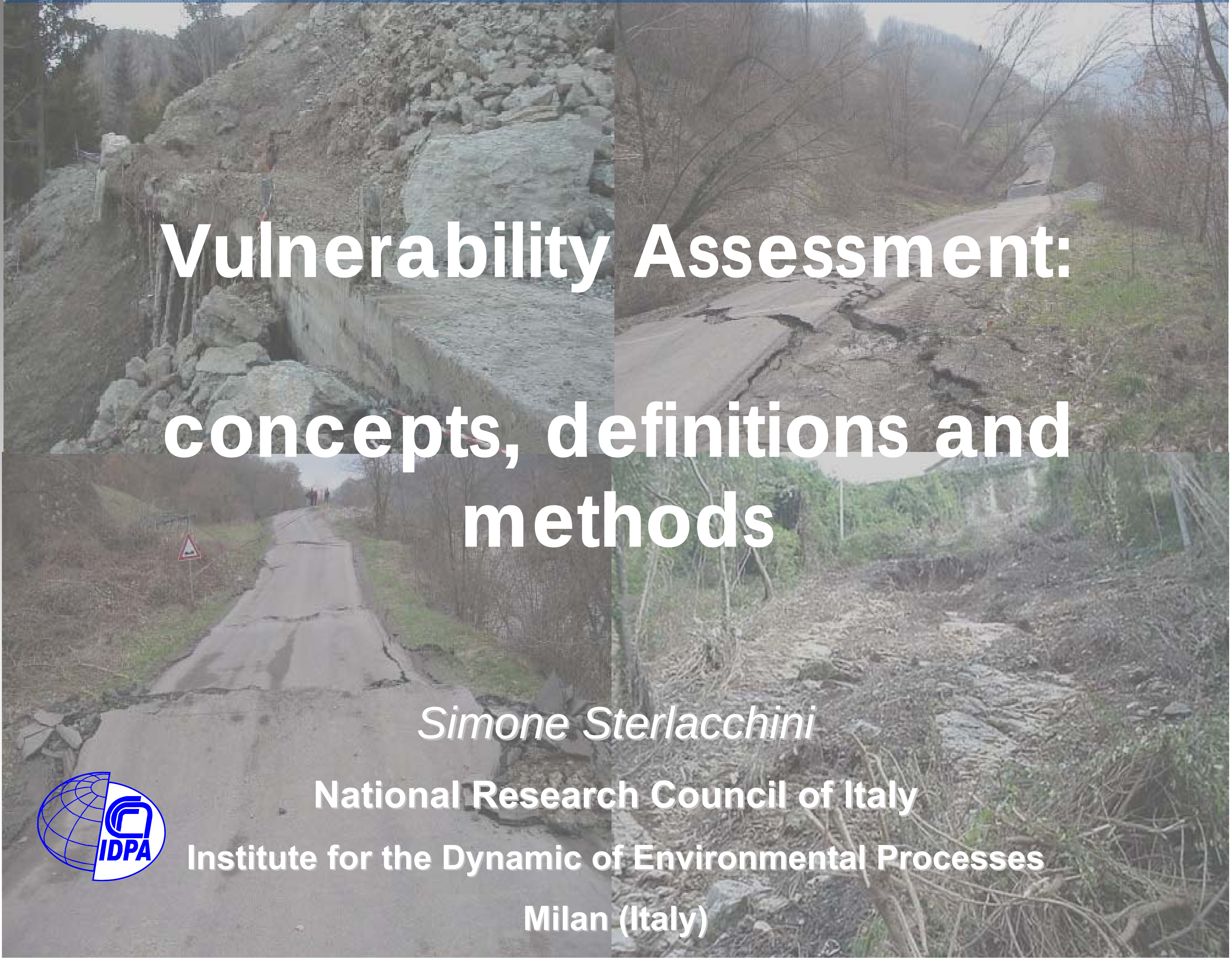

Vulnerability Assessment: concepts, definitions and methods

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CHANGES Risk=HVA

MARIE CURIE ACTIONS

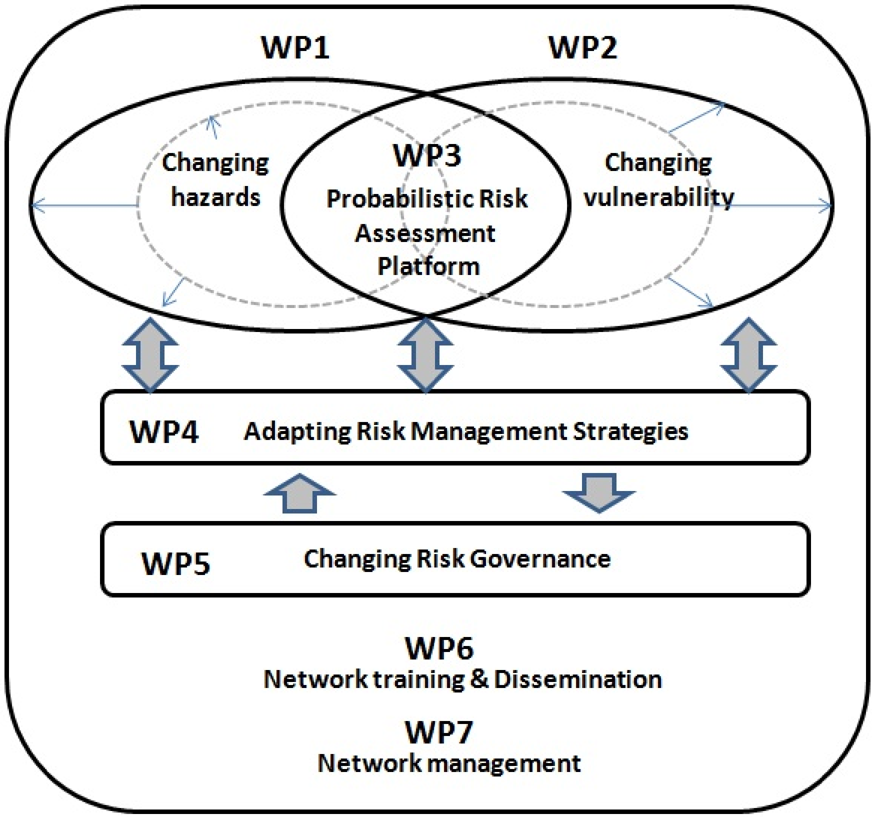
SEVENTH FRAMEWORK PROGRAMME

Introduction

√ why is it so important?
- why is it so difficult to assess?
- who is interested in the assessment?

- In general terms, vulnerability expresses the propensity of an element or a set of elements (organized in a system) exposed to hazards to suffer damage

- **Vulnerability** allows the assessed level of HAZARD to be translated into an estimated level of RISK



Introduction

√ why is it so important?
- why is it so difficult to assess?
- who is interested in the assessment?

A **Quantitative Risk Assessment** could be addressed only by:

- a quantitative Hazard assessment (… it is possible …)
- a quantitative Vulnerability assessment (… it is difficult or even impossible …)

in terms of hazard consequences on the different dimensions of a single element or group of elements (system, community):

✓ physical/functional/operational;
✓ socio-economic
✓ socio-cultural;
✓ ecological/environmental;
✓ political/institutional

Introduction

√ why is it so important?
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- who is interested in the assessment

- the **physical/functional** dimension relates to the predisposition of a structure, infrastructure or service, to be damaged due to the occurrence of a harmful event, associated with a specific hazard;

- the **socio-economic** dimension relates to the economic stability of a region endangered by a decrease in income due to a decline in production, distribution and consumption of goods. The economic dimension of vulnerability offers an interesting approach to regional vulnerability, especially from the insurance company point-of-view of damage potential (Kumpulainen, 2006);

- the **socio-cultural** dimension relates to the presence of human beings (individually or aggregated in communities) and their coping capacities in the event of disaster. It encompasses issues related to social and health status, gender, age, etc.;

Introduction

√ why is it so important?
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- the **ecological/environmental** dimension that refers to the interrelation between different natural ecosystems/environments and their ability to cope with and recover from different hazards (Kumpulainen, 2006) and to tolerate stressors over time and space (Williams & Kaputska, 2000);

-the **political/institutional** dimension related to those issues targeted to prevent the consequences of a harmful event and reduce the negative effects through political/institutional actions (livelihood diversification, relocation of belongings or the community distribution of emergency drug supplies, etc.).

Introduction

- why is it so important?
√ why is it so difficult to assess?
- who is interested in the assessment?

Vulnerability is often poorly assessed because of:

❑ the lack of observational data related to:
- hazardous events (physical and mechanical parameters of hazard(s)

❑ the difficulty to collect data of the inherent characteristics of the elements at risk:
- spatial and temporal exposure of elements at risk to hazard
- the number of dimensions to be explored (physical/structural/functional, socio- economic, socio-cultural, ecological/environmental, political/institutional, …).
- the complexity of the damage mechanism (acting differently on different dimension

… and it is a function of:

❑ aim of the study (number of dimensions to be included)
❑ temporal and spatial scale of analysis

A multi-disciplinary approach is requested.

Introduction

- why is it so important?
√ why is it so difficult to assess?
- who is interested in the assessment?

This is probably due to the many components (or dimensions) which need to be investigated in vulnerability assessment:

- the physical/functional dimension (engineers, architects, geologists, etc.);
- the socio-economic dimension (geographers, economists);
- the socio-cultural dimension (geographers, humanists, etc.);
- the ecological/environmental dimension (naturalists, ecologists, etc.);
- the political/institutional dimension (politicians, jurists, etc).

… a multi-disciplinary approach …

Introduction

- why is it so important?
- why is it so difficult to assess?

√ who is interested in the assessment?

A thorough vulnerability assessment study can meet the needs of the following potential end-users:

- public administrators (responsible for urban planning and development);

- economic & spatial planners (analysing the socio-economic trends acting in a given area);

- managers (owning or dealing with services, buildings or other vulnerable facilities);

- insurance and re-insurance companies (which guarantee those facilities);

- lawmakers – policymakers (drafting building regulations or codes of practise for construction, whose task is to ensure that adequate protection is provided at minimum cost);

- people responsible for civil protection, relief and emergency services (whose job is to prepare contingency plans).

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An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Vulnerability is one of those terms that seems to defy consensus usage showing many different connotations, depending on the research orientation and perspective.

There is no consensus about the precise meaning of the term vulnerability in the scientific literature, and it seems to be open to interpretation.

The IPCC aimed to systematise the approach to vulnerability in the Third and Fourth Assessment Report (IPCC, 2001, 2007).

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

The review of current vulnerability definitions demonstrates that, at least, two different perspectives exist:

- the former on an engineering and natural science point of view;

- the latter one based on a social science outlook.

It all depends on the components (dimensions) of vulnerability each school of thought takes into account and privileges.

Definitions related to the different perspectives of vulnerability are reviewed and listed by Cutter (1996), Weichselgartner (2001), Klein et al. (2003), Glade (2003), Adger, (2004), Fuchs et al. (2007) ….

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Engineering and natural science perspective

According to the forerunner definition proposed by **Varnes & IAEG Commission on Landslides and other Mass-Movements** (1984), "vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a hazard of a given magnitude in a given area".

According to **United Nations Development Programme** (UNDP, 1994), "vulnerability depends upon the degree of loss to a given element at risk at a certain severity level. Generally, it is expressed as the percentage of loss (between 0: no damage to 1: total damage) for the given hazards".

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Engineering and natural science perspective

Later on in the years, vulnerability is:

"… the potential to experience adverse impacts" (Alexander, 1999);

"… a measure of the damage suffered by an element at risk when affected by a hazardous process" (Wisner and Luce, 1993; DHA, 1992; Dooge, 2004; Wisner et al., 2005);

"… a measure of the robustness or the fragility of an element" (Vandine et al., 2004);

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Engineering and natural science perspective

"… a measure of the exposure to or protection from the expected potentially damaging event" (Vandine et al., 2004);

"… the ability of an element to withstand hazards of a given type or size" (Alexander, 2005).

In general terms, all the definitions relate vulnerability to the consequences of hazard impacts able to cause damage and losses to a given element or set of elements at risk, expressed as the percentage of loss (between 0: no damage to 1: total damage)

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Social science perspective

Among social scientists, there is a quite convergence of opinions among people that see vulnerability in terms of variation in people's (system's) capacity to cope with hazards (Few, 2003).

Blaikie et al. (1994) defines vulnerability as "characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of natural hazards".

Adger (2000) provides an alternative definition closer to this sense: "the presence or lack of ability to withstand shocks and stresses to livelihood".

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Social science perspective

Cannon et al. (2003) define social vulnerability as "a complex set of characteristics that includes a person's initial wellbeing, livelihood and **resilience**, self-protection, social protection and social and political networks and institutions".

Cutter et al. (2003) define social vulnerability as "a multidimensional concept that helps identify those characteristics and experiences of communities (and individuals) that enable them to respond and recover from natural hazards".

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

To sum up, definitions of vulnerability tend to fall into two broad categories that deal with vulnerability:

• in terms of (potential) damage caused to a system by a particular hazard or climate-related event (hazards and impacts approach), or

• in terms of system state that exists within a system before it encounters an external hazard event.

In the former perspective, the role of the system in mediating the outcomes of hazards is downplayed or neglected.

In the latter formulation, vulnerability is a property of a system ("inherent vulnerability" or, in the case of people, "social vulnerability", Adger et al., 2004) and it is the interaction of hazard with system vulnerability that produces an outcome (Brooks, 2003)

- An overview on concepts and definitions

√ there is a need for a clarification of the terminology

In social Science overview there is the "seed" of the concept of (reactive-proactive) resilience.

Hurricane Katrina and New Orleans City is a good example … … …

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

The city is situated seven feet below sea level, with the Mississippi River and Lake Pontchartrain at its borders.

In the 1920s and 1930s, the U.S. Army Corps of Engineers constructed a complex system of levees and pumps to keep the city dry and operational.

The levee system, built to withstand Category 3 hurricanes, had not been adequately maintained, and requests for federal financing to reinforce the levees were repeatedly denied.

When Katrina, a Category 4 (5) hurricane with winds up to 145 miles per hour, made landfall slightly east of New Orleans on August 29, 2005 at 6:10 a.m., inhabitants of the city breathed a collective sigh of relief that the city had escaped a direct hit.

But at 2:00 p.m. that afternoon, the 17th Street levee breached, allowing the waters of Lake Pontchartrain to flood the city ... And the disasters took place


The Water
is
Rising
Pleas

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

… an unlikely mix of internal fragilities …

New Orleans, once a thriving port city, had in recer of its economic base as the petroleum industry wea **Socio-economic**

Unemployment had increased, and approximately inhabitants were living in poverty. **Socio-economic**

Requests for federal financing to reinforce the lev denied **Physical/political**

Many of these people did not have transportation o leaving the city, even if they wished. **Socio-economic**

The lack of public knowledge regarding the likely cons severe hurricanes. **Socio-cultura**

The racial disparities revealed in the sobering impact the population of New Orleans belied the legal framew justice (Young 2002). **Socio-cultura**

• An overview on concepts and definitions

√ there is a need for a clarification of the terminology

Hurricane Katrina can legitimately be termed a natural disaster; that is, an event outside of human control. But the second and more serious disaster, the flooding of the city when the levees failed, was regrettably a product of unintended human design.

It is extremely rare to lose an entire city to disaster, as occurred in New Orleans on August 29, 2005. Even in the San Francisco earthquake of April 18, 1906, sections of the city remained intact and operational. In the Great Chicago Fire of October 9, 1871, whole neighbourhoods remained functional.

In contrast, the destruction in New Orleans left the entire city uninhabitable, with no functional services - communications, water, electrical power, sewerage, transportation, gas distribution - for weeks.

More than 25,000 people crowded into the Superdome, without adequate water, food, or security

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

The **Resilience Alliance** defines the resilience of social-ecological systems by considering three distinct dimensions (Carpenter et al., 2001):

• the amount of disturbance a system can absorb and still remain within the same state or domain of attraction,

• the degree to which the system is capable of self-organisation,

• the degree to which the system can build and increase the capacity for learning and adaptation.

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

The first specific attribute refers to what Dovers and Handmer (1996) call **reactive resilience**, which enables what is known in the natural hazards literature as coping (e.g., Corbett, 1988) and what the climate change community labels autonomous adaptation (e.g., Carter et al., 1994).

Both these attributes are, to a greater or lesser degree, amenable to measurement and monitoring, although questions about the relationship between natural system and social system resilience remain to be fully explored.

An overview on concepts and definitions

√ there is a need for a clarification of the terminology

The second and the third specific attributes refer to **proactive resilience**, that is the adaptive capacity that includes the ability to plan, prepare for, facilitate, and implement adaptation options against hazards, as well as to implement technical measures before, during, and after a hazard event.

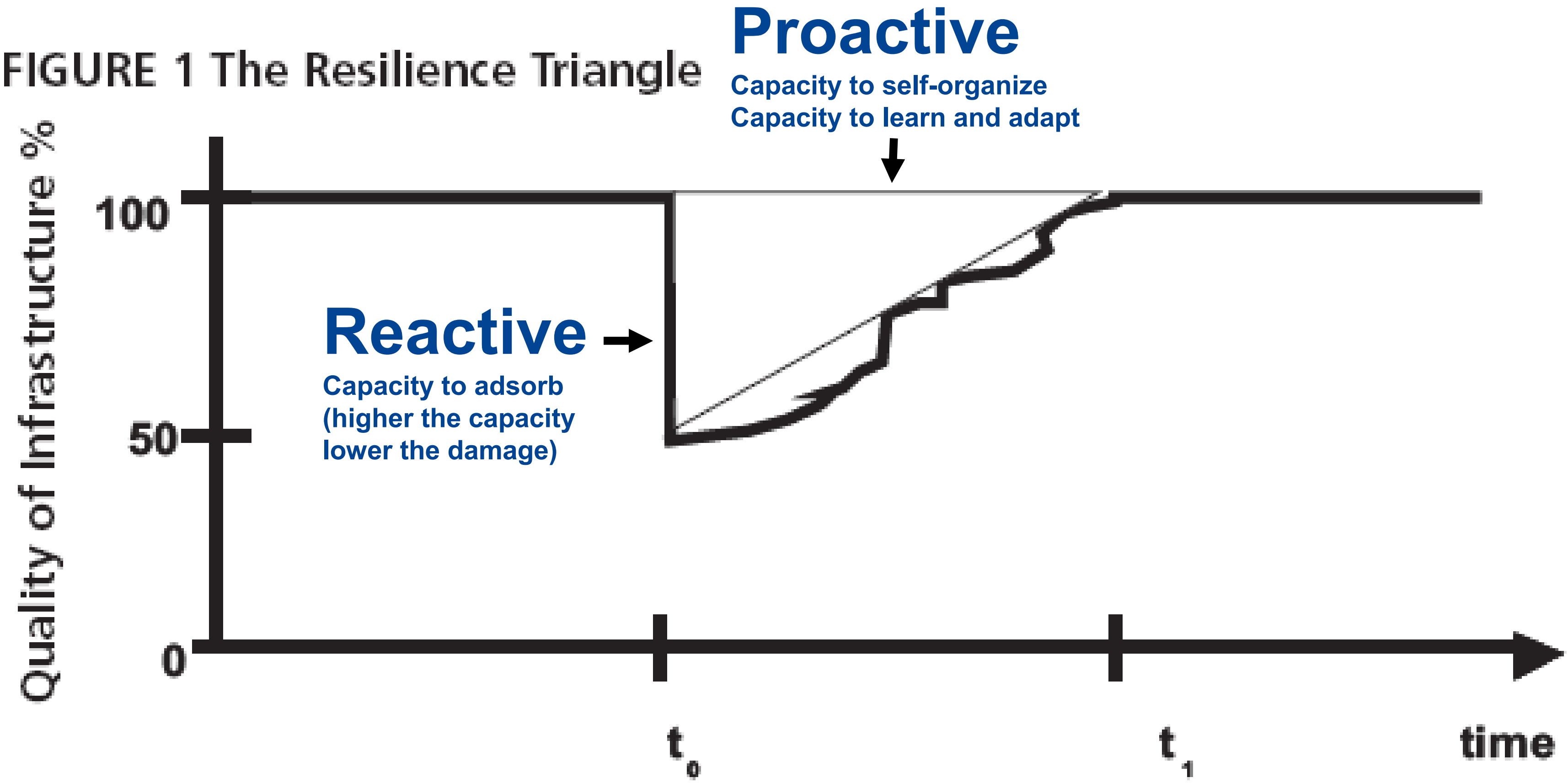
Factors that determine a country's or community's adaptive capacity to hazards include its economic wealth, its technology and infrastructure, the information, knowledge and skills that it possesses, the nature of its institutions, its commitment to equity, and its social capital (Smit et al., 2001). It is therefore not surprising that most industrialised countries have higher adaptive capacities than developing countries.

Proactive resilience links the analysis of present and future hazardous conditions with the evaluation of specific strategies for enhancing the capacity for disaster prevention and preparedness.

Towards a shareable definition

√ is it possible to "sum up" all the definitions into an exhaustive and comprehensive one?

FIGURE 1 The Resilience Triangle



The figure plots the quality or functionality and the performance of an infrastructure after a 50 percent loss. The "resilience triangle" in the figure represents the loss of functionality from damage and disruption, as well as the pattern of restoration and recovery over time.

(from Multidisciplinary Center for Earthquake Engineering Research (MCEER))

Topics of discussion

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Towards a shareable definition

√ is it possible to "sum up" all the definitions into an exhaustive and comprehensive one?

The ESPON Hazards project (2005) defines vulnerability as the degree of fragility of a person, a group, a community or an area towards defined hazards. Vulnerability is a set of conditions and processes resulting from **physical, social, economic and environmental factors** that increase the susceptibility of a community to the impact of hazards. It also encompasses the idea of response and coping, since it is determined by the potential of a community to react and withstand a disaster.

Towards a shareable definition

√ is it possible to "sum up" all the definitions into an exhaustive and comprehensive one?

The IPCC aimed to systematise the approach to vulnerability in the Third & Fourth Assessment Report (IPCC, 2001, 2007). According to the Definitions Section of the reports, "vulnerability is a function of the

- character,
- magnitude,
- and rate of climate variation

"hazards and impacts"
depends on the likelihood that a system will encounter a particular hazard

And it depends on system's

- exposure,
- its sensitivity,
- and its adaptive capacity"

"system state" or "inherent vulnerability"
vulnerability purely depends on the internal characteristics of a system

(Climate variation, climate change, extremes, etc. = hazards)

Towards a shareable definition

√ is it possible to "sum up" all the definitions into an exhaustive and comprehensive one?

… and … "vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes." (IPCC, 2001, p. 995).

It depends not only on a system's sensitivity but also on its adaptive capacity.

Exposure is defined as "the nature and degree to which a system is exposed to significant climatic variations."

Sensitivity is "the degree to which a system would be affected, either adversely or beneficially, by a particular change in climate or climate-related variable".

Different systems may differ in their sensitivity to climate change, resulting in different levels of impact.

Towards a shareable definition

√ is it possible to “sum up” all the definitions into an exhaustive and comprehensive one?

Adaptive capacity is “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities, or to cope with the consequences.”

Adaptive capacity can be an inherent property of the system, i.e. it can be a spontaneous or autonomous response. Alternatively, adaptive capacity may depend upon policy, planning and design decisions carried out in response to, or in anticipation of, changes in climatic conditions.

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Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

Identification and mapping of the **elements at risk** are essential tasks for vulnerability assessment studies, providing one of the main spatial data layer required for a total risk calculation (van Westen et al., 2008).

In general terms, elements at risk comprise the population, properties, economic activities, private and public services (Alexander, 2005) potentially threatened by a harmful event in a territory.

Elements at risk are defined as objects which possess the potential to be adversely affected (Hufschmidt et al., 2005).

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

van Westen et al. (2009) defines the elements at risk as the objects, populations, activities and processes that may be differently affected by hazardous phenomena, in a particular area, either directly or indirectly.

An exhaustive list of elements at risk and related spatial and non spatial characteristics is presented hereafter …

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

1. Essential Facilities

- recreational/tourist facilities (hotels, resorts, parks, public gardens, camping grounds, sporting areas, etc.)
- parking areas
- place of worships (churches, cathedral, etc.)
- educational facilities (schools, universities, etc.)
- medical and healthcare facilities (hospital, ambulatory, etc.)
- emergency response facilities (fire station, police station, shelters, etc.)
- governmental offices
- post offices
- town halls
- law courts
- banks and financial centres
- markets and shopping centres
- cemeteries
- prisons
- military areas
- waste management sites

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

2. Industrial and High Potential Loss Facilities

- dams and ponds
- nuclear power plants
- military installations
- fuel reservoirs, pipelines and pumps,
- gas power plant, storage and pipelines,
- power (electric) generating plants and lines,
- water power plants, tanks and lines,
- hydroelectric power plants and lines
- food processing facilities
- timber processing facilities

3. Transportation Lifelines

- highway segments, bridges and tunnels
- railway track segments, bridges, tunnels and facilities
- light rail track segments, bridges, tunnels and facilities
- bus facilities
- ports and harbours facilities
- ferry facilities
- airports facilities and runways

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

4. Utility Lifelines

- potable water facilities, pipeline segments and distribution lines
- waste water facilities, pipeline segments and distribution lines
- oil systems facilities and pipeline segments
- natural gas facilities, pipeline segments and distribution lines
- electric power facilities and distribution lines
- communication facilities (stations) and distribution lines (cables, networks)

5. Facilities Containing Hazardous Materials (already considered in 2. High Potential Loss Facilities)

- nuclear power plants
- military installations
- fuel reservoirs, pipelines and pumps
- gas power plants, storage and pipelines

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

All buildings and structures belonging to each of the categories listed above has to be characterized by collecting the following data, related to their general state (including their damage history):

1. geo-coding

- street, street number, zip code, city, etc.

2. type of use

- residential
- industrial
- commercial
- tourist
- educational
- other

3. general information

- number of people
- rate of occupancy or number of residents
- evacuation plans available
- past disasters experience

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

4. geometrical configuration

- height
- areas
- volumes

5. structural features (blue prints, building design plans)

- building technique
- national/local building codes
- construction material (concrete, pre-stressed concrete, masonry, metal (aluminum, wrought iron or cast iron), steel, timber, other
- structural components (beams, columns, walls (thickness), foundations, roof frame, anchoring structures, straps, rafters, door type (wood, metal), window type, roof system)
- retrofitting works
- number of floors
- maintenance works (methods of repair and reconstruction)

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

13. Demographic Data

- population distribution (high density areas)
- gender, age, people with disabilities, ethnic, and income distribution (data from Local Registry Offices)
- buildings geo-coding (address, street number, etc.)

13.a List of potential "vulnerable populations"

- aboriginal or indigenous people
- alcohol/drug dependent individuals
- children (especially those of pre-school age)
  - when isolated from parents during impact
  - when gathered in large groups (i.e., schools)
  - when the ratio of children to adults is significantly high (e.g., daycares, day homes)
- ethnic minorities
- families of emergency service personnel
- homeless or "street people"
- immigrants (especially those from "visible" cultures, or cultures that are diverse from the local "mainstream")
- ….. continue ……

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

- incarcerated individuals
- language-limited (i.e., those who do not speak the mainstay language)
- large and high-density households
- livestock owners
- marginalized groups (i.e., by society or the community)
- medication dependent individuals (e.g., diabetics, schizophrenics)
- migrant workers
- people depending on public transport (versus car owners)
- people living below the poverty line
- people on social assistance
- people with disabilities
  - mobility-specific
  - hearing-related
  - visual
  - communication
  - physical
  - mental or cognitive
  - multiple chemical sensitivities
  - dependency on electricity for life-support systems

- ….. continue ……

Methods

√ the targets of the analysis: the elements at risk

- explore the different approaches to vulnerability and risk recognised in literature

- pet owners
- renters (especially in low-rental areas)
- seniors
  - limited mobility
  - isolated or confined
  - medically fragile
  - heavily dependent on medication
  - heavily dependent on life-support system(s)
- single-parent families, especially those who are:
  - on public “assistance”
  - unable to take time off (e.g., during the response or recovery period)
- socially isolated people
- tourists
- transients
- unemployed
- women, especially those who are:
  - single
  - single parents
  - unemployed

- ….. It’s more than enough ……

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Damage can be broadly classified into two groups:

- tangible
- and intangible losses.

Tangible loss relates to the physical/functional and economic dimensions of vulnerability.

Intangible loss refers to the other dimensions as previously discussed.

In general, vulnerability can be measured either on a metric scale, in terms of a given currency, or on a non-numerical scale, based on social values or perceptions and evaluations (Glade, 2003).

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

In vulnerability assessment, tangible losses can be described/measured/quantified using different methodological approaches:

- heuristic
- economic
- empirical
- probabilistic

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Heuristic approach

The heuristic approach expresses vulnerability of structures and infrastructure in qualitative (descriptive) terms and the level of damage can be described as:

- aesthetic,
- functional,
- and structural.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

For **aesthetic** (minor) damage, it is assumed that the functionality of the elements at risk is not compromised at all and the damage can be repaired rapidly and at low cost.

For **functional** (medium) damage, the functionality of the affected elements is compromised, and the damage takes time and large resources to be fixed.

Finally, for **structural** (total) damage, the elements at risk are severely or completely damaged and extensive works, long time and large resources are required to fix the damage; demolition and reconstruction may be required (Cardinali et al., 2002; Reichenbach et al., 2005).

In the framework of a heuristic approach, people's vulnerability can be described by a qualitative description of expected casualties (e.g., none, few, numerous, very numerous).

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Economic approach

However, disaster consequences can be expressed through other parameters, being **economic** cost one widely accepted. It is a currency for considering a wide range of effects.

According to Alexander (2000, 2005), when expressed economically, the degree of loss of the elements at risk can be defined in terms of:

✓ monetary value, i.e., the price or current value of the asset, or the cost to reconstruct or replace it with a similar or identical asset if totally destroyed or written off;

✓ intrinsic value, i.e., the extent to which an asset is considered important and irreplaceable; and

✓ utilitarian value, i.e., the usefulness of a given asset, or the monetary value of its usage averaged over a specified time span.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

<ins>Tangible losses</ins> expressed in terms of **economic** cost can be classified into direct and indirect.

The former can be considered as the "most visible" economic consequence; they may be quantified in terms of cost of recovering and/or restoring the original conditions (for aesthetic and/or functional damage) or in terms of cost of partial or complete reconstruction (for structural damage).

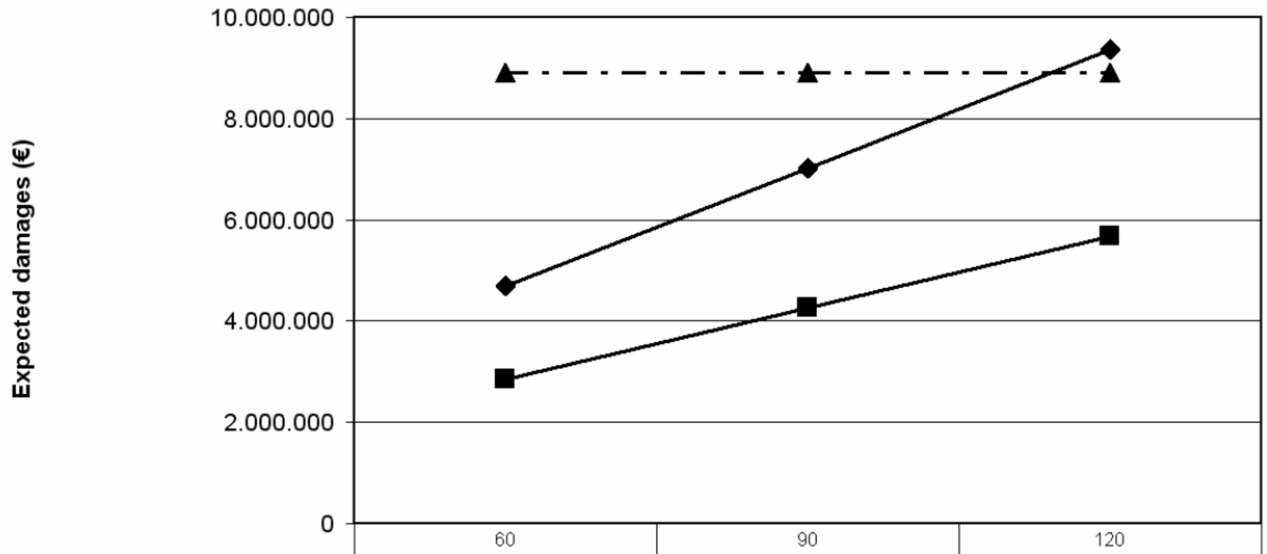
The latter, instead, are generally related to the loss of revenue and income, increase in unemployment, and other economic aspects related to the interruption or the reduction of production, distribution and consumption of goods (economic activity).

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Corvara in Badia (central Dolomites, Italian Alps): the total amount of direct damage was estimated in 8.913.000 euro; on the contrary, indirect damage ranged considerably from 2.840.000 to 9.350.000 euro, depending on the selected temporal scenario and the expected closing time of the potentially affected structures.



	60	90	120
INDIRECT DAMAGES - AUTUMN SEASON	4.682.787	7.024.180	9.358.018
INDIRECT DAMAGES - SUMMER SEASON	2.839.557	4.259.336	5.679.114
DIRECT DAMAGES	8.913.010	8.913.010	8.913.010

Expected recovery time (days)

(Sterlacchini et al., 2007)

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

The interaction between the hazard event(s) and the exposed elements can be analyzed using empirical damage or fragility curves for several types of hazards.

This approach is mainly based on data derived from well-documented case studies.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Fuchs et al. (2007) derived an empirical vulnerability function analyzing data from a well-documented debris flow event (occurred in 1997 in the Austrian Alps) linking process intensities to object vulnerability values.

Elements at risk: brick masonry and concrete buildings located on the fan of the torrent.

Vulnerability is calculated in terms of damage ratio (that described the amount of loss related to the overall potential damage of the structure) and the debris flow intensity.

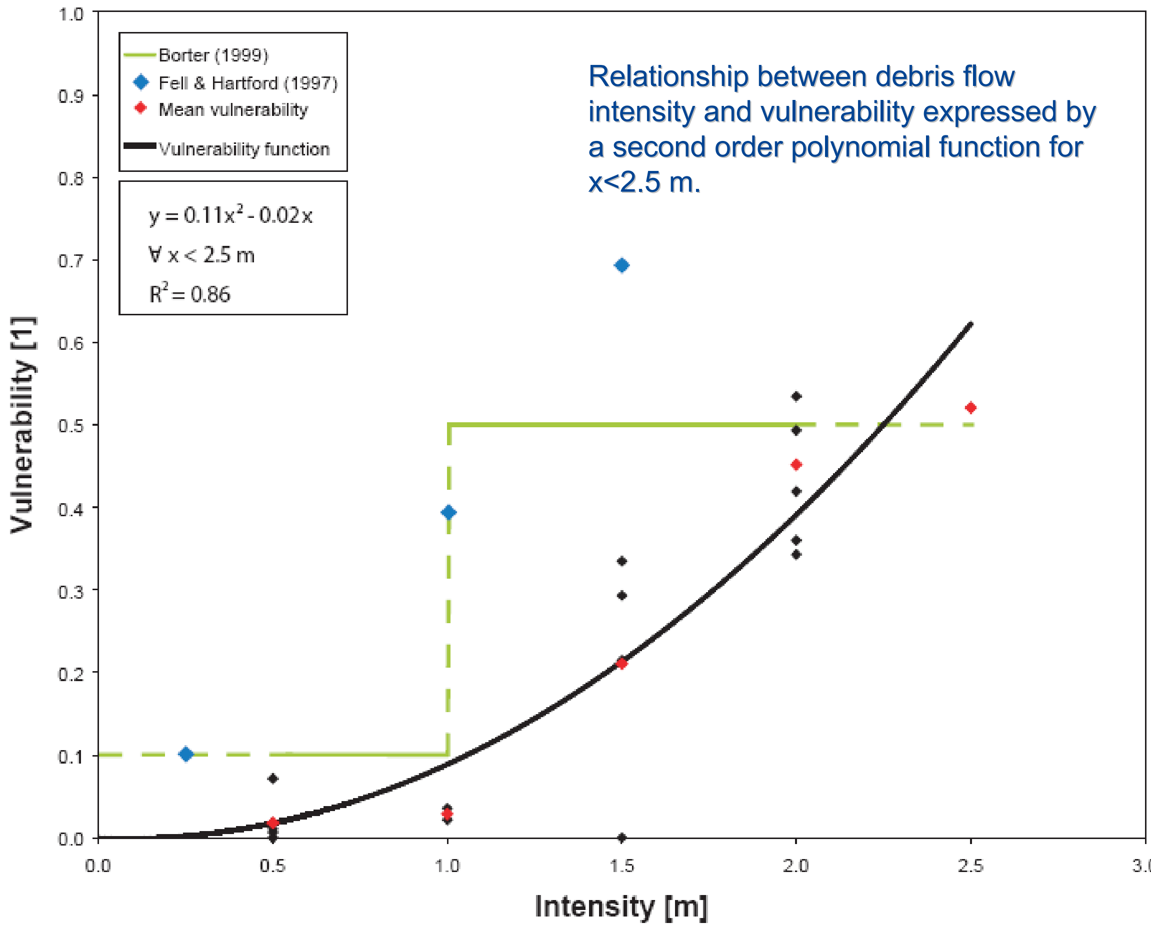
Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Consequently, this vulnerability function was used as a proxy for structural resistance of buildings with respect to dynamic debris flow impacts, and thus was used for a spatially explicit assessment of debris flow susceptibly.

Results from the study site are indicated by black dots, the corresponding mean vulnerability is indicated by red dots. In addition, mean vulnerability values published by Borter (1999) are shown by green lines; values not explicitly specified are dashed. Mean vulnerability values by Fell and Hartford (1997) are represented by blue dots assuming low intensity to be 0.25 m, medium intensity to be 1.0 m, high intensity to be 1.5 m.



Relationship between debris flow intensity and vulnerability expressed by a second order polynomial function for x<2.5 m.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Blahut et al. (2009) developed an empirical vulnerability function based on the data from the 13 July 2008 debris flow event in the village of Selvetta located in Italian Alps.

Damage-related data were obtained from the official documents called RASDA (Raccolta Scheda Danni – Damage Assessment Forms), which are mandatory to be drafted within 48 hours after a disaster for insurance claim purposes.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

In this study, vulnerability is calculated using an economic approach, and is defined as the ratio between the loss and the individual reconstruction value. This ratio was calculated for each of the thirteen building structures that were affected by the debris flow event. The obtained ratios were coupled with the corresponding deposition heights, to compare the results and perform a critical assessment of the previously-mentioned vulnerability functions developed for debris flows.

For each building the approximate reconstruction value was calculated according to building type and size, using the data given in the Housing Price Book prepared by the Engineers and Architects of Lombardy Region.

CHANGES Risk=HVA
MARIE CURIE ACTIONS
SEVENTH FRAMEWORK PROGRAMME

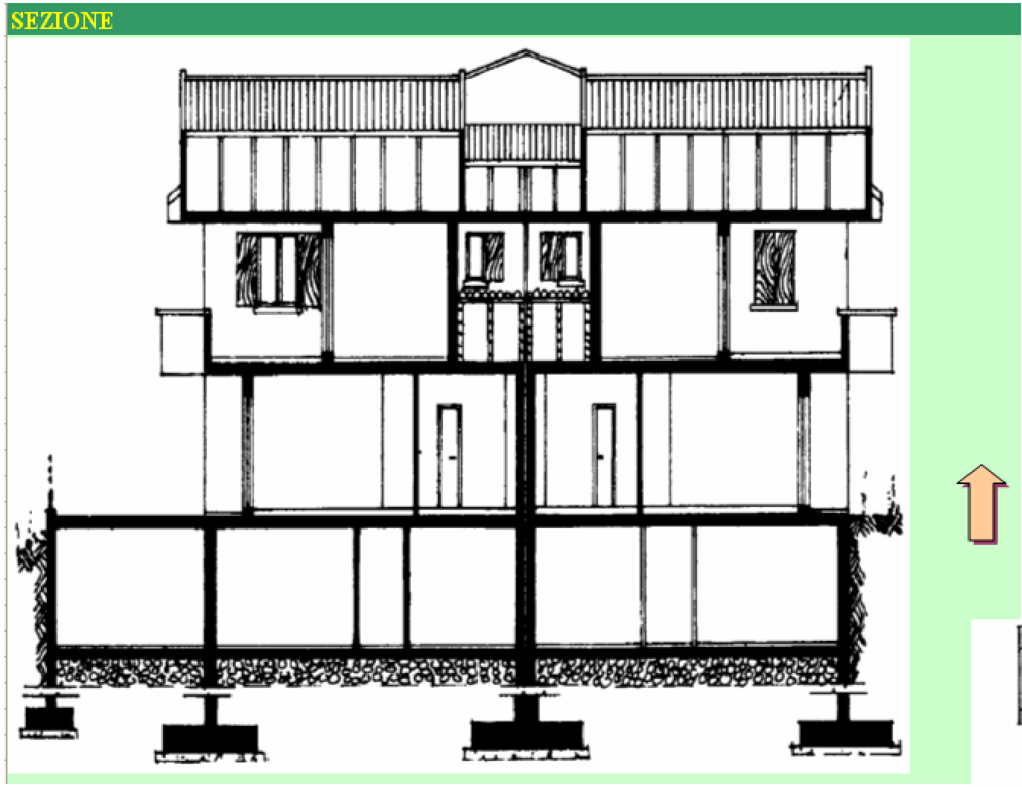
Methods

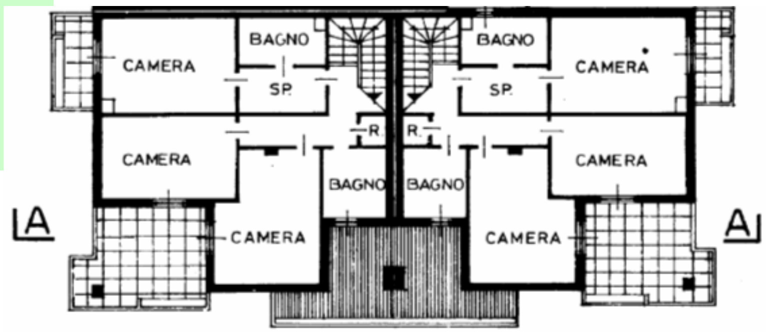
- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Blueprints





CHANGES Risk=HVA

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Costs for each building type expressed Euros per m^2 or m^3

Price List

A2 Edificio unifamiliare

dei TIPOGRAFIA DEL GENIO CIVILE

DESCRIZIONE | TAB. COSTI PARAMETRICI | TEMPI | DISEGNI | INDICE

TABELLA RIASSUNTIVA DEI COSTI E PERCENTUALI D'INCIDENZA

Codice	Descrizione	Costo in Euro	Incidenza
1	Scavi e rinterri	**21.263,00**	3,02%
2	Opere in c.a.	**143.707,00**	20,44%
3	Vespai sottofondo	**53.403,00**	7,59%
4	Isolamento e impermeabilizzazioni	**12.857,00**	1,83%
5	Murature e tavolati	**160.581,00**	22,84%
6	Intonaci	**68.114,00**	9,69%
7	Canne e fognature	**12.919,00**	1,84%
8	Rivestimenti e zoccolini	**28.989,00**	4,12%
9	Serramenti in legno	**52.785,00**	7,51%
10	Opere in ferro	**10.570,00**	1,50%
11	Copertura e lattonerie	**38.260,00**	5,44%
12	Impianto di riscaldamento	**29.112,00**	4,14%
13	Impianto idrosanitario	**38.260,00**	5,44%
14	Impianto elettrico	**28.989,00**	4,12%
15	Impianti gas e antincendio	**3.400,00**	0,48%
	Costo Totale	**703.209,00**	**100,00%**

5-Detached Houses

TABELLA DEI COSTI PARAMETRICI

703.209,00 / 798	**881,00** Euro	**Costo dell'opera al m^2**
703.209,00 / 2.633	**267,00** Euro	**Costo dell'opera al m^3**

MARIE CURIE ACTIONS

SEVENTH FRAMEWORK PROGRAMME

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Market values according to the Agenzia del Territorio (Euro/m^2)

Banca dati delle quotazioni immobiliari - Risultato

Risultato interrogazione: Anno 2008 - Semestre 2

Provincia: SONDRIO
Comune: TIRANO
Fascia/zona: Centrale/VIA VISOLI (PARTE), VIA ANDRES (PARTE), VIALE DEI CAPPUCCINI (PARTE)
Codice di zona: B2
Microzona catastale n.: 4
Tipologia prevalente: Abitazioni civili
Destinazione:

Tipologia	Stato conservativo	Valore Mercato (€/mq)		Superficie (L/N)	Valori Locazione (€/mq x mese)		Superficie (L/N)
		Min	Max		Min	Max	
Abitazioni civili	NORMALE	1400	1600	L	4,5	5,2	L
Abitazioni civili	Ottimo	1680	2140	L	5,4	7	L
Box	NORMALE	980	1200	L	3,9	4,9	L
Posti auto coperti	NORMALE	670	830	L	2,7	3,4	L
Posti auto scoperti	NORMALE	395	495	L	1,6	2	L
Ville e Villini	NORMALE	1450	1800	L	4,9	6,1	L
Ville e Villini	Ottimo	1850	2340	L	6,2	7,9	L

- Lo STATO CONSERVATIVO indicato con lettere MAIUSCOLE si riferisce a quello più frequente di ZONA
- Il Valore di Mercato è espresso in Euro/mq riferito alla superficie Netta (N) ovvero Lorda (L)
- Il Valore di Locazione è espresso in Euro/mq per mese riferito alla superficie Netta (N) ovvero Lorda (L)
- La presenza del carattere asterisco (*) accanto alla tipologia segnala che i relativi Valori di Mercato o di Locazione sono stati oggetto di rettifica.
- Per le tipologie Box, Posti auto ed Autorimesse non risulta significativo il diverso apprezzamento del mercato secondo lo stato conservativo
- Per la tipologia Negozi il giudizio O/ N /S è da intendersi riferito alla posizione commerciale e non allo stato conservativo dell'unità immobiliare

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

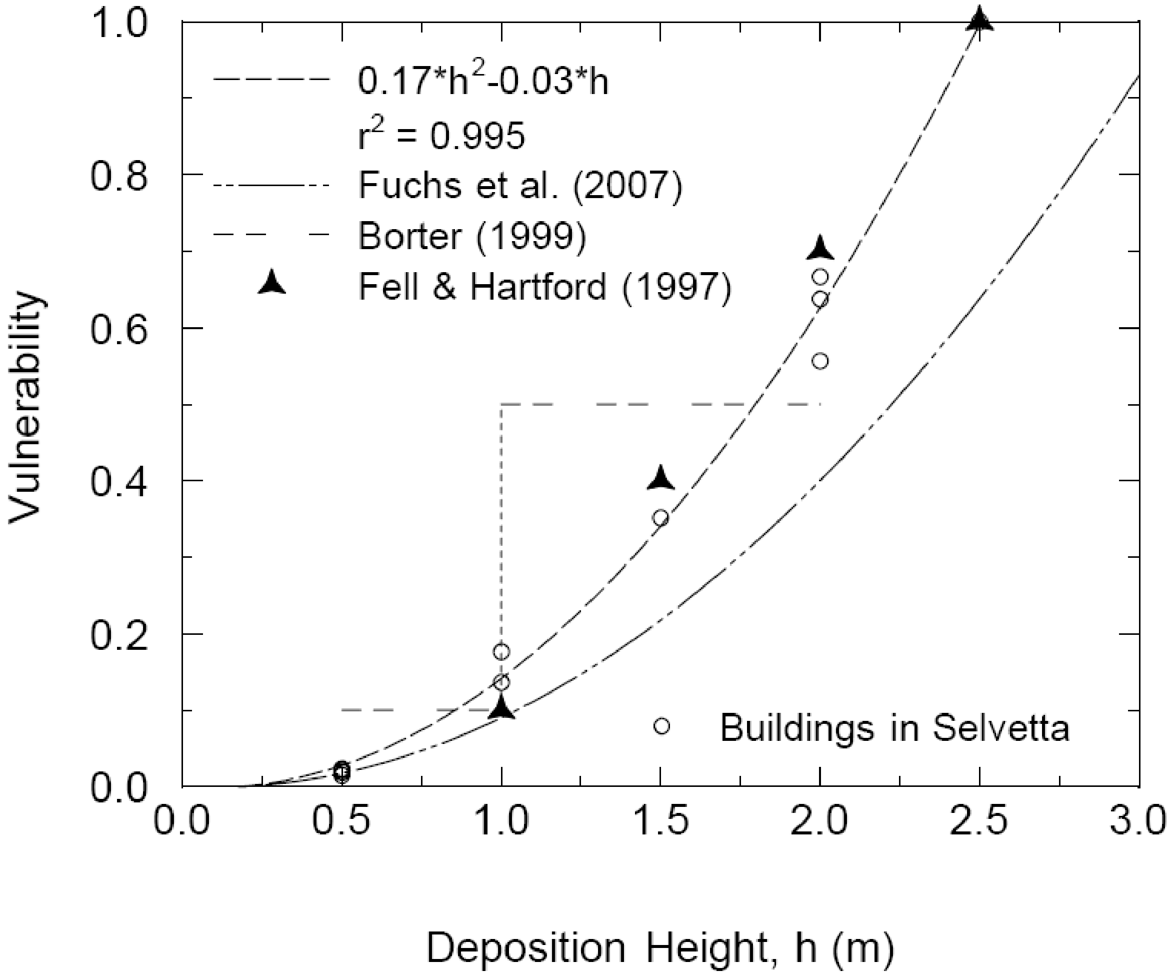
Empirical approach

$V = 0.17h^2 – 0.03h$

in which

h = deposition height

The obtained function is compared to those reported in the literature. Differences in the estimated vulnerabilities resulting from the use of different methods suggest that there is a need for further studies with additional data, to construct empirical vulnerability functions that can be used with a higher confidence level.



Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Quan Luna et al. (2010, 2011) derived synthetic physical vulnerability curves that related the outputs of the numerical dynamic run-out models (flow depth and impact pressures) with the economic values of physical damage to the elements at risk (buildings).

Case study: July 2008 Selvetta debris flow (Valtellina Valley, Sondrio Province, Northern Italy) that caused damage to thirteen buildings.

Elements at risk: single to three-storey brick masonry and concrete buildings (Quan Luna et al., 2011).

Vulnerability was defined as the ratio between the loss and the restoration/reconstruction value of the thirteen buildings affected by the debris flow event.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Vulnerability curve using flow depth

An average height of accumulation values near building walls oriented towards the flow direction was considered.

The Authors proposed a logistic function with a coefficient of determination (r^2) equal to 0.99, for intensities between 0 and 3.63 m:

$$v = \frac{1.49 * |h/2.513|^{|-1.938|}}{1 + |h/2.513|^{|-1.938|}}$$ for h ≤ 3.63 m

$$v = 1$$ for h > 3.63 m

Where

V is vulnerability and

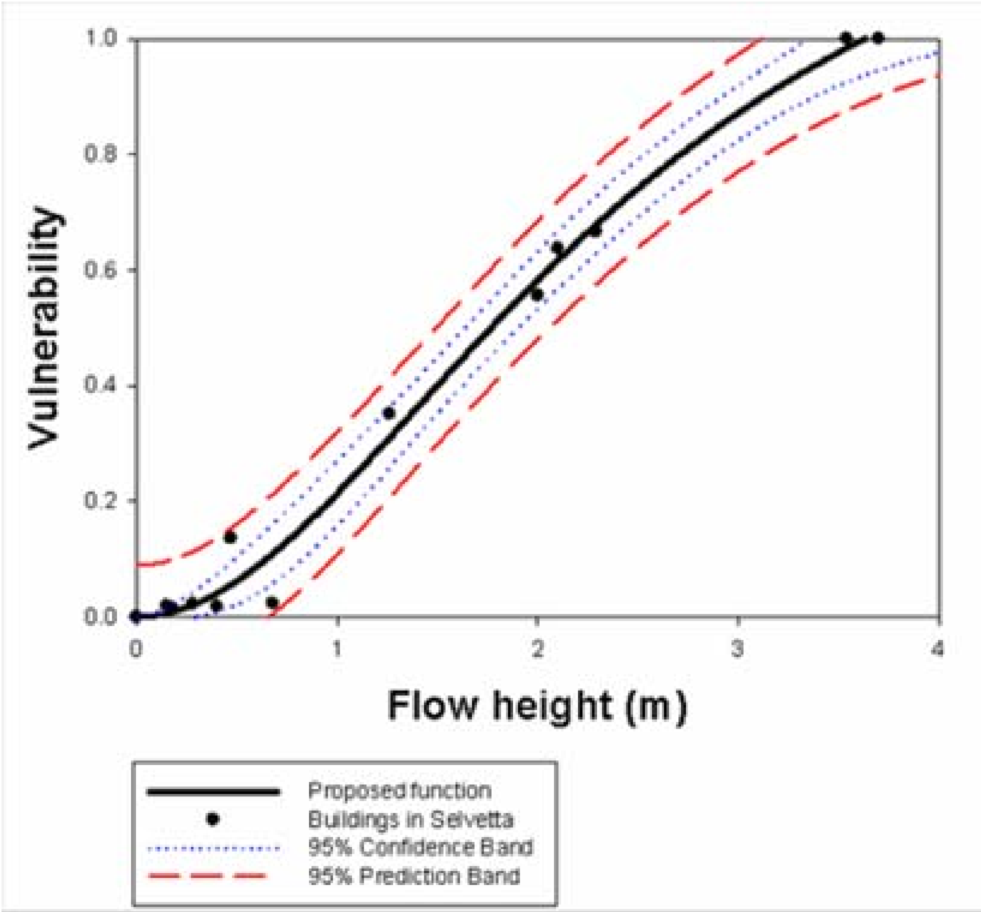
h is the modelled height of accumulation

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach



From its definition, vulnerability cannot exceed 1; thus for intensities higher than 3.63 m, vulnerability is equal to 1.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Vulnerability curve using impact pressures

The maximum modelled value of impact pressures were extracted near building walls oriented towards the flow direction and used to calculate the vulnerability function.

A logistic function which fits the results has a coefficient of determination (r^2) of 0.98 for impact pressures up to 37.49 kPa:

$$v = \frac{1.596 * |P/28.16|^{|-1.808|}}{1 + |P/28.16|^{|-1.808|}}$$ for $P \leq 37.49$ kPa

$$v = 1$$ for $P > 37.49$ kPa

where

V is vulnerability and

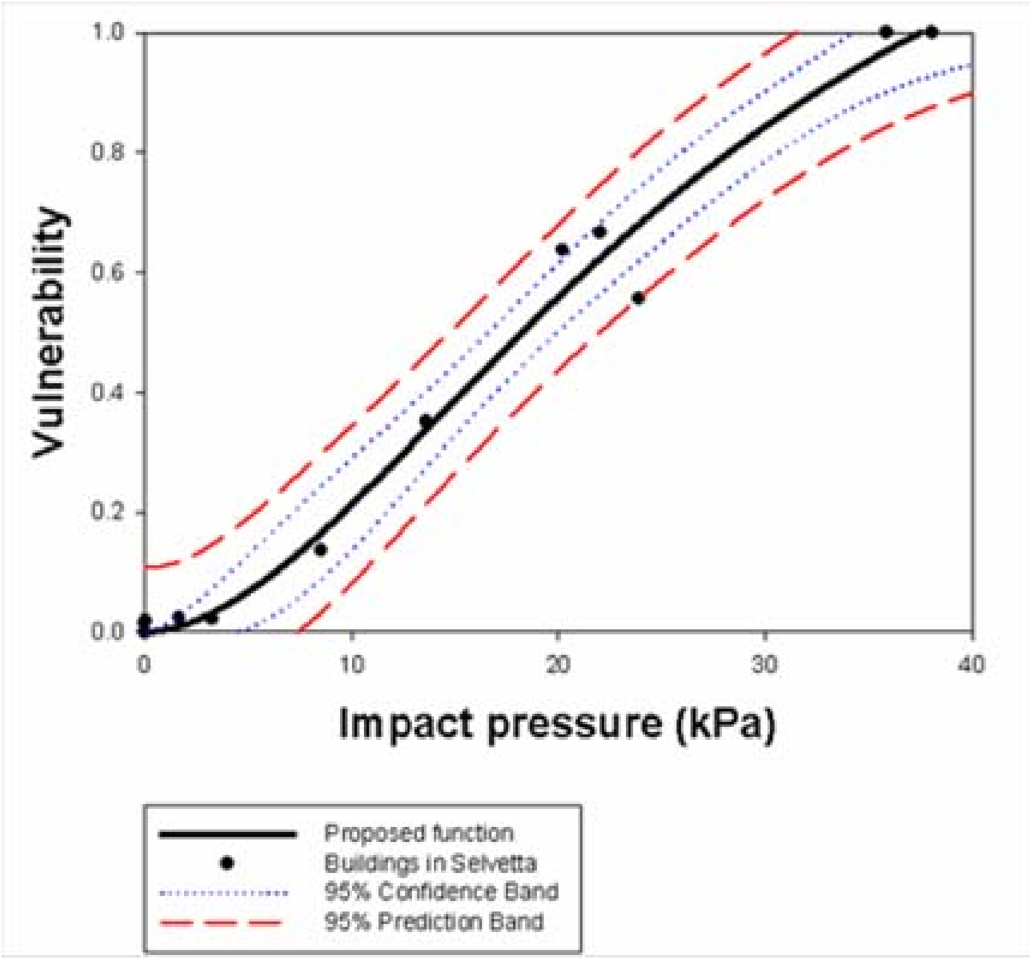
P is the modelled impact pressure.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Empirical approach



From its definition, vulnerability cannot exceed 1; thus for intensities higher than 37.49 kPa, vulnerability is equal to 1.

Methods

- the targets of the analysis: elements at risk

√ - explore the different approaches to vulnerability and risk recognised in literature

Empirical approach

Barbolini et al. (2004) derived vulnerability curves relating damage state (the ratio between the cost of repair and the building value) with the avalanche dynamic parameters, such as velocity and flow depth.

Elements at risk: some alpine buildings, as well as people inside them and people directly exposed to avalanches.

Case study: data derived from the Austrian Institute for Avalanche and Torrent Research and referred to several alpine areas.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

The vulnerability of buildings is defined as the ratio between the cost of repair and the building value (referred as specific loss, SL). The buildings have been divided in five classes according to five pressure ranges:

$$SL = \begin{cases} 0.0297 P_{imp} & if \ P_{imp} \leq 34\, kPa \\ 1 & if \ P_{imp} > 34\, kPa \end{cases}$$

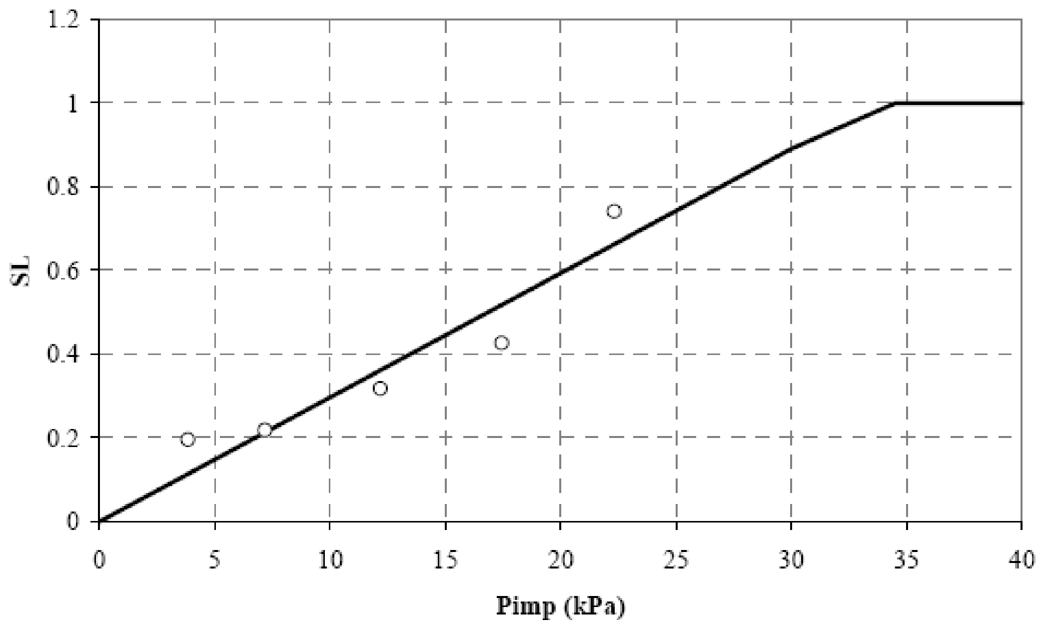
0-5 kPa,

5-10 kPa,

10-15 kPa,

15-20 kPa,

>20 kPa)



and an average value of SL has been estimated for each class.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

The vulnerability for people inside buildings (D_{in}), is defined as the probability of being killed by an avalanche if one stays inside a building when the accidents occurs.

D_{in} has been calculated for each building dividing the number of victims by the number of people inside it. The data have been divided in five classes according to the pressure ranges, and an average value of vulnerability has been calculated for each class.

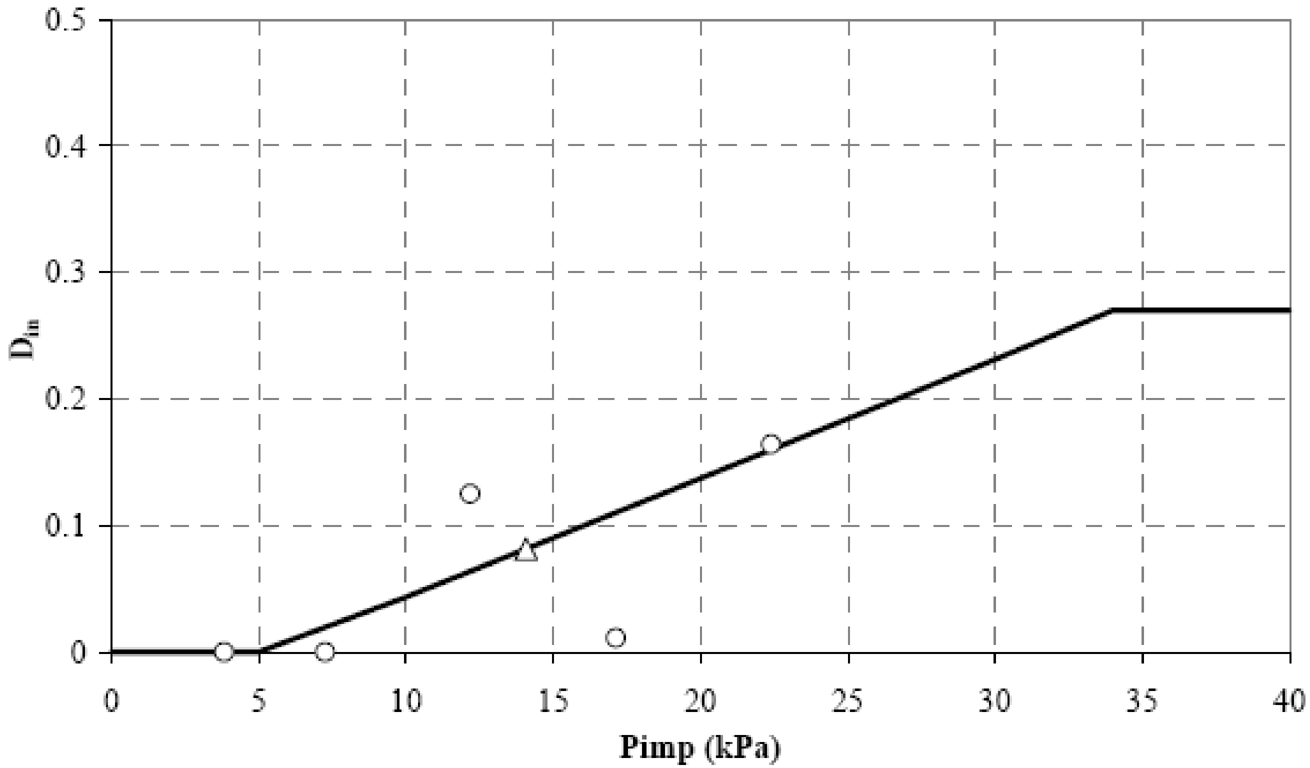
The average impact pressure and the average D_{in} for each class have been plotted, and the points obtained have been fitted by a linear last square regression, obtaining the following relation:

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

$$D_{in} = \begin{cases} 0 & for\ P_{imp} \leq 5\,kPa \\ 0.0094P_{imp} - 0.0508 & for\ 5\,kPa < P_{imp} \leq 34\,kPa \\ 0.27 & for\ P_{imp} > 34\,kPa \end{cases}$$



Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

To obtain a vulnerability relation for people outside buildings the idea was of relating the probability of being killed by an avalanche to the degree of burial. The degree of burial is then tentatively related to flow depth of the avalanche (h).

Using available data, the death probability outside buildings (D_{out}) is calculated for each degree of burial class as the ratio between the number of death and the number of people involved in the accidents.

In particular:
- a flow depth equal to 2 m in the case of complete burial of people;
- a flow depth equal to 1 m for people partially buried;
- a flow depth of 30 cm for people not buried.

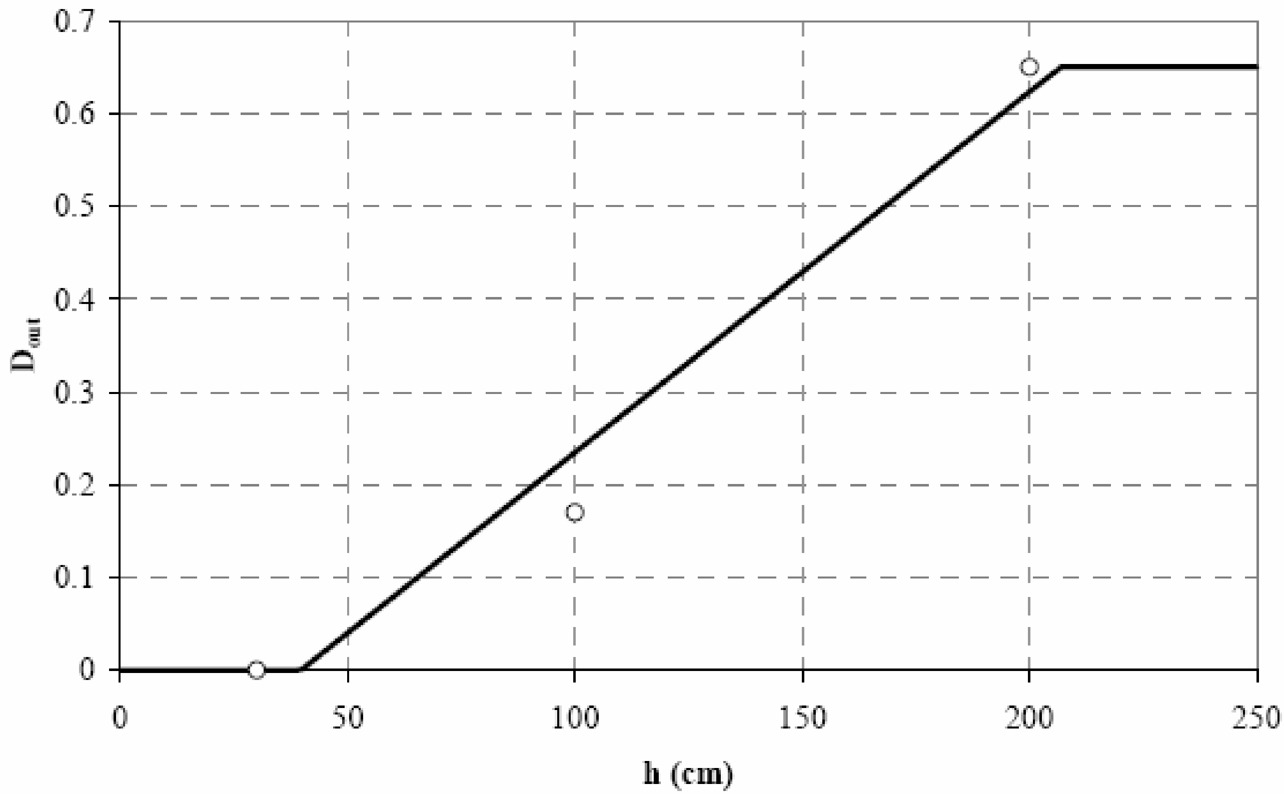
Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Degree of burial	h (cm)	D_{out}
completely buried	200	0.65
partially buried	100	0.17
not buried	30	0

$$D_{out} = \begin{cases} 0 & \text{if } h \le 40\,cm \\ 0.0039h - 0.1546 & \text{if } 40\,cm < h \le 210\,cm \\ 0.65 & \text{if } h > 210\,cm \end{cases}$$



Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach

The interaction between the hazard event(s) and the exposed elements can be also analyzed using damage or fragility curves and functions for several types of hazards into a probabilistic framework.

Extensive work has been carried out in USA by FEMA (Federal Emergency Management Agency) on vulnerability functions for earthquakes, floods and hurricanes.

These functions are used to quantitatively estimate the losses in terms of direct costs, regional economic impacts and casualties (Hazus, 2006).

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach – Earthquake

Fragility curves describe the probability of reaching or exceeding different earthquake damage states for different model building/structure types due to the building/structure response to the level of ground shaking (or degree of ground failure):

PGA (Peak Ground Acceleration),
PGD (Permanent Ground Acceleration),
etc.

The extent and severity of damage to structural and non-structural components of a given building type is described by one of five damage states: None, Slight, Moderate, Extensive, and Complete.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach - Earthquake

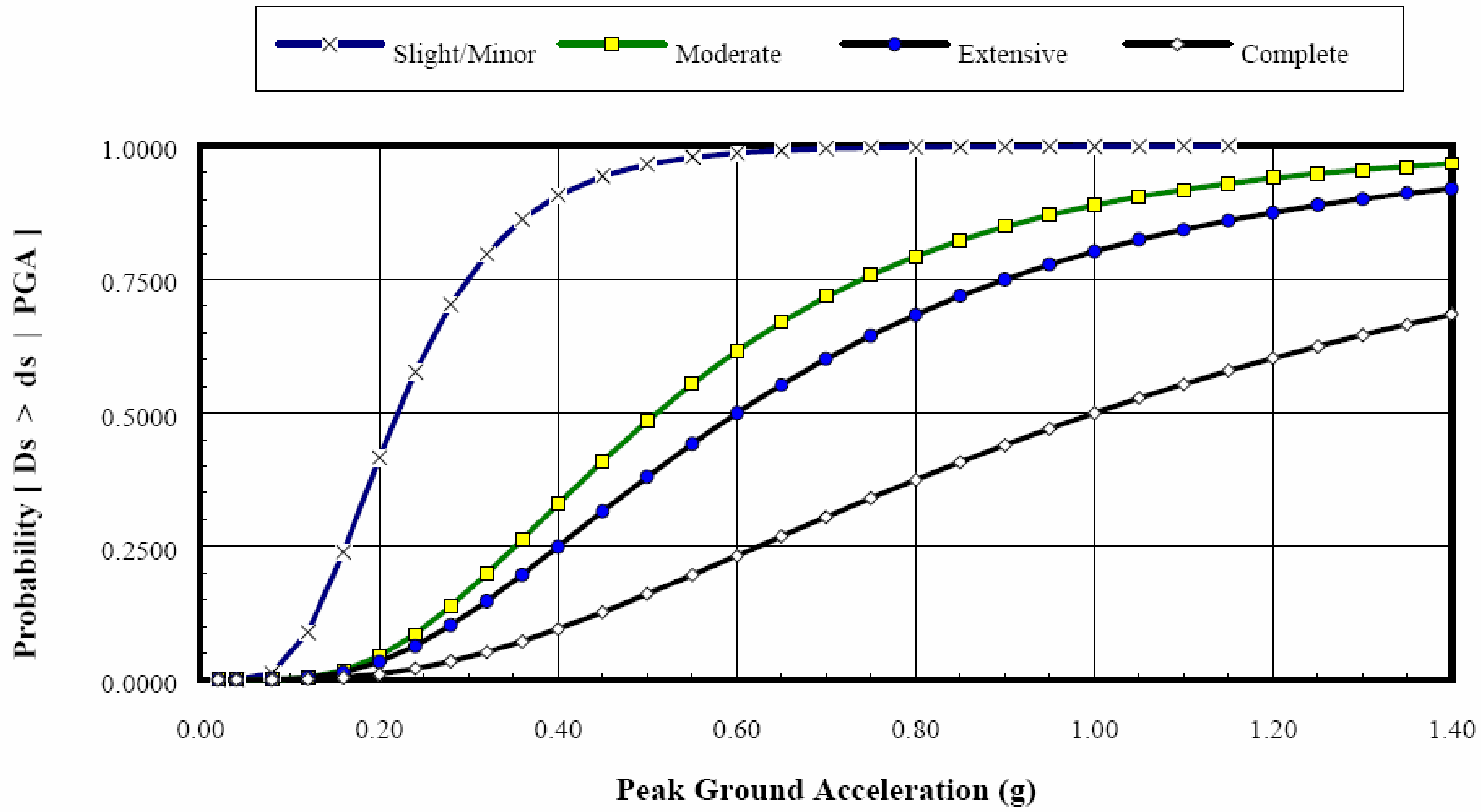


Figure 7.16 Fragility Curves at Various Damage States for Conventionally Designed Railway Bridges Subject to Peak Ground Acceleration.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach - Earthquake

Reinforced Concrete Moment Resisting Frames (C1):

Slight Structural Damage: Flexural or shear type hairline cracks in some beams and columns near joints or within joints.

Moderate Structural Damage: Most beams and columns exhibit hairline cracks. In ductile frames some of the frame elements have reached yield capacity indicated by larger flexural cracks and some concrete spalling. Nonductile frames may exhibit larger shear cracks and spalling.

Extensive Structural Damage: Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement; nonductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns which may result in partial collapse.

Complete Structural Damage: Structure is collapsed or in imminent danger of collapse due to brittle failure of nonductile frame elements or loss of frame stability. Approximately 13%(low-rise), 10%(mid-rise) or 5%(high-rise) of the total area of C1 buildings with Complete damage is expected to be collapsed.

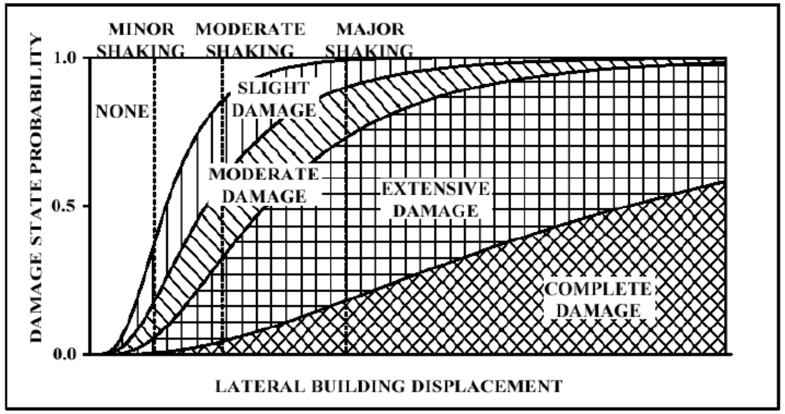


Figure 9.18 Sample building fragility curve.

Wood, Light Frame (W1):

Slight Structural Damage: Small plaster or gypsum-board cracks at corners of door and window openings and wall-ceiling intersections; small cracks in masonry chimneys and masonry veneer.

Moderate Structural Damage: Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

Extensive Structural Damage: Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of "room-over-garage" or other "soft-story" configurations; small foundations cracks.

Complete Structural Damage: Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. Approximately 3% of the total area of W1 buildings with Complete damage is expected to be collapsed.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach – Hurricane

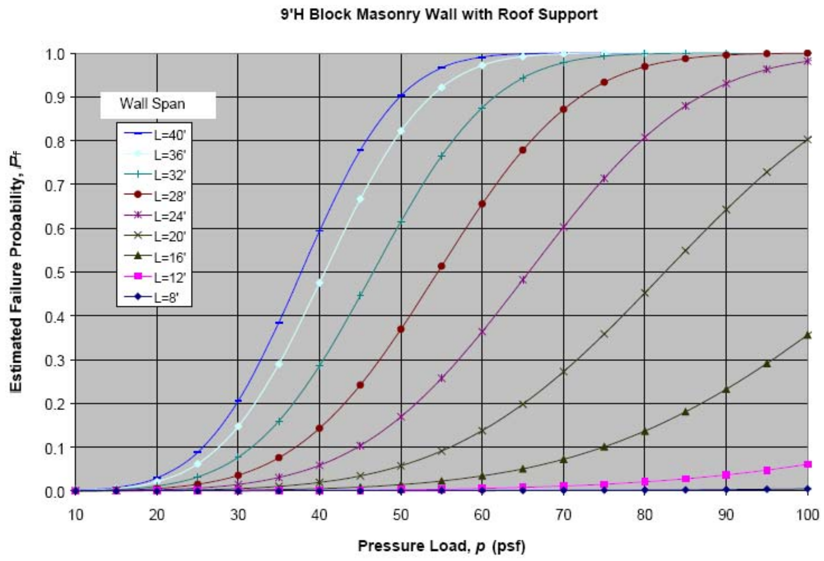


Figure 6.8. Estimated Failure Probability as a Function of Pressure Load for Various Wall Spans with Roof Support.

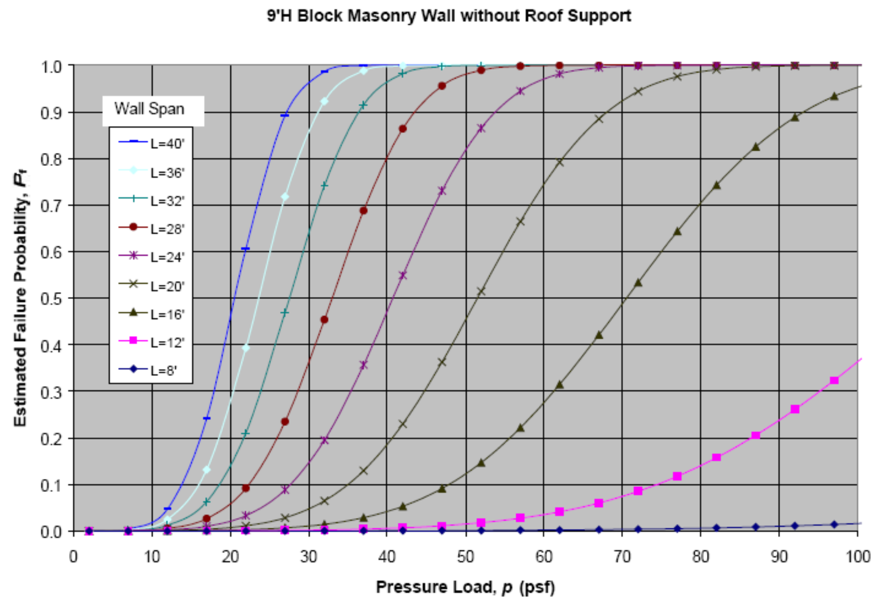


Figure 6.9. Estimated Failure Probability as a Function of Pressure Load for Various Wall Spans without Roof Support.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach – Flooding

Table 5.5 Velocity-Depth Damage Relationship for Wood Buildings

Material	# Stories (hgt)	Depth Threshold in feet DT(hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential			
				V < 2 fps any Depth	V < VT(hgt) D < DT(hgt)	V < VT(hgt) D >= DT(hgt)	V >= VT(hgt) any Depth
Wood	1 story	10	5.34	no collapse	no collapse	collapse	collapse if $D > 268.38V^{-1.9642}$
Wood	2 story	15	4.34	no collapse	no collapse	collapse	collapse if $D > 268.38V^{-1.9642}$
Wood	3 story	20	3.75	no collapse	no collapse	collapse	collapse if $D > 268.38V^{-1.9642}$
Wood	4+ stories			no collapse	no collapse	no collapse	no collapse

Table 5.6 Velocity-Depth Damage Relationship for Masonry and Concrete Buildings

Material	# Stories (hgt)	Velocity Threshold in feet/sec VT(hgt)	Collapse Potential		
			V < 2 fps	V < VT(hgt)	V >= VT(hgt)
Masonry & Concrete	1 story	6.31	no collapse	no collapse	collapse if $D > 525.09V^{-2.0406}$
Masonry & Concrete	2 story	7.47	no collapse	no collapse	collapse if $D > 1210.6V^{-1.9511}$
Masonry & Concrete	3 story	9.02	no collapse	no collapse	collapse if $D > -4.8864V+69.086$
Masonry & Concrete	4+ stories		no collapse	no collapse	no collapse

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach – Flooding

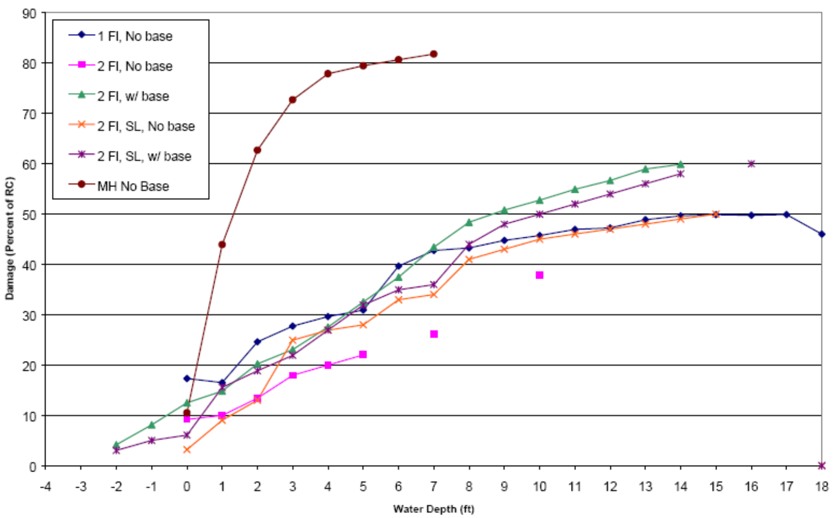


Figure 5.2 FIA Credibility-Weighted Building Depth-Damage Curves as of 12/31/1998

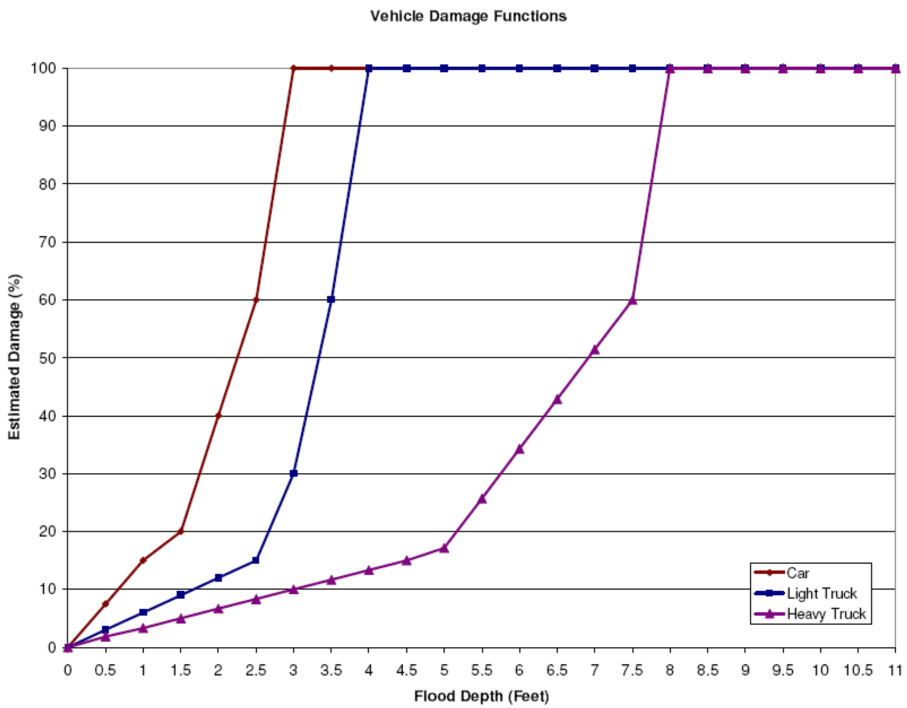


Figure 8.2 Vehicle Depth Damage Functions

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach - landslide

Kaynia et al. (2008) applied to a real event a probabilistic methodology to estimate the physical vulnerability of building structures and the population to landslides. They define quantitatively the vulnerability as the product of landslide intensity and the susceptibility to damage of elements at risk.

Haugen and Kaynia (2008) assessed the physical (structural) vulnerability to a debris flow by damage state probability functions. This was done by using the principles of dynamic response of simple structures to earthquake excitation and fragility curves proposed in Hazus (FEMA).

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach

Li et al. (2010) proposed new functions for the vulnerability of structures and people based on the landslide intensity and the resistance of the exposed elements.

Akbas et al. (2010, 2011) developed a theory-based generalized methodology for estimating the damage on buildings due to debris flow impact along with the associated uncertainties.

This methodology is based on the construction of fragility curves which express the "probable damage" to an element at risk for a "given level of hazard" that is specified as a result of hazard assessment. For a given hazard scenario, damage to different types of elements at risk are probabilistically estimated using corresponding fragility curves.

Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach

This approach has strong similarities with that employed in earthquake: the debris flow impact will lead to structural vibrations and will damage the structure approximately in the same way as an earthquake.

Intensity parameter: the energy level is denoted as velocity^2*depth.

Building damage is modelled as a function of lateral building displacement (different for each of the three proposed building classes used in the study sites).

This approach estimates the probability of reaching or exceeding of the engineering demand parameter (building displacement) at a specific debris flow intensity (Pf) for a specific building type.

This procedure is repeated for different damage states to obtain the complete set of fragility curves.

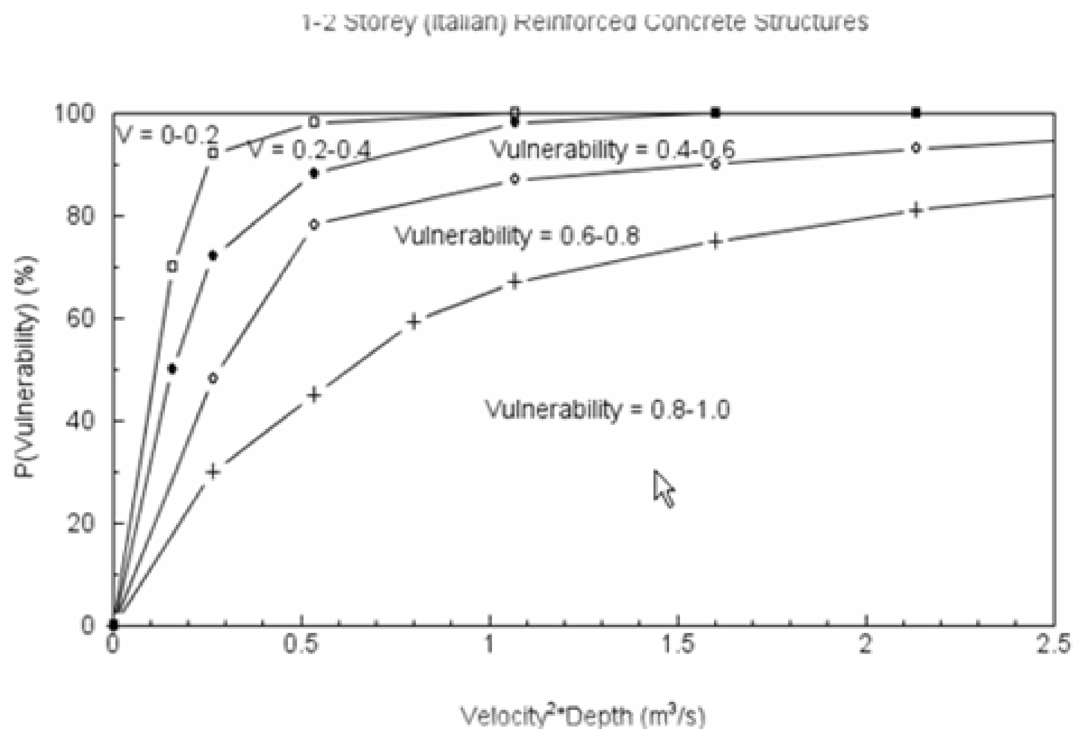
Methods

- the targets of the analysis: elements at risk

√ explore the different approaches to vulnerability and risk recognised in literature

Probabilistic approach

A sample (preliminary) output, i.e., vulnerability curves for 1 to 2 storey reinforced concrete structures is given below (damage state: slight, moderate, extensive, complete).



Final Remarks

Vulnerability assessment is a crucial step in risk assessment, translating Hazard levels into Risk levels.

It requires the analysis of hazard consequences on the different components or dimensions of a system, community, etc.

It is a function of the type, magnitude and frequency of hazard and it depends on system's exposure, sensitivity and its adaptive capacity.

In short term, when a disaster strikes, the primary concern are the potential losses due to casualties (deaths, missing persons and injured people) physical consequences on services, buildings and infrastructure and direct economic losses.

In the long term, indirect economic losses, social disruption and environmental degradation may become of greater importance.

Final Remarks

Many consequences cannot be measured/quantified easily. These are referred to as intangible losses:

- ✓ environmental degradation,
- ✓ social and cultural disruption,
- ✓ political/institutional disruption,
- ✓ and psychological consequences resulting from disasters.

The same system may be accounted for tangible and intangible losses. A building collapse (tangible) can cause deaths and injuries; this may produce the interruption or the reduction to a lower level of the economic activities (tangible) but also social and psychological effects on remaining community (intangible) affected by a threat.

The differences between tangible and intangible losses make their aggregation into a single indicator of disaster impact practically impossible.