficient information in relation to the expected output; M=moderate: a considerable investment would be needed, which only moderately justifies the output; G=good: the necessary input data can be gathered with a reasonable investment related to the expected output

N=not very useful: the method due not result in very useful maps at the particular scale; U=useful, but it is often necessary the integration with other techniques; VU= very useful, anyway the integration with other techniques it is possible, but not necessary

METHODS	PRE EVENT			DURING EVENT			POST EVENT		
	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale
Traditional survey	L-N	M-U	G-U	L-N	L-N	L-N	L-N	M-U	G-U
Terrestrial photogrammetry	L-U	L-U	G-U	L-N	L-N	L-N	L-N	M-VU	G-U
Terrestrial laser scanning	L-U	M-U	G-VU	L-N	L-N	L-N	L-N	M-VU	G-U
Ground based RADAR	L-U	M-U	G-VU	L-N	M-N	M-N	L-N	M-VU	G-U
Mobile mapping system	L-N	L-N	L-N	L-N	M-VU	G-VU	L-N	M-U	M-VU
Thermo IR	L-N	M-U	M-VU	L-N	L-N	L-N	L-N	M-N	M-U
Wireless sensor network	L-N	M-U	G-VU	L-N	L-N	L-N	L-N	M-N	M-U
Remote sensing (satellite system)	L-U	G-U	G-VU	M-U	M-U	M-VU	M-U	M-U	G-VU
Remote sensing (aircraft system)	L-U	G-U	G-VU	M-U	G-U	G-VU	M-U	G-U	G-VU

Table 36 - Application of investigation methods to slope in soil, macro-group of landslide (modified by Mantovani et al., 1996)

L=low: it would take too much time and money to gather sufficient information in relation to the expected output; M=moderate: a considerable investment would be needed, which only moderately justifies the output; G=good: the necessary input data can be gathered with a reasonable investment related to the expected output

N=not very useful: the method doe not result in very useful maps at the particular scale; U=useful, but it is often necessary the integration with other techniques; VU= very useful, anyway the integration with other techniques it is possible, but not necessary

METHODS	PRE EVENT			DURING EVENT			POST EVENT		
	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale	Small scale	Medium scale	Large/detailed scale
Traditional survey	L-N	M-U	M-VU	L-N	L-N	L-N	L-N	M-U	M-VU
Terrestrial photogrammetry	L-U	M-U	M-U	L-N	L-N	L-N	L-N	M-N	M-U
Terrestrial laser scanning	L-U	M-U	G-VU	L-N	L-N	L-N	L-N	M-U	G-VU
Ground based RADAR	L-U	M-U	G-VU	L-N	M-N	M-N	L-N	M-U	G-U
Mobile mapping system	L-N	L-N	L-N	L-N	M-U	G-VU	L-N	M-U	M-VU
Thermo IR	L-N	M-U	M-U	L-N	L-N	L-N	L-N	M-U	M-U
Wireless sensor network	L-N	L-U	G-U	L-N	L-N	L-N	L-N	M-U	M-U
Remote sensing (satellite system)	M-U	M-U	M-VU	M-U	M-U	M-VU	M-U	M-U	G-VU
Remote sensing (aircraft system)	M-U	M-U	M-VU	M-U	G-U	G-VU	M-U	G-U	G-VU

Table 37 - Application of investigation methods flow movement, macro-group of landslide (modified by Mantovani et al., 1996)

L=low: it would take too much time and money to gather sufficient information in relation to the expected output; M=moderate: a considerable investment would be needed, which only moderately justifies the output; G=good: the necessary input data can be gathered with a reasonable investment related to the expected output

N=not very useful: the method doe not result in very useful maps at the particular scale; U=useful, but it is often necessary the integration with other techniques; VU= very useful, anyway the integration with other techniques it is possible, but not necessary

Rock fall.

- Pre event phase, the most useful methodologies are ground based surveys:
  - Terrestrial photogrammetry;
  - Terrestrial laser scanning;
  - Ground based radar.

These methods have the capability to formulate hypotheses about the structure, evaluating the possible mechanisms and the possibility to theorize movements of individual blocks. They have, also, the ability to collect detailed information and the realization of a digital model permits to perform measurements and processing subsequently in laboratory. Moreover, the rapid execution of the survey involves the reduction of the time on the field, so also decreases the possibility of exposure to hazard conditions. However, these are limited to the area of observation, does not provide an overview of the adjacent sectors.

Secondly, another method used is:

- Remote sensing (high/very high resolution satellite images or aircraft system)

The main usefulness of analysis of images acquired by satellite or aerial platform is that can used in order to identify, in large and complex area, slopes potentially subject to collapse thus identifying areas for action from the ground investigation. Indeed, using the remote sensing survey it is possible to assess conditions in adjacent sectors and to trace the tectonic fractures and alignments, in conditions of slopes with scarce vegetation, but not to speculate on the movement of individual blocks. Since the rockfall phenomena are characterized by sudden detachment of rock mass along steep slopes, the ground surveys allow to get a better view of the slope and to collect more accurate than using the remote sensing. This method can be conveniently integrated by ground surveys.

Finally:

- Traditional survey

It is a good investigation method due to its ability to collect detailed information on the field, but it is often necessary the integration with other techniques. Moreover, since operators work directly on target area, there is the possibility of exposure to hazard conditions, and also it is characterized by long period of data acquisition and processing.

- During event phase, the useful method is:
  - Remote sensing (both satellite system and aircraft system)

It is useful in order to evaluate the effects of a natural disaster on the territory and to identify the affected population/infrastructures and to produce suitable cartographic outputs.

- Mobile mapping system,

Its utility is not fully exploited in the case of rock fall, but also it is important since it allows rapid collection of data in order to perform an accurate assessment of conditions on the ground and road/infrastructures. Moreover, with the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks.

- Post event phase, in order to define the affected area the best method are:
  - Remote sensing (high/very high resolution satellite images or aircraft system)

The analysis of images acquired by satellite or aerial platform can classify the damaged areas and can be perform a first assessment of losses. Moreover, it defines the collapsed slopes in order to identify areas for ground investigation through a comparison between pre and post event images.

- Mobile mapping system

Its utility is not fully exploited in the case of rock fall, but also it is important since it allows rapid collection of data in order to perform an accurate assessment of conditions on the ground and road/infrastructures. The sensor used for the data acquisition is positioned on a vehicle; this allows to move quickly in the studied area and to acquire large amounts of data in a short time. Moreover, with the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks. Obviously the data acquisition is functional to area accessibility; this method cannot be used if the vehicle does not have the possibility of movement.

These methods can be conveniently integrated by ground surveys, in particular:

- Terrestrial photogrammetry;
- Terrestrial laser scanning;
- Ground based radar.
- Traditional survey.

They have the ability to formulate hypotheses about the mechanisms and movements of individual blocks. Also they collect detailed information and the realization of a digital model permits to perform measurements about the volume and size of the area involved. These data can be processed subsequently in laboratory. Moreover, the rapid execution of the survey involves the reduction of the time on the field, so also decreases the possibility of exposure to hazard conditions.

Concerning the traditional survey, since operators work directly on target area, there is the possibility of exposure to hazard conditions, and also it is characterized by long period for the acquisition and data processing.

Slope in soil.

- Pre event phase, the most useful methodologies are ground based surveys:
  - Terrestrial photogrammetry;
  - Terrestrial laser scanning;
  - Ground based radar.
  - Thermo IR
  - Wireless sensor network

These methods provide detailed information working medium and large/detailed scale resolution, according rapid execution of the survey and reduction of the time of operation on the field. They have emphasis on monitoring of deformations and geomorphology/geological information through their ability to formulate hypotheses about the structure of slope and to evaluate the possible mechanisms of movements (terrestrial photogrammetric, terrestrial laser scanning, ground based radar). They have, also, the ability to realize a digital model that permits to perform measurements and processing subsequently in laboratory. Moreover, they can be acquiring continuous data (thermo IR wireless sensor network, ground based radar). These methods make tools useful for early warning. However, these are limited to the area of observation, does not provide an overview of the adjacent sectors.

- Traditional survey

It is a good investigation method due to its ability to collect detailed information on the field, but it is often necessary the integration with other techniques. Moreover, since operators work directly on target area, there is the possibility of exposure to hazard conditions, and also it is characterized by long period for the acquisition and data processing.

All these methods are limited to the area of observation, for this reason is used

- Remote sensing (high/very high resolution satellite images or aircraft system)

The main usefulness of analysis of images acquired by satellite or aerial platform, with high/very high resolution, is that can used in order to investigate in the adjacent areas. The collection and analysis of relevant data and information are useful to identify causal factors (both natural and human) which contribute to the hazard; development of a sufficient knowledge of the processes and of the causal factors leading to the hazard. The remote sensing instruments can provide input data for early warning systems dedicated to the evaluation of the impacts of natural components variability (e.g. the climate) on natural disasters occurrences, constituting natural disaster predictions systems.

➢ During event phase, the useful methods are:

- Remote sensing (high/very high resolution satellite images/aircraft system)

It is useful in order to evaluate the effects of a natural disaster on the territory and to identify the affected population/infrastructures and to produce suitable cartographic outputs.

- Mobile mapping system,

It allows rapid collection of high-quality spatial information in order to perform an accurate assessment of ground and road/infrastructures conditions. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks.

Concerning the ground based methods:

- Ground based radar

This not operates directly on the examined area and it has the ability to perform continuous data acquisition, in this case this instrument make tool useful in order to record the mass movement.

➢ Post event phase, in order to define the affected area the best method are:

- Remote sensing (high/very high resolution satellite images or aircraft system)

The analysis of images acquired by satellite or aerial platform can classify the damaged areas and can be perform a first assessment of losses through a comparison between pre and post event images. It defines the collapsed sectors in order to identify areas for ground investigation. Moreover, this survey is used for estimating the volume of disaster, a first estimate for disasters is rarely computed from ground measurements as that would be time consuming and potentially logistically challenging. Instead, volume estimates are generally made using satellite imagery or aerial photographs. Also, where the location is logistically complicated, it is possible to use only satellite imagery or aerial photographs or LiDAR flights.

- Mobile mapping system

Its utility allows rapid collection of data in order to perform an accurate assessment of conditions on the ground and road/infrastructures. The sensor used for the data acquisition is positioned on a vehicle; this allows to move quickly in the studied area and to acquire large amounts of data in a short time. Moreover, with the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks. Where the traditional techniques of geo-referencing aerial photography, ground profiling radar, or Lidar are prohibitively expensive or the site is in inaccessible areas, it is useful using mobile mapping system.

Subsequently, these methods can be conveniently integrated by ground surveys:

- Terrestrial photogrammetry;
- Terrestrial laser scanning;

- Ground based radar.
- Traditional survey

They are good investigation methods due to their ability to collect detailed information on the field working medium and large/detailed scale resolution. Since operators work directly on target area, there is the possibility of exposure to hazard conditions. They have emphasis on geomorphology/geological information, so they can be used for environmental monitoring and waste volume estimation through their ability to formulate hypotheses about the structure of slope and to realize a digital model that permits to perform measurements and processing subsequently in laboratory (comparison between pre and post event surface digital model). Moreover, since some method can be acquire continuous data (ground based radar), they make tools useful for system monitoring concerning the slope stability.

Flow movements.

➢ Pre event phase, the most useful methodologies are ground based surveys:

- Terrestrial laser scanning;
- Ground based radar.
- Thermo IR
- Wireless sensor network

These methods provide detailed information working medium and large/detailed scale resolution, according rapid execution of the survey. They have emphasis on monitoring of deformations and geomorphology/geological information through their ability to formulate hypotheses about the structure of slope and to evaluate the possible mechanisms of movements (terrestrial photogrammetric, terrestrial laser scanning, ground based radar). They have, also, the ability to realize a digital model that permits to perform measurements and processing subsequently in laboratory. Moreover, they can be acquiring continuous data (thermo IR wireless sensor network, ground based radar). These methods make tools useful for early warning. However, these are limited to the area of observation, does not provide an overview of the adjacent sectors.

- Traditional survey

It is a good investigation method due to its ability to collect detailed information on the field, but it is often necessary the integration with other techniques. But also it is characterized by long period for the acquisition and processing data.

All these methods are limited to the area of observation, for this reason is used

- Remote sensing (high/very high resolution satellite images or aircraft system)

The main usefulness of analysis of images acquired by satellite or aerial platform, with high/very high resolution, is that can used in order to investigate in the adjacent areas. The collection and analysis of relevant data and information are useful to identify causal factors (both natural and human) which contribute to the hazard; development of a sufficient knowledge of the processes and of the causal factors leading to the hazard. The remote sensing instruments can provide input data for early warning systems dedicated to the evaluation of the impacts of natural components variability (e.g. the climate) on natural disasters occurrences, constituting natural disaster predictions systems.

➢ During event phase, the useful methods are:

- Remote sensing (high/very high resolution satellite images or aircraft system)

It is useful in order to evaluate the effects of a natural disaster on the territory and to identify the affected population/infrastructures and to produce suitable cartographic outputs.

- Mobile mapping system,

It allows rapid collection of high-quality spatial information in order to perform an accurate assessment of ground and road/infrastructures conditions. With the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks.

➢ Post event phase, in order to define the affected area the best method are:

- Remote sensing (high/very high resolution satellite images or aircraft system)

The analysis of images acquired by satellite or aerial platform can classify the damaged areas and can be perform a first assessment of losses through a comparison between pre and post event images. It defines the collapsed sectors in order to identify areas for ground investigation. Moreover, this survey is used for estimating the volume of disaster, a first estimate for disasters is rarely computed from ground measurements as that would be time consuming and potentially logistically challenging. Instead, volume estimates are generally made using satellite imagery or aerial photographs. Also, where the location is logistically complicated, it is possible to use only satellite imagery or aerial photographs or LiDAR flights.

- Mobile mapping system

Its utility allows rapid collection of data in order to perform an accurate assessment of conditions on the ground and road/infrastructures. The sensor used for the data acquisition allows to move quickly in the studied area and to acquire large amounts of data in a short time. Moreover, with the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks. Where the traditional techniques of geo-referencing aerial photography, ground profiling radar, or Lidar are prohibitively expensive or the site is in inaccessible areas, it is useful using mobile mapping system.

Subsequently, these methods can be conveniently integrated by ground surveys:

- Terrestrial laser scanning;
- Ground based radar.
- Traditional survey

They are good investigation methods due to their ability to collect detailed information on the field working medium and large/detailed scale resolution. Since operators work directly on target area, there is the possibility of exposure to hazard conditions. They have emphasis on geomorphology/geological information, so they can be used for environmental monitoring and waste volume estimation through their ability to formulate hypotheses about the structure of slope and to realize a digital model that permits to perform measurements and processing subsequently in laboratory (comparison between pre and post event surface digital model). Moreover, since some method can be acquire continuous data (ground based radar), they make tools useful for system monitoring concerning the slope stability.

The parameters expressed in the above tables have been applied to a real case represented by the case study of Vernazza (Liguria) to assess their feasibility (Table 38). In this area, slope instability is mainly due to the presence of land-slide-hill and lithological composition of the substrate to which has been added, over the last decades, the gradual loss of maintenance and defense of the territory operated by human activity. Generally, it is affected by debris flows and/or rock falls, that fall into two of macro-groups above mentioned. This case study has been considered as post event situation. Based on observations made in the field, it can be concluded:

Rock falls - *Post event phase*

The remote sensing has been used to identify the most affected sectors in order to investigate their by ground surveys. This is very useful as a first filter; also it needs to use accurate images (aerial images or satellite images very high resolution). At medium or large/detailed working scale, the useful/ meaningful methods is terrestrial laser scanning, that provide an accurate representation of the slope and the data collection for the realization of the DEM, using subsequently for laboratory analysis.

Finally, the mobile mapping system is useful to perform an accurate assessment of conditions on the ground and road/infrastructures in the adjacent sector affected by slide movement.

Flow movements - *Post event phase*

At medium and large/detailed working scale, the useful/ meaningful methods are terrestrial laser scanning, because it acquires detailed data by ground observation, and remote sensing (aerial images or satellite images very high resolution), because it is a first filter to identify the affected sectors and provides an analytical information enabling to make conclusions on type and mass movement (area and volume involved).

Moreover, the mobile mapping system is useful to perform an accurate assessment of conditions on the ground and road/infrastructures in the adjacent sector affected by slide movement.

It is possible to note similar values feasibility of obtaining the information and the usefulness methodology, between the values applied in the field experience and those based on comparing advantages and disadvantages for each method. This probably because in the case study it must also take into account external factors, such as weather conditions or visibility of the study area. Instead, in the theoretical application it tends to consider external conditions as ideal (perfect visibility, perfect weather conditions). It can assert, in general, a good applicability and usefulness of the presented methods in accordance with the literature review

Therefore, based on observations made in the field, it can assume that it is possible to hypnotize, using this methods, the behavior, likely to reality, also for the other phases of the disaster management:

Rock falls - Pre event phase

At medium or large/detailed working scale, the useful/ meaningful methods are terrestrial laser scanning and traditional survey. These methods provide detailed information about slide conditions (such as dip, dip direction, families of discontinuity, hypotheses about the structure, evaluating the possible mechanisms and movements of individual blocks).

The remote sensing is used to identify probable sectors in order to investigate their by ground surveys, to investigate adjacent areas to evaluate evidence of movement, infrastructure and sectors most affected during a rock fall and it can be used a first filter in the hazard and risk zoning. Also it is possible to trace the tectonic fractures and alignments, in conditions of slopes with scarce vegetation; it needs to use accurate images (aerial images or satellite images very high resolution).

During event phase

The remote sensing is useful in order to evaluate the effects on the territory and to identify the affected infrastructures and to produce timely and accurate suitable cartographic outputs in the organization of the emergency relief.

Parallel, the mobile mapping system allows rapid collection of high-quality spatial information in order to perform an accurate assessment of ground and road/infrastructures conditions. The sensor used for the data acquisition is positioned on a vehicle, a bike; this allows to move quickly in the studied area and to acquire large amounts of data in a short time.

Flow movements - Pre event phase

At medium and large/detailed working scale, the useful/ meaningful methods are terrestrial laser scanning and traditional survey, because they acquire detailed information (slope structure, evaluating the possible mechanisms and slope movements). The remote sensing provides information in the change of slope morphology and in the possible mechanisms, using multi-temporal images or PS method. Also it provides a model of the movements, and it is able to assess conditions in adjacent sectors or triggering factors (human or natural). Also it needs to use detailed images (aerial images or satellite images very high resolution).

During event phase

The remote sensing is able to evaluate the effects on the territory and to identify the affected areas and to produce timely and accurate suitable cartographic outputs in the organization of the emergency relief. Parallel, the mobile mapping system allows rapid collection of high-quality spatial information in order to perform an accurate assessment of road/infrastructures conditions. The sensor used for the data acquisition is positioned on a vehicle, a bike; this allows to move quickly in the studied area and to acquire large amounts of data in a short time.

Type of methods	Rock fall				Flow movement			
	Case study Vernazza (post-disaster phase)		Application of investigation methods (post-disaster phase)		Case study Vernazza (post-disaster phase)		Application of investigation methods (post-disaster phase)	
	Medium scale	Large/detailed scale	Medium scale	Large/detailed scale	Medium scale	Large/detailed scale	Medium scale	Large/detailed scale
Remote sensing (satellite / aerial data)	M-U	G-VU	M-N	G-U	G-U	G-VU	M-U	G-VU
Traditional survey	M-N	M-U	M-U	G-U	L-N	G-U	M-U	M-VU
Terrestrial laser scanning	M-VU	G-VU	M-U	G-VU	M-VU	G-VU	M-VU	G-VU
Mobile mapping system	L-U	M-U	L-N	M-U	M-U	M-U	M-U	M-VU

Table 38 - Comparison between the parameters applied in the case study and these applied in the methodology review (modified by Mantovani et al., 1996)

L=low: it would take too much time and money to gather sufficient information in relation to the expected output; M=moderate: a considerable investment would be needed, which only moderately justifies the output; G=good: the necessary input data can be gathered with a reasonable investment related to the expected output

N=not very useful: the method doe not result in very useful maps at the particular scale; U=useful, but it is often necessary the integration with other techniques; VU= very useful, anyway the integration with other techniques it is possible, but not necessary

Finally, concerning the applicability of the analyzed methods according to the time available to perform the analysis and as a function of the accuracy of the results, it is possible to note that:

Rapid data acquisition. The methodologies recommended for rapid data acquisition appear to be:

- Remote sensing system. It allows rapid data acquisition that can be easily combined with GIS technologies in order to create reliable and timely accessible reference base geographic datasets for cartographic outputs. It can used in order to timely identify, in large and complex area, slopes potentially subject to collapse thus identifying areas for action from the ground investigation. For this reason, this method is very functional in emergency phase for the rapidity of acquisition and processing of the data.
- Mobile mapping system. It allows rapid collection of high-quality spatial information. Moreover, with the innovation in the communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. For this reason, this method too is very useful in emergency phase for the rapidity of acquisition and processing of the data.
- Terrestrial laser scanning, Ground based radar and Terrestrial photogrammetry are able to rapid execution of the survey, with acquisition of detailed data/information. However, because the extension of the area of observation is limited and the time for processing data can be prolonged, these methods are not very useful in emergency phase, while they are useful for operations preparedness, mitigation and prevention.
- Wireless sensor network. This technology has the capability of quick capturing, processing, and transmission of data in real-time with high resolution, it has the ability to perform continuous data acquisition. With the development of communication technologies, such data can be disseminated and accessed through Internet. In particular, this instrument makes the tool useful in case of early warning, especially in hazardous or remote scenarios.

Accuracy of the results. The methodologies recommended for accuracy data acquisition appear to be:

- Ground based methodologies (terrestrial photogrammetry, laser scanning terrestrial, ground based radar, thermo IR, wireless sensor network) are characterized by the ability to collect detailed information and to realize an accurate DEM (used for perform measurements in the laboratory).
- Mobile mapping system. It allows collection of high-quality spatial information in order to perform an accurate assessment evaluation.
- Remote sensing. In particular are considered the aerial platforms and satellite images at high/very high resolution.

Conclusions

The issues related to landslides are important in territory management, in the definition of risk scenarios and in the preparation of opportune measures of forecasting and prevention. For these reasons, it is essential to develop methods based on the collection of survey data and monitoring in order to define scenarios and to implement warning system and/or civil protection plans.

On the basis of a critical analysis of available literature and experience obtained in several projects, it has been proposed a classification of landslide hazard assessment methodologies. The aim of this study was to investigate the different techniques and to check the potential of their use in order to evaluate the most appropriate instruments in the landslide hazard assessment as a function of time available to perform the analysis and the results requested. An approach focused to better the quality of information obtained from measurement activities/surveys and optimize data and speed to deliver the same to the relevant bodies in phases of emergency pre/post and during the event. Careful consideration being given to the varying strengths, weaknesses and limitations inherent in each methodology.

Important starting point is to involve characterizing the landslide (classification, size, velocity, mechanics, location, travel distance) and the corresponding frequency (annual probability) of occurrence. As discussed in previous chapters, the landslides have different characteristics, geographical geological and morphological, involving materials ranging from rocks of high resistance to cohesive soils inconsistent, and involving volume which can vary from a few to hundreds of millions of m^3 and develop at speeds between a few mm/year and m/s.

The great variability of the types of phenomena determines morphological characters and kinematic therefore requiring several measuring instruments suitable depending on main characteristic s and in particular by: extension of the phenomenon, type of movement, speed of evolution and involved material. In this study, it has been tried to divide the different types of slope movements in three macro-groups based on materials and type of movement: rock falls/slides in rock; slides in soil; flow landslides.

In order to investigate the potential failure mechanisms and/or the monitoring measures in the different phase of disaster management, the choice of correct analysis technique is necessary. The study points out that all the available techniques present both advantages and disadvantages, also presents some considerations regarding the scale of applicability of the various approaches. Not all site investigations are applicable to all classes of slopes, or to all stages of investigation. This depends on site conditions, potential mode of failure/type of movement, time available to perform the analysis and the results requested.

The main results of the conducted study include:

- In order to correctly select appropriate instruments for define the landslide hazard assessment, a needs evaluation phase has been performed. The main aim of the activities carried out during this phase has been to identify all the steps of landslide management, all the applications which have been used in the evaluation of hazard and to define the slope model and all the advantages and disadvantages of different methods. The main result of this phase has been to obtain a systematic look at each methodology. In addition, the needs assessment activity itself can be considered as a useful learning tool.

- The remote sensing, according to previous experiences show that its use constitute a main factor for the success of emergency operations, allowing the acquisition of information about the losses entity, destroyed infrastructure and the roads viability. All of these data are useful to produce timely and accurate suitable cartographic outputs in the organization of the emergency relief.
  Generally, the main advantages (the rapid data acquisition, the non-exposure to hazard conditions and ability to detect areas potentially affected by events) make the remote sensing (satellite system and aerial system) a useful tool to capture and process data rapidly and combined with Geographic Information Systems (GIS) technologies, to create reliable and easily accessible reference base

geographic datasets, main factor for the success of emergency operations and for developing valuable natural disaster mitigation and prevention systems.

Considering the pre emergency phase or post event phase, the following constraints of remote sensing determine the choice of appropriate data: the impossibility to identify the type and causes of a mass movement at scales smaller than 1:25,000; the impossibility to speculate on the movement of individual blocks; the limitation in the images spatial resolution. The most suitable remotely sensed data for natural disaster mitigation and prevention system development are satellite images, preferably at high resolutions. In fact this type of data can be helpful in identifying slopes potentially subject to collapse, monitoring the evolution and the interactions with the adjacent sectors. However this method lacks detailed information (i.e. geotechnical data, dip and dip direction) that must be retrieved from interactions on the ground.

Moreover concerning urban planning and/or reconstruction steps, the remote sensing can be used such as a first filter in the hazard zoning map and to identify area for action from the ground investigation.

- Ground based methodologies (terrestrial photogrammetry, terrestrial laser scanning, ground based radar, thermo IR, wireless sensor network) represent the most useful methodologies, in the pre event and post event phase. The main advantages, such as ability to collect detailed information, also the realization of a digital model in order to perform measurements and processing in the laboratory, rapid execution of the survey and reduction of the time of operation on the field, real-time image data link from a field mobile mapping system to an office GIS, make these methods very useful for operations preparedness, mitigation and prevention. Moreover, they are used in the phases of detailed zoning for urban planning and/or reconstruction (collect detailed information about geotechnical, geological and geomorphological characteristics, slope model).
  However, because of the possible exposition of the operators to hazardous conditions and the limitation of the area of observation and modality and time for acquisition/processing data, these methods are not very useful in emergency phase, where it is preferable to use the remote sensing or mobile mapping system.

- The traditional surveys (e.g. topographic survey, geological survey, geomorphological survey), are good investigation methods due to their ability to collect detailed information on the field, but they are often to be integrated with other techniques. Moreover, since the operators work directly on the target area, their exposure to hazard conditions are not negligible. Moreover the traditional technique is characterized by long period of data acquisition and processing.
- Mobile mapping systems allows rapid collection of high-quality spatial information in order to perform an accurate assessment of ground and road/infrastructures conditions. The sensor used for the data acquisition is positioned on vehicle, a car or a bike; this allows to move quickly in the studied area and to acquire large amounts of data in a short time. Moreover, with the development of fast communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized. Furthermore, such data can be disseminated and accessed through Internet and even wireless networks. Where the traditional techniques of geo-referencing aerial photography, ground profiling radar, or Lidar are prohibitively expensive or the site is in inaccessible areas, it is useful to use mobile mapping system. These characteristics determine its usefulness during the emergency and monitoring / evaluation of the damage after the event.

Finally, concerning the applicability of the analyzed methods according to the time available to perform the analysis and as a function of the accuracy of the results, it is possible to note that:

Rapid data acquisition. The methodologies recommended for rapid data acquisition appear to be:

- Remote sensing system. It allows rapid data acquisition that can be easily combined with GIS technologies in order to create reliable and timely accessible reference base geographic datasets for cartographic outputs. It can be used in order to timely identify, in large and complex area, slopes potentially subject to collapse thus identifying areas for action from the ground investigation.

- Mobile mapping system. It allows rapid collection of high-quality spatial information. Moreover, with the innovation in the communication and image compression technologies, real-time image data link from a field mobile mapping system to an office GIS can be realized.
- Terrestrial laser scanning, Ground based radar and Terrestrial photogrammetric are able to rapid execution of the survey, with acquisition of detailed data/information. However, the extension of the area of observation is limited and the time for processing data can be prolonged, these methods are not very useful in emergency phase, while they are useful for operations preparedness, mitigation and prevention.
- Wireless sensor network. This technology has the capability of quick capturing, processing, and transmission of data in real-time with high resolution, it has the ability to perform continuous data acquisition. With the development of communication technologies, such data can be disseminated and accessed through Internet.

Accuracy of the results. The methodologies recommended for accurate data acquisition appear to be:

- Ground based methodologies (terrestrial photogrammetric, laser scanning terrestrial, ground based radar, thermo IR, wireless sensor network) are characterized by the ability to collect detailed information and to realize an accurate DEM (used for perform measurements in the laboratory).
- Mobile mapping system. It allows collection of high-quality spatial information in order to perform an accurate assessment evaluation.
- Remote sensing. In particular are considered the aerial platforms and satellite images at high/very high resolution.

Finally, the selection of the approach to be adopted for a given disaster assessment project is very often based more on economic concerns (cost/benefit analysis, political convenience, etc.) than on the technical nature of the problem. We can assert, in general, a good applicability and usefulness of the presented methods in accordance with the literature review.

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