Design approaches for landslide risk mitigation through structural measures

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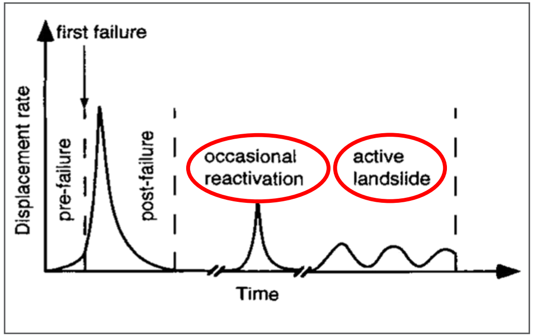
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Slow-moving landslides

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity
7	Extremely Rapid		
		5×10^{3}	5 m/sec
6	Very Rapid		
		5×10^{1}	3 m/min
5	Rapid		
		5×10^{-1}	1.8 m/hr
4	Moderate		
		5×10^{-3}	13 m/month
3	Slow		
		5×10^{-5}	1.6 m/year
2	Very Slow		
		5×10^{-7}	15 mm/year
	Extremely SLOW		

Landslide velocity classes (Cruden and Varnes 1996)



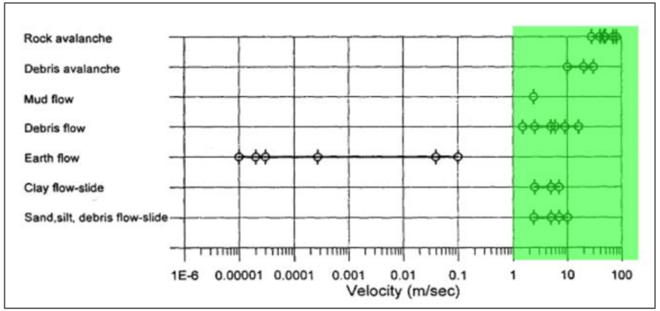
Stages of landslide movements (Leroueil et al. 1996)

Ancona , Marche region (1982)

Lungro, Calabria region (2015)

Cavallerizzo di Cerzeto, Calabria region (2005)

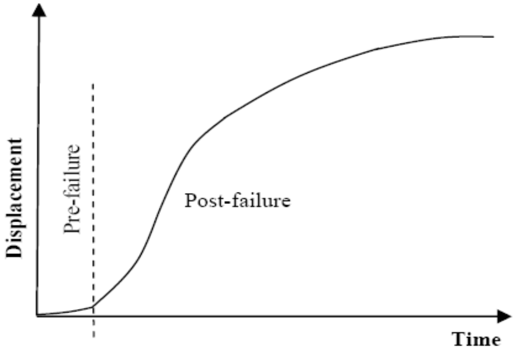
Fast-moving landslides



Maximum velocities of flow-like landslides (Hungr et al. 2001)

Salerno, Campania region (1954)

Nocera Inferiore, Campania region (2005)



Flowslide evolution in loose cohesionless materials (Cascini 2005)

Sarno, Campania region (1998)

Decision

Risk mitigation is required?

NO *(this means tolerance)*

- Maintenance of slope (e.g., removal of fallen / felled trees and solid waste) and mitigation works (if any)
- Verification of the effectiveness of the surface drainage systems and the disposal of wastewater
- Ordinary and extraordinary maintenance of the exposed facilities
- Activities of territorial survey and further deepening of knowledge

YES

………

Available approaches: FSA and DEA

- **Factor of Safety Approach (FSA)**: this approach is applied to structural prevention measures. In particular, it compares the values of the safety factor obtained with the stability analysis in the presence and in the absence of mitigation interventions by referring to the shear strength parameters along the sliding surface (existing or potential).

- **Design Event Approach (DEA)**: it adopts a risk-based design framework and is applicable when designers opt for mitigation of natural terrain landslide risk without carrying out a formal QRA. Uncertainties are generally considered in an implicit manner through the assessment of the design event (e.g., a landslide of a certain size with a given degree of mobility).

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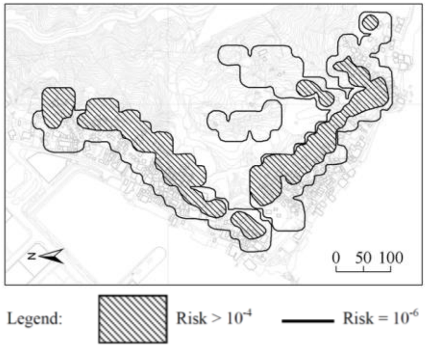
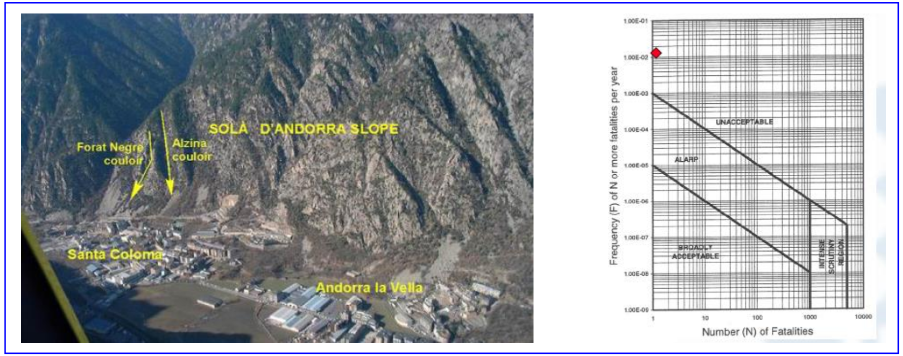
Available approaches: QRA

A **quantitative risk analysis (QRA)** is *“based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk”.*

The scale of work most suitable for QRA purposes is the detailed one (>1:5,000).



A case study in Hong Kong (Hardingham et al. 1998)

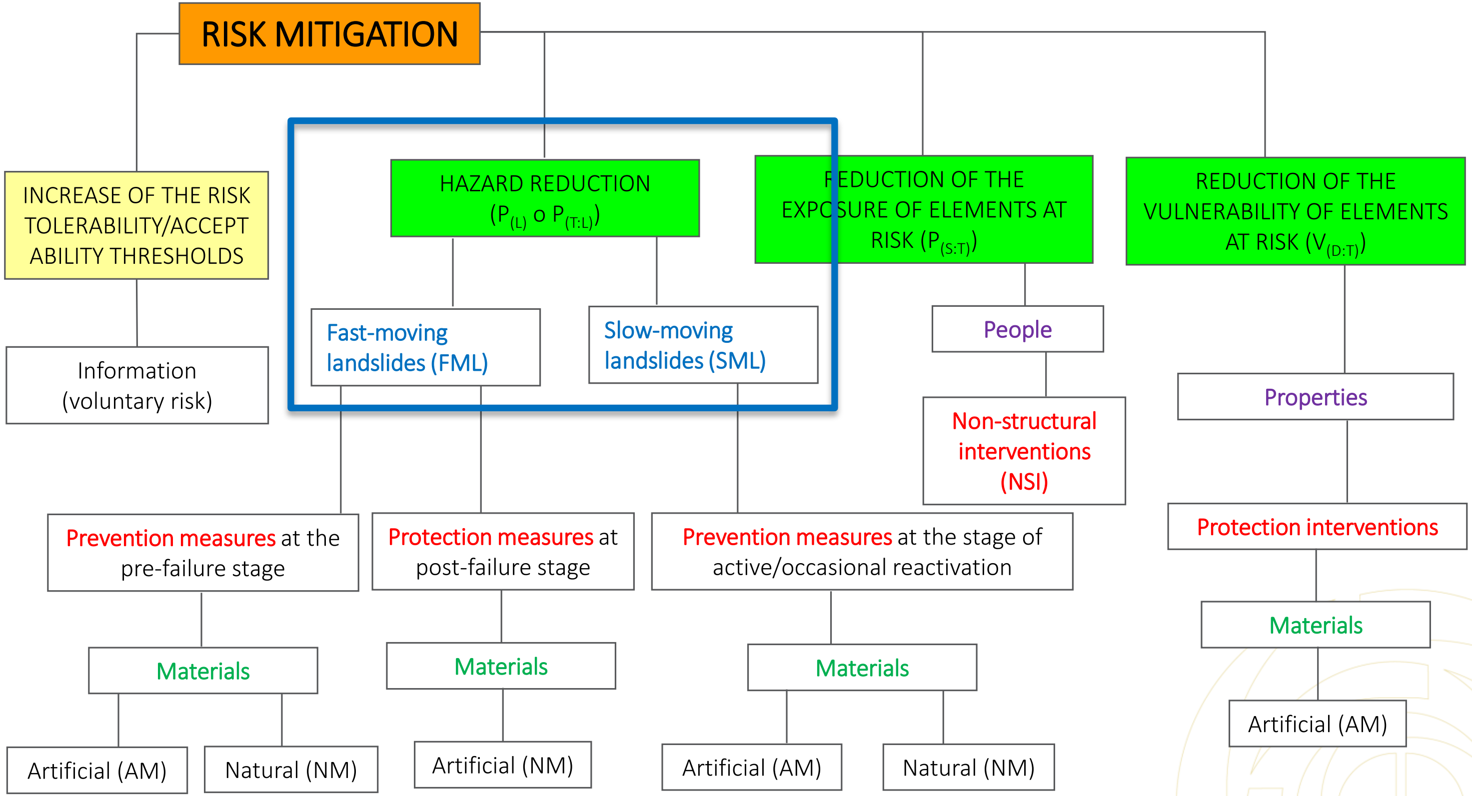


The case study of Solà d’Andorra (Corominas et al. 2005)

A case study in Canada (Porter et al. 2007)

Types of intervention

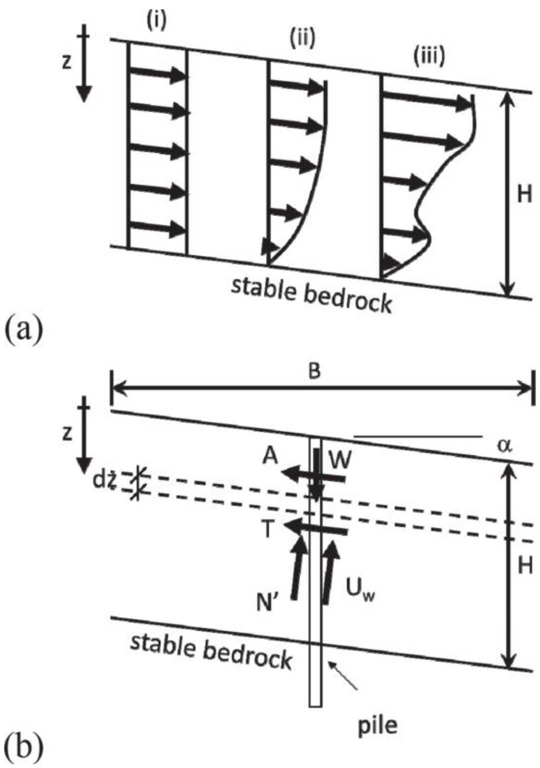
$$P_{(LOL)} = P_{(L)} \times P_{(T:L)} \times P_{(S:T)} \times V_{(D:T)}$$



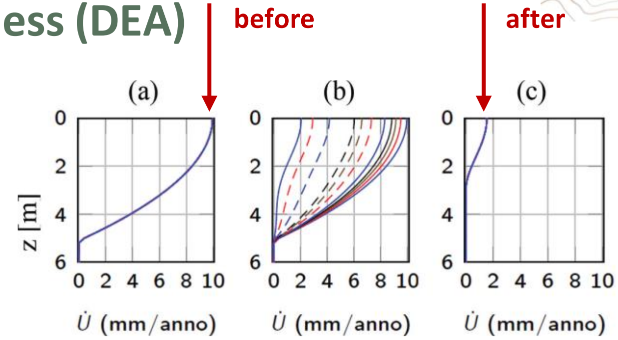
Verification of the intervention effectiveness (FSA and DEA)

With specific reference to risk mitigation interventions, the verification of their effectiveness and, therefore, their ability to protect people and property can be demonstrated "in terms of hazard reduction" (Par. C6.3.5 of Circular No. 7 of 21 January 2019 of the Superior Council of Public Works). The estimated increase in the factor of safety (FSA) and/or the verification that the chosen control variable is below an established limit (DEA), over the nominal design life of the intervention, are in themselves a demonstration that the hazard has been reduced.

Verification of the intervention effectiveness (DEA)



(a) examples of soil displacement rate profiles: (i) uniform, (ii) continuous, (iii) irregular; (b) equilibrium of a generic soil layer of thickness z



Evolution of soil displacement rate profile: (a) without any intervention; (b) stabilizing piles with passive ground anchors; (c) stabilizing piles with active ground anchors.

It is evident how the case of passive anchors gives a very slow progressive reduction of the values of the soil displacement rate, without allowing the complete stabilization of the unstable layer. On the contrary, the case of active anchors allows an immediate reduction of the soil displacement rate, which then remain constant over the considered time window. For the considered case, however, residual superficial failure mechanisms are still active, with a soil displacement rates of about 2 mm/year up to a depth of about 2.5 meters from the ground level.

(di Prisco et al., 2016)

Verification of the intervention effectiveness (QRA)

General view of the Sol`a d'Andorra with the rockfall active slopes and talus cones at their foot

Basin	Rock size (m^3)	$P_{(R)}$	$P_{(T:R)}$	$P_{(S:T)}$	$V_{(prop:S)}$	$R_{(R)}$
Forat Negre	0.5	0.0992	0	1.0	0.1	0
	1	0.0678	0	1.0	0.1	0
	2.5	0.0290	0.0043	1.0	0.2	2.5×10^{-5}
	5	0.0029	0.0171	1.0	0.2	1.0×10^{-5}
	10	0.0010	0.1667	1.0	0.3	5.1×10^{-5}
				Total risk		8.6×10^{-5}

Annual residual risk expressed as degree of loss due to rockfall events for buildings located in the basin of the Forat Negre protected with the lower fence line (Corominas et al., 2005)

Rock block 2.3 m^3 from the rockfall event of August 17, 2003, trapped by the protection fence of the Forat Negre basin

Two rock blocks of 0.25 and 4 m^3 respectively from the rockfall event of April 2, 2004, trapped by the protection fence of the Forat Negre basin

Conclusions

Ultimately, it appears necessary:

- the deepening of knowledge, also for the identification of intervention priorities (especially in the presence of limited budgets);

- the care of the existing, starting from the built-up environment;

- the definition of rules of good practice, based on experience already gained;

- the harmonization of technical legislation and that on the risk of landslides;

- participation of the actors involved and sharing of choices, with a view to the sustainable development.

Thanks for the attention

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