Structural Vulnerability in Earthquakes

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Conference on Earthquake Engineering
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RISKS
BENEFITS

Some definitions in every day usage

Taken from http://www.dictionary.com

- **Risk** – possibility of suffering harm, loss; danger – a hazard
- **Hazard** – a chance and accident, possible source of danger
- **Vulnerability** – susceptibility to injury or attack

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Technical definitions are many and various – see Table 1 of written paper

Risk is
Probability * loss
Probability * consequence
Probability of a consequence
Probability of a hazard
Depends on three elements, hazard, vulnerability and exposure
Vulnerability * Hazard

Hazard is
Potential threat
An event with potential to cause harm
Probability of potentially damaging phenomenon e.g. an earthquake

Vulnerability
Susceptibility to damage
Susceptibility to disproportionate damage
Finding the weakest link
Resilience, adaptability

hazard is **'potential for harm'**

- it is a 'state of the system'
- can be in past, present or future
- can incubate to create an 'accident waiting to happen' or an opportunity to be taken to add value

vulnerability is **'susceptibility to damage'**

- potential for damage (i.e. specific part of hazard)
- a state of the form of the system which makes it susceptible to particular actions (e.g. earthquake, terrorism)

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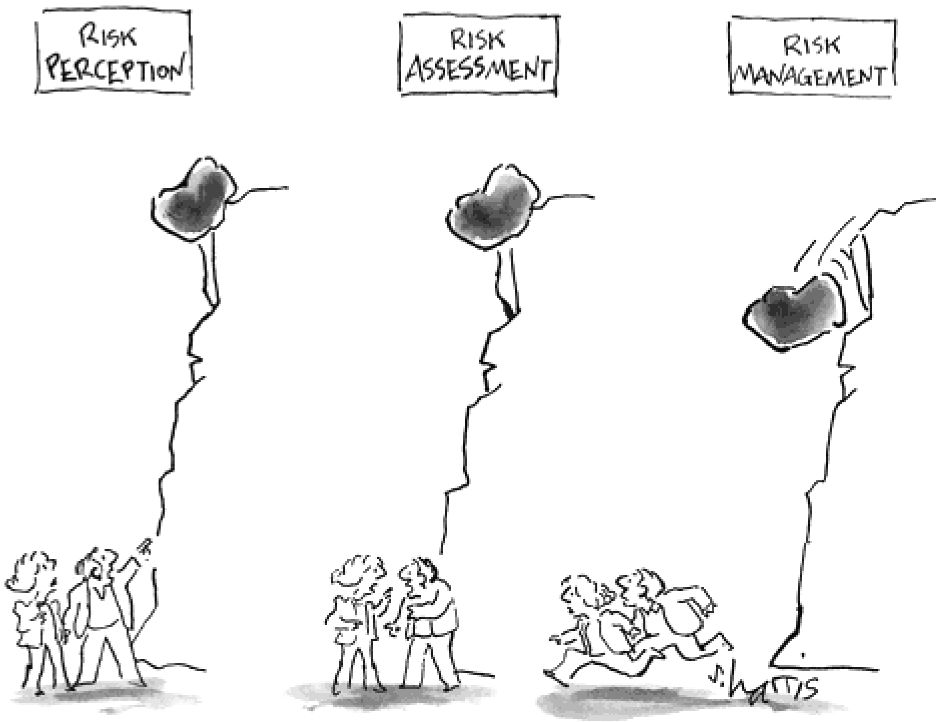
RISK PERCEPTION
RISK ASSESSMENT
RISK MANAGEMENT
S. HARRIS

Risk

- The **chance** of an **event** in the future

- Harmful event arises out of future **hazard**

- Unforeseen opportunities to **add value**

- Must be **understood** and accepted or tolerated in a context
  e.g. degree of control by individual – dangerous sports

- Acceptable public risks determined through a **political process**

- Engineers must therefore play a part in that process

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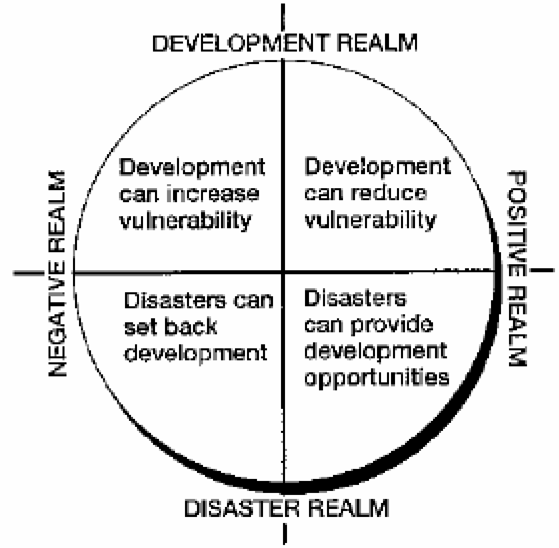
"'BE CAREFUL'! ALL YOU CAN TELL ME IS 'BE CAREFUL'?"

“Decision makers who ignore these relationships between disasters and development do a disservice to the people who place their trust in them.

Increasingly around the world, forward thinking Ministries of Planning and Finance with the support of the UN and NGOs are assessing developmental Projects in the context of disaster Mitigation and are designing disaster Recovery programs with long term development in mind.”

UNDP 1994



Aspects of a community's development and vulnerability to disasters are charted on the above figure. The graphic shows the various "orientations" with which you may analyze the "field" of development and disaster vulnerability.

The field is divided into positive and negative aspects of the disaster/ development relationship by the vertical axis. The right half reflects the positive or optimistic side of the relationship and the left side of the diagram deals with the negative aspects of the relationship. The short statement given in each quadrant sums up the basic concept derived from the overlap of the two realms.

Taken from UNDP disaster management training programme

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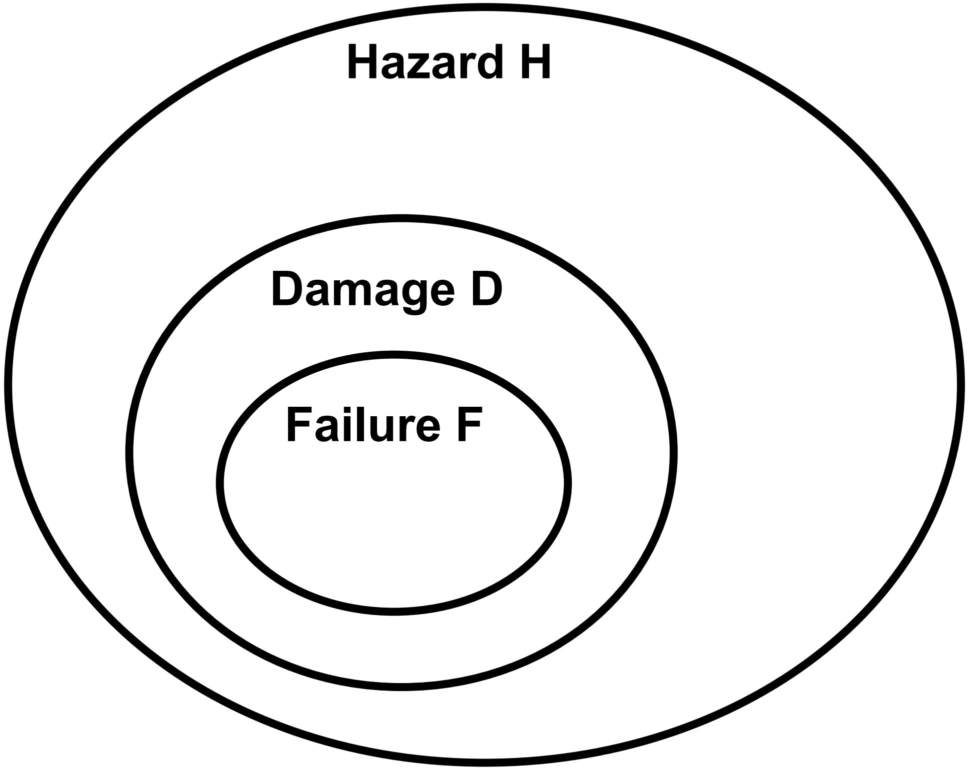

Assumptions

1 Failure ⊃ Damage

which means no failure without damage i.e. the damage is necessary to get failure.

2 Damage ⊃ Hazard

which means no damage without hazard i.e. the hazard is necessary to get damage

$$\mathbf{p\,(F \,\&\, D \,\&\, H) = p\,(F / H \,\&\, D)\,.\,p\,(D/ H)\,.\,p\,(H)}$$

$$\mathbf{= \underbrace{p\,(F / D)\,.\,p\,(D / H)}_{\text{Vulnerability}}\,.\,p\,(H)}$$

Vulnerability Hazard

Here vulnerability, response and hazard are defined In terms of the chance of a particular level of damage and hazard. Failure is the final level of total damage

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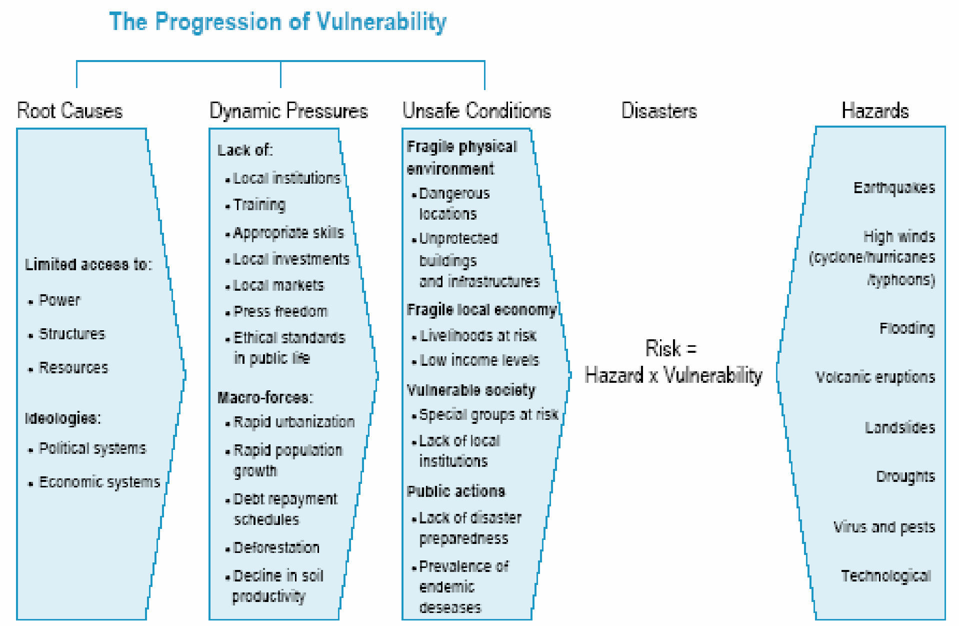
TABLE T.2 VULNERABILITY INDICATORS

Categories of Vulnerability	Indicators	Drought	Flood Earthquakes Cyclones	Source[c]
Economic	Gross Domestic Product per inhabitant at purchasing power parity	X	X	WB
	Human Poverty Index (HPI)	X		UNDP
	Total debt service (% of the exports of goods and services)		X	WB
	Inflation, food prices (annual %)		X	WB
	Unemployment, total (% of total labour force)		X	ILO
Type of economic activities	Arable land (in thousand hectares)		X	FAO
	% of arable land and permanent crops		X	FAO
	% of urban population		X	UNPOP
	% of agriculture's dependency for GDP	X		WB
	% of labour force in agricultural sector	X		FAO
Dependency and quality of the environment	Forests and woodland (in % of land area)		X	FAO
	Human-Induced Soil Degradation (GLASOD)	X	X	FAO/UNEP
Demography	Population growth		X	UNDESA
	Urban growth		X	GRID[d]
	Population density		X	GRID[e]
	Age dependency ratio		X	WB
Health and sanitation	% of people with access to improved water supply (total, urban, rural)	XXX		WHO/UNICEF
	Number of physicians (per 1,000 inhabitants)		X	WB
	Number of hospital beds		X	WB
	Life expectancy at birth for both sexes		X	UNDESA
	Under-five-years-old mortality rate	X		UNDESA
Early warning capacity	Number of radios (per 1,000 inhabitants)		X	WB
Education	Illiteracy rate		X	WB
Development	Human Development Index (HDI)	X	X	UNDP

Source: UNDP/UNEP

Figure 2.11

Vulnerability analysis



Adapted from: Blaikie et al., 1994

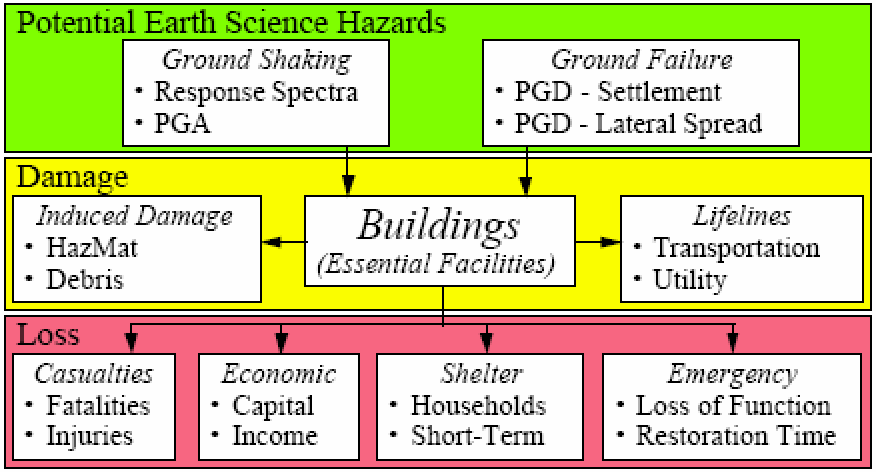


Figure 2.1. Building-Related Modules of the FEMA/NIBS Methodology

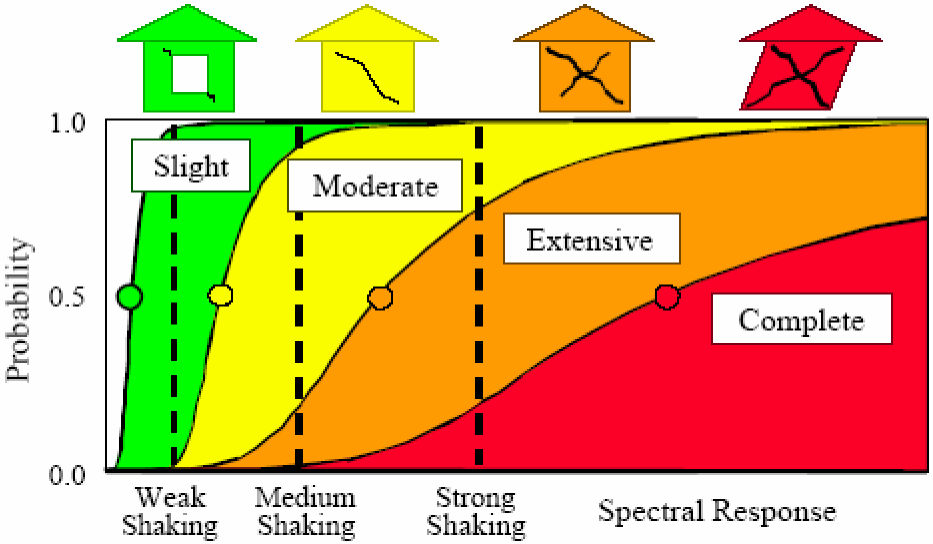


Figure 2.5. Example Fragility Curves for Slight, Moderate, Extensive and Complete Damage

Table 1: Identifying Probable Influence of the Different Vulnerability Factors on the Seismic Performance of Buildings

Vulnerability Factors		Increasing Vulnerability of the Building by different vulnerability factors				
		High	Medium	Low	N/A	Not known
Building System	Load Path					
	Weak Storey					
	Soft Storey					
	Geometry					
	Vertical Discontinuity					
	Mass					
	Torsion					
	Deterioration of Material					
	Cracks in Infill Wall					
	Cracks in Boundary Columns					
Lateral Force Resisting System	Redundancy					
	Shear Stress Criteria					
Connection	Connectivity between different Structural Elements					
Others	Pounding Effect					

Guidelines for Seismic Vulnerability of Construction Types according to EMS 1998
(NOTE: structural systems correspond to Table 4.3 in the report)

Material	Type of Load-Bearing Structure	*No*	*Subtypes*	Vulnerability Class					
				A	B	C	D	E	F
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	O					
		2	Massive stone masonry (in lime/cement mortar)		|-	O	-|		
	Earthen/Mud/Adobe /Rammed Earthen Walls	3	Mud walls	O					
		4	Mud walls with horizontal wood elements	|-	O	-|			
		5	Adobe block or brick walls	O					
		6	Rammed earth/Pise construction						
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	|-	O	-|			
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts						
		9	Unreinforced brick masonry in cement or lime mortar with reinforced concrete floor/roof slabs		|-	O	-|		
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams			|-	O	-|	
	Concrete block masonry	11	Unreinforced in lime or cement mortar (various floor/roof systems)						
		12	Reinforced, in cement mortar (various floor/roof systems)			|-	O	-|	
		13	Large concrete block walls with concrete floors and roofs						
Structural concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	|-	-	O	-|		
		15	Designed with seismic features (various ages)			|-	-	O	-|
		16	Frame with unreinforced masonry infill walls						
		17	Flat slab structure		|-	O	-|		
		18	Precast frame structure						
		19	Frame with concrete shear walls-dual system						
		20	Precast prestressed frame with shear walls						
	Shear wall structure	21	Walls cast in-situ				|-	O	-|
		22	Precast wall panel structure		|-	O	-|		

A1 Classification of damage according to EMS 98

A1.1 Classification of damage to masonry buildings

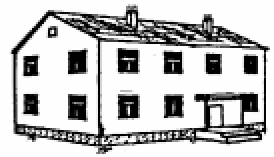
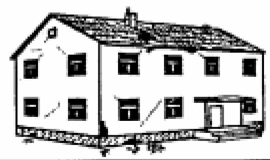
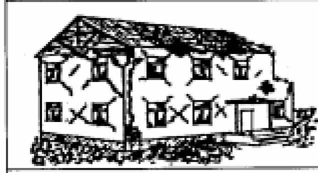
	**Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.	D_1
	**Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.	D_2
	**Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).	D_3
	**Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.	D_4
	**Grade 5: Destruction (very heavy structural damage)** Total or near total collapse.	$D_5 = F$

Figure A1.1: Classification of damage to masonry buildings [EMS 98]

Damage classes

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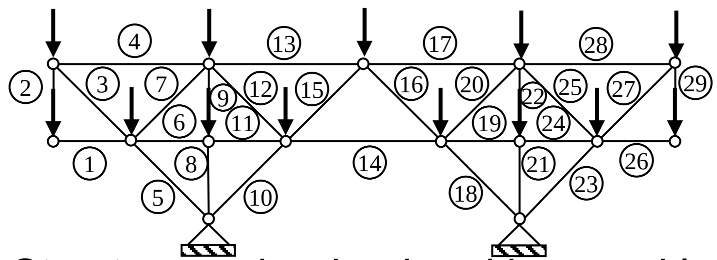
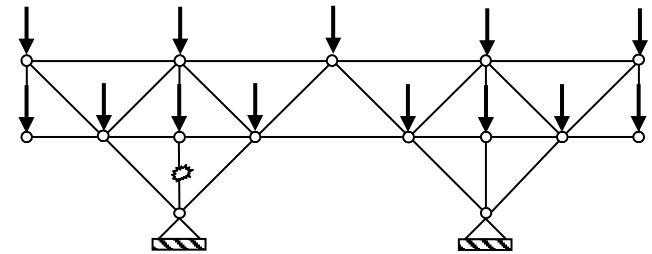
Example of progressive collapse

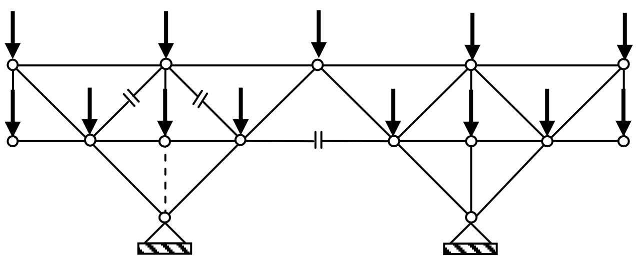
from damage events d_1 to d_4



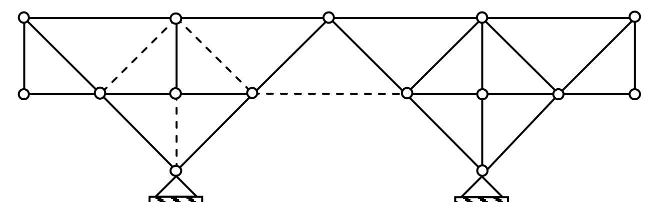
a) Structure under dead and imposed load



b) First deteriorating event d_1 (initial damage of m_8)



c) The failure of m_8 results in the failure of m_7, m_{12} and m_{14} i.e. events d_2, d_3, d_4



d) The structure becomes a mechanism

Initial damage

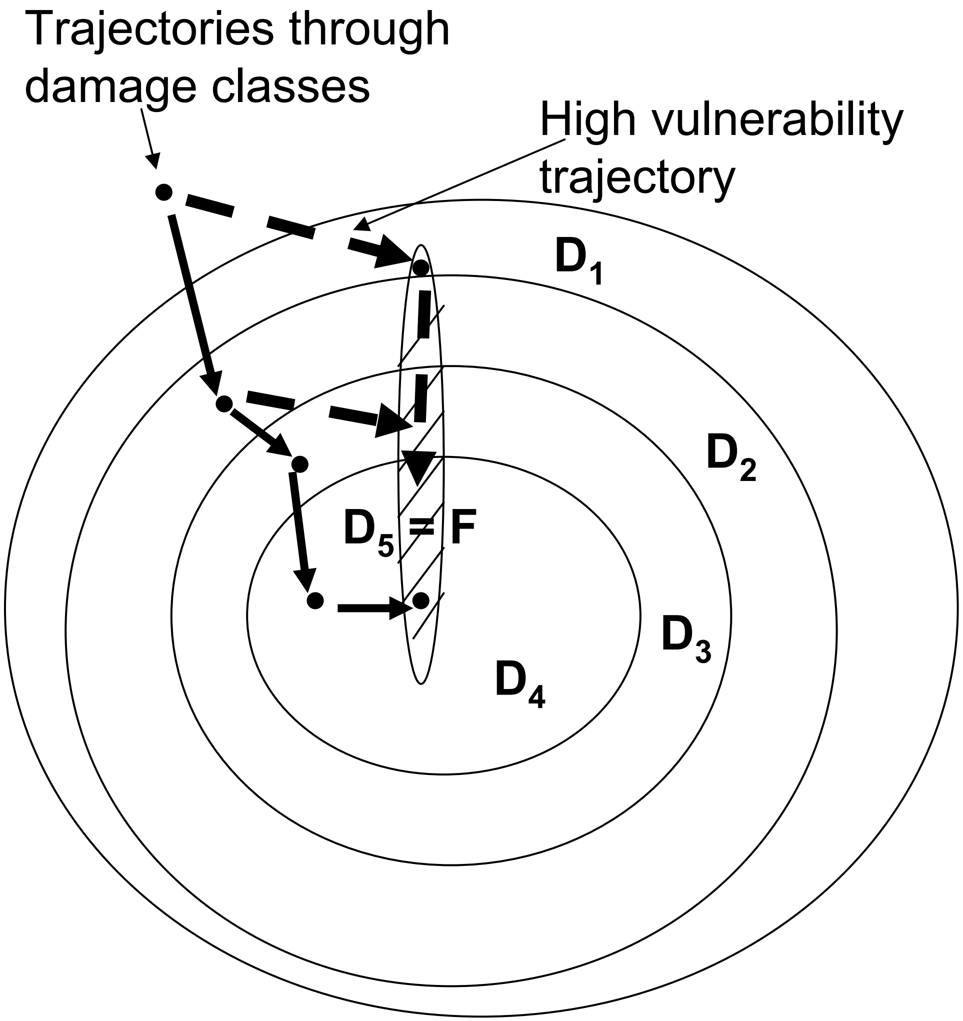
Member failing under dead and imposed load

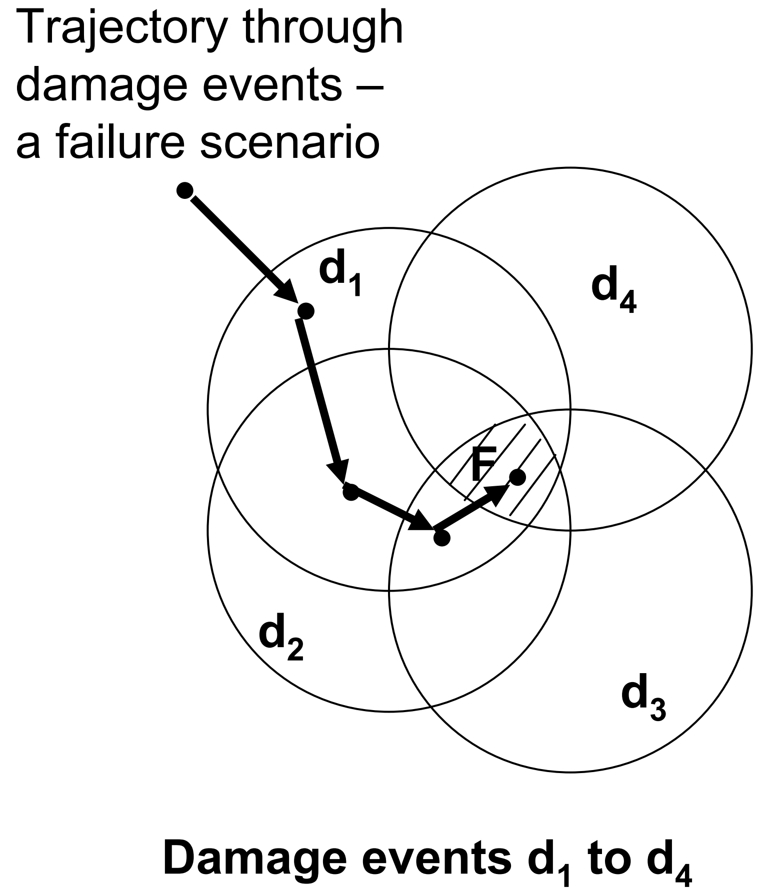
Failed member

Robustness of Structures

- Common measures for protection
  - Strengthening schemes
  - Manage loads and usage

- Examine the form of the structure
  - identify inherent weakness in form
  - explore actions posing the threats
  - manage the associate risks





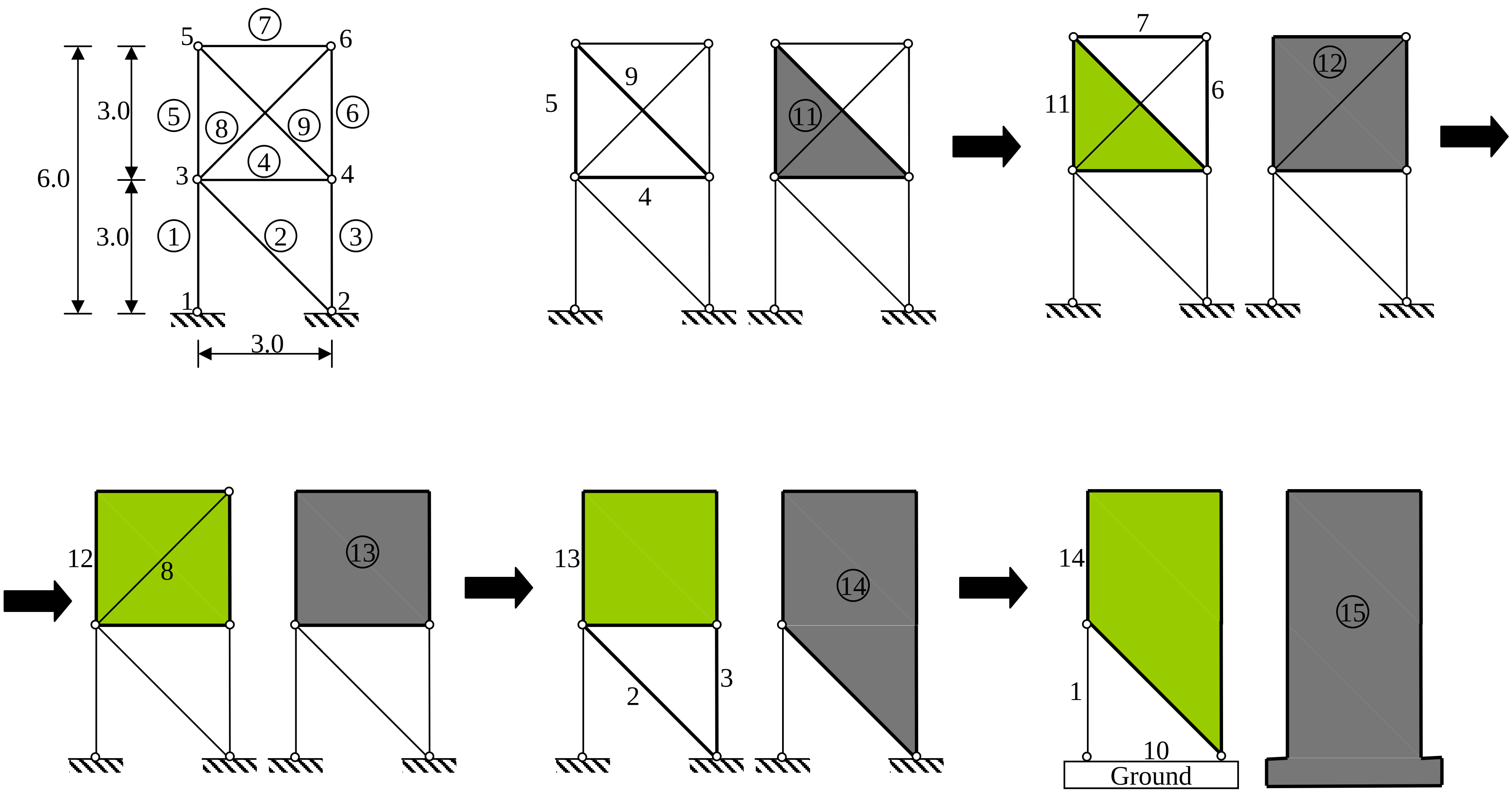
Progression through Damage Classes
D_1 to $D_5 = F$ in a given hazard

One possible failure scenario
of 4 damage events -
each has a vulnerability index

Vulnerability

- A system is vulnerable if small damage produces disproportionate consequences.
- If a system is vulnerable in any one way, it is not robust.
- There is no accepted theory of robustness.
- Vulnerability theory helps us to find the ‘weak links’ in a system
- Hazard – potential for harm
- Vulnerability – susceptibility to damage, weakest link

Example 1



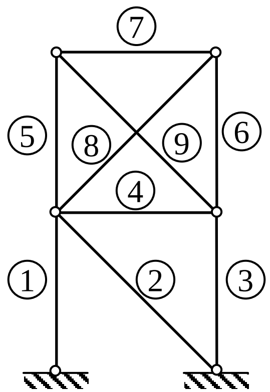
Key:

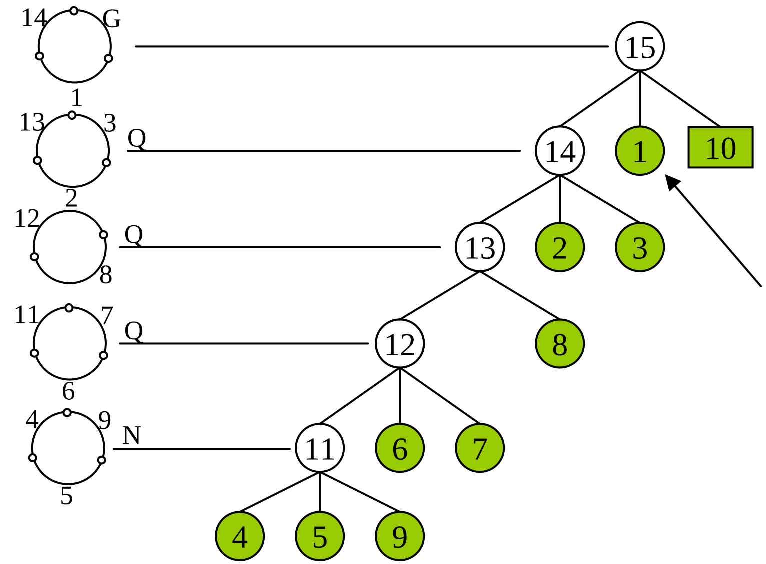
n Primitive cluster

n Already formed cluster

n Newly formed cluster

Failure Scenarios





Minimum Demand Failure Scenario	To damage member 2 or 8 or 9
Minimum Failure Scenario	Member 1
Maximal Failure Scenario	To damage member 2
Total Failure Scenario	To damage member 2

Managing Structural Risks

Likelihood of failure scenario in the future	low	medium	high
high	moderate	high	very high
medium	low	moderate	high
low	very low	low	moderate

Vulnerability/Hazard of Scenario

A measure of hazard potential

Thermodynamic entropy

- Measure of:
  - Amount of energy in a system not available to do work.
  - Disorder in a system.
  - i.e. the higher the entropy the less useful work can be done and the greater the disorder

$$\Delta Entropy = \frac{\Delta HeatFlow}{Temp.}$$

A measure of hazard potential

$$Temp = \frac{\Delta ThermalEnergy}{\Delta Entropy} \rightarrow HazardPotential = \frac{\Delta StrainEnergy}{\Delta Wellformedness}$$

$$HazardPotential_i^j = \frac{\left(\dfrac{StrainEnergy_i}{StrainEnergy_0}\right)}{\left(\dfrac{Wellformedness_i}{Wellformedness_0}\right)}$$

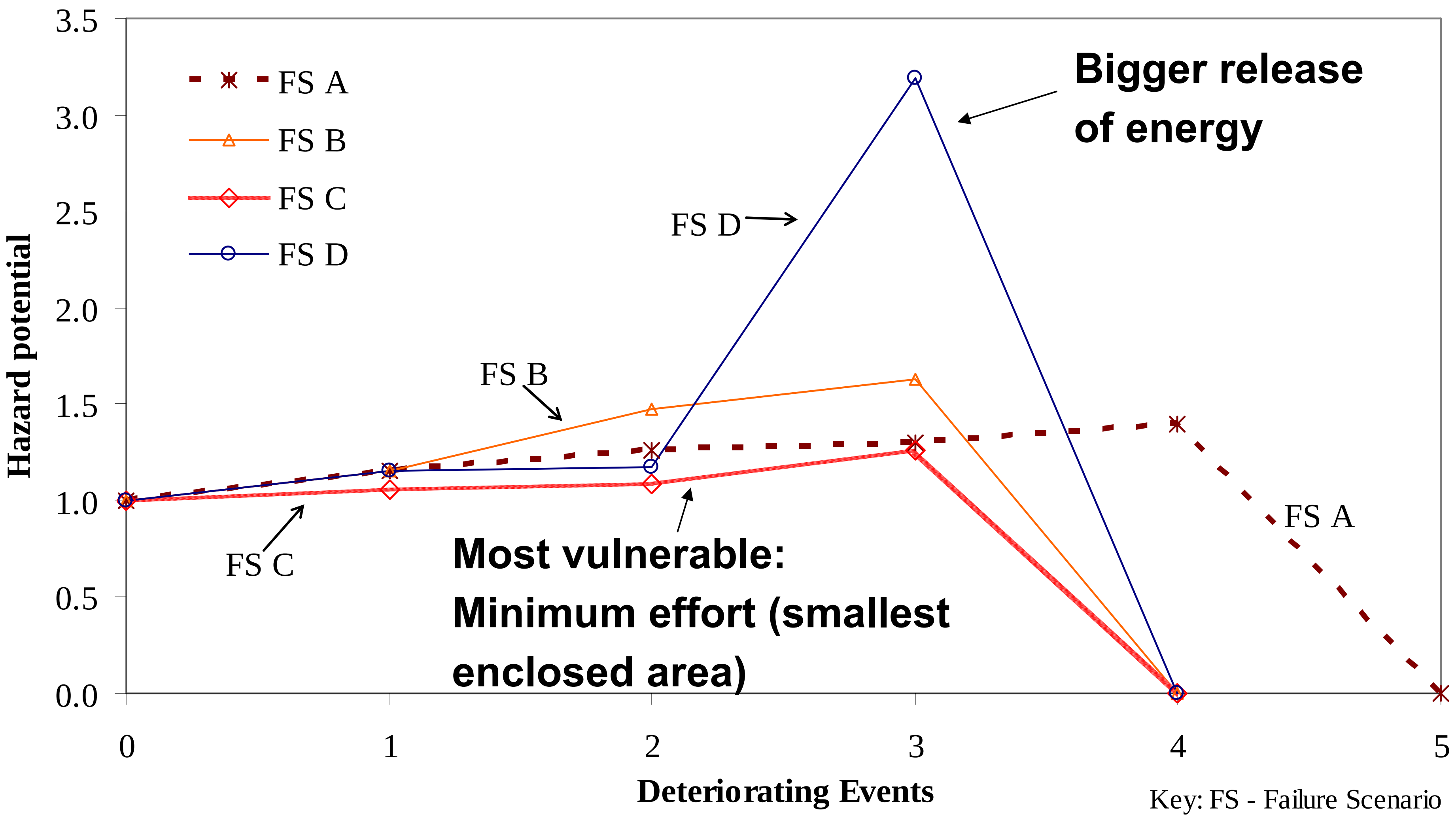
ith deteriorating event

jth failure scenario

$H_i^j \geq 0$

Hazard potential curves for different failure scenarios in a structure

'A measure of an accident waiting to happen'



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Risks ultimately depend on the **competence of people** – structural engineers

Tony Gibbs ‘There is no need for the setting up of elaborate inspectorates to enforce building codes’

In the UK there is a politically driven motivation to **reduce regulation**
Government is encouraging self – certification provided no reduction in safety

England & Wales – submit plans to local authority
Scotland – self certification run by SER Ltd of IStructE/ICE
Similar scheme for England & Wales being lead by John Hill
Northern Ireland moving in this direction
British Columbia
Hong Kong
Singapore

See **Sue Doran Structural Engineer Sept 2005**

Conclusions

1. **In everyday language risk, hazard and vulnerability are used interchangeably**
2. **There are different technical ways of defining risk**
3. **Risk is in the future**
4. **Acceptable risk is decided through the political process**
5. **Earthquake risks must be assessed**
6. **The UN has defined the terms for use in earthquake Engineering**
7. **Risk combines vulnerability and hazard**
8. **There are various vulnerability Indices**
9. **Vulnerability is also about susceptibility to disproportionate collapse**
10. **New measure of robustness proposed**
11. **Hazard potential – increases with damage to a maximum**
12. **Self certification is becoming possible through IStructE**