# MiCHe project

# Multi-risk Hazard_ Norman Tower of Craco

## Mitigation

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# I.4 State of the art for the study and management/mitigation of Landslide Risk

## I.4.1 Assessment of hazards

Landslide hazard depends on numerous concurrent factors: morphology, geology, tectonics, hydrogeology, vegetation cover, land use, etc. Based on the type of approach used to evaluate it we have:

- **relative hazard (susceptibility)**: through the application of heuristic methods (based on qualitative and subjective estimates) or indirect statistical methods (based on the areal frequency of the landslides), generally used for spatial forecasting on a regional scale;
- **absolute hazard**: through the use of direct deterministic or statistical methods (based on the cause-effect relationship), whose reliability is strictly connected to the quantity and quality of the data and, therefore, generally guaranteed only for reduced territorial scales (eg.Single slope). The evaluation of absolute hazard is often a step consequent to that of the relative hazard, which thus assumes the purpose of identifying the most dangerous areas on which to concentrate subsequent studies.

It is therefore clear that the techniques for assessing landslide hazard differ substantially in relation to the scale of analysis. In relation to the type of landslide phenomenon, some intuitive criteria are suggested:

- a landslide that has already occurred will tend to reactivate with the same typology;
- areas with characteristics similar to those in which existing landslides have been detected will be susceptible to similar phenomena;

- the geological, hydrological and geomorphological set-up can provide indications on the typology of potential instability phenomena (a clay slope with a moderate slope will not be subject to landslides).

### I.4.2 Regional risk assessment methods

The following are the main methods for evaluating macro-hazard (eg 1: 25,000 or 1: 15,000):

**Indirect statistical methods**: they are based on the use of bi-varied or multivariate statistical analysis techniques; starting from the cartography of different factors determinant for landslide hazard (weighed according to their relative importance) and the past landslide map, the critical combinations (in terms of landslide frequency) of the various factors are identified (previously divided into classes of values), extrapolating the information also to areas currently not affected by landslides, thus circumscribing the potentially most dangerous areas. In this context, the correct identification of the basic territorial units, i.e. of a spatially homogeneous and objectively mappable domain, to which to refer in the implementation of the GIS, plays a fundamental importance. They can be:

- geomorphological units: natural limits (lithology, morphology, ongoing processes) →these are subjective representations, with manual acquisition of the data, which, however, has a significant physical meaning;
- sub-basins and main slopes: geomorphologically significant subdivision, implementable with algorithms starting from an accurate digital elevation model of the ground;
- unique condition units (homogeneous units): deriving from overlapping operations and intersection of thematic maps (GIS) →poor compliance with the spatial territory;

- elementary cells: discretization using a regular grid (pixel) → poor compliance with the spatial territory.

These indirect statistical methods [24], which have had considerable diffusion over the past years, generally refer to the following factors:

- geological factors:
    - lithology,
    - structural arrangement (faults, fractures, stratification, etc.);
- geomorphological factors:
    - inclination of the slopes,
    - relative height,
    - relative height difference
    - proximity to major landslides,
    - distance from the nearest ridges;
- hydrology and climatology;
- vegetation;
- analysis of existing or past landslides.

The process of cartographic representation (scale 1: 15.000) of these methods is articulated as follows (Fig 9):

1. divide the area under examination into units, for example through a grid;
2. a weight is attributed to each of the factors mentioned above according to their relative importance as a cause of landslide;

3. a map of past landslides is constructed, to then be superimposed on the thematic maps of the single factors to identify the units in which landslides have already occurred and then carry out a statistical analysis;
4. each factor is subdivided into classes and a numerical evaluation is assigned to each class according to the areal frequency of the landslides;
5. the thematic maps of each factor are superimposed and, through a weighted sum operation, a numerical index representing the degree of danger is attributed to each unit of territory.

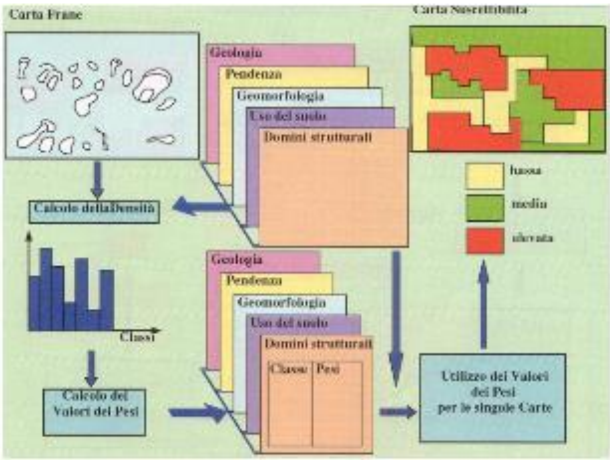


FIGURE 9EXAMPLE OF EVALUATION OF THE DANGER OF AN AREA BY MEAN OF INDIRECT STATISTICAL METHODS (VAN WASTEN, 1996).

The main advantage of these methods evidently consists in being able to analyze large portions of territory in a relatively short time. Among the limitations of this approach, in addition to subjectivity in the choice of the parameters and their weight, the low resolution (depending on the density of the available information) and the fact that the danger thus obtained is expressed in a relative scale is emphasized. In large-scale studies, the analysis of the interactions between underground water circulation and slope stability is generally limited to the definition of rainfall thresholds for the triggering of superficial landslides, ignoring the effects of water circulation on the deeper landslides; this simplification obviously derives from the complexity of the processes that govern the phenomenon, as well as from the frequent difficulty in finding sufficient hydrogeological data. To overcome these limits it is necessary to combine indirect methods with detailed analysis, to be carried out at the scale of the single slope.

**Simplified deterministic models**[25-27]: they are based on the use of a GIS in which extremely simplified geotechnical (indefinite slope) and hydrological models are implemented (models infiltration and trigger thresholds), which allows to identify potentially unstable areas; the results can then be validated by comparing the instability mapping. The great advantage of this approach is to provide an absolute hazard assessment over large areas; on the other hand, its major limitation is inherent in the extremely simplifying hypotheses that form the basis of the models used and which make it possible to take into account only the superficial forms of instability (translational slips, soil slips, surface flows).

### I.4.3 Methods for hazard assessing on a slope scale

For the estimation of landslide hazard (generally expressed in absolute terms) on a slope scale, reference can be made to two approaches:

**Direct statistical approach**: it is based on the statistical analysis of cause-effect relationships between the triggering of a landslide and its causal factors; it consists, for example, of reconstructing the probability distribution of the safety factor $F_s$ (using Monte Carlo simulations) as a function of the probability distribution of the various strength parameters, interstitial pressures, etc. and, therefore, calculate the probability of breaking as (Fig. 2):

$p_f = p(F_s \leq 1)$

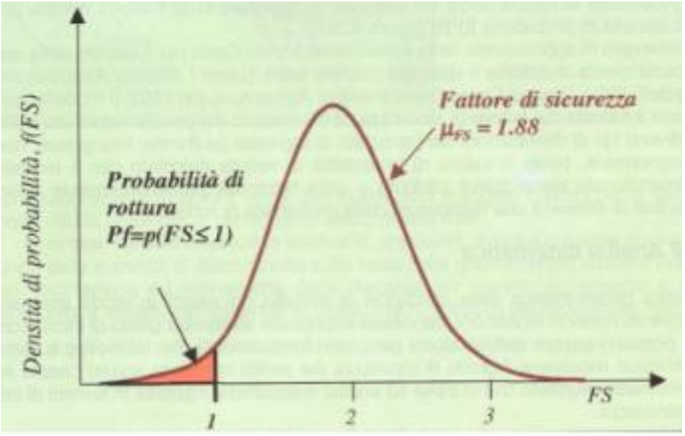


FIGURE 10– EXAMPLE OF HAZARD EVALUATION D$_I$ IN TERMS OF PROBABILITY OF FAILURE.

Much more complex and, to date, little applied (if not in the field of scientific research) is the temporal forecasting of the event according to the historical series of past events (often schematized, for recurrent events, through a Poisson distribution), possibly in combination with historical series of trigger factors (human activity, erosion, precipitation, earthquakes, etc.); in this case the hazardis expressed in terms of conditional probability:

Prob. evento stimata in base a serie temporale

$$P[\,evento_i | indicatore\,] = \frac{P[\,evento_i\,] * P[\,indicatore | evento_i\,]}{\sum_{i=1}^{n} P[\,indicatore | evento_i\,] * P[\,evento_i\,]}$$

Prob. indicatore quando si verifica l'evento

Such an approach presupposes:

- an analysis of the time series of events,
- an analysis of the time series of trigger factors (eg.Rains, earthquakes, etc.),
- monitoring of the area.

The main difficulty in making temporal forecasts of this type derives from the fact that often catastrophic landslides are mono-episodic; moreover, even for recurrent landslides, it is often difficult to find the historical series of events (depending on their intensity) and, above all, the various indicators. Deterministic approach: it is based on the use of functions (eg.Safety factor) or, more often (given the complexity of the phenomena), physical-mathematical models able to predict the evolution in space and time of the landslide, identifying their areas of expansion and accumulation. The type of model to be used is chosen based on the kinematics being examined, for example: the simulation of the slope-deformation behavior of slopes in earth and in rock, respectively,the modeling of landslides of collapse, the reconstruction of dynamics (triggering, propagation and stop with relative expansion areas) of debris flows. The application of these models evidently requires the knowledge of punctual and specific geotechnical or geo-mechanical data for the different types of instability and, therefore, the execution of tests on the site and in the “ad hoc” laboratory. Consequently, the deterministic models are listed for types of disasters that can be easily schematized, such as for example translational slips and colonies, or on specific sites and for particular details (a slope scale). The simulations can be conducted taking into account the different intensity of the event, different cause predisposed and triggering (among which the underground water circulation is particularly important, as already mentioned previously) and, possibly, also to the resistance parameters of the material. With a sufficient number of simulations, it is possible not only to predict the spatial and temporal evolution of the instability, but also to stimulate its probability of priming and the risk associated with the expansion and accumulation zones. This evaluation is of fundamental importance especially for landslides characterized by high speed (egCollapse) and considerable spreading distance (eg Castings). Through the topographical reconstruction of the slope and the calibration of the geo-mechanical parameters it is possible to construct on the slope scale an absolute hazard map (Fig. 11) as a function of the probability of detachment of the boulder and of the subsequent dynamic fall.

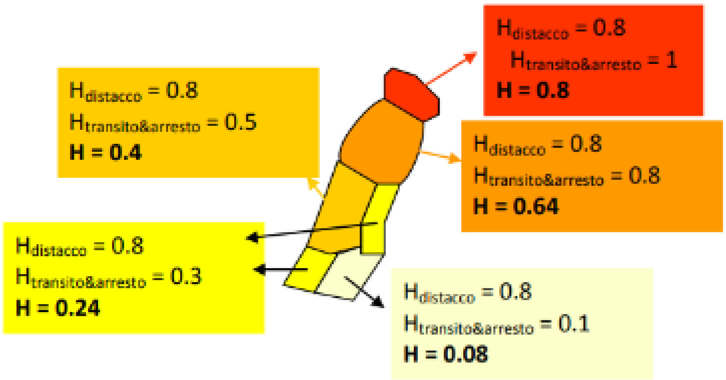


FIGURE 11. EXAMPLE OF AN ABSOLUTE HAZARD CHART AT A SLOPE SCALE FOR A CROSSO LANDSLIDE.

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