The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

H4.SMR/1645-25

"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

14 - 25 February 2005

IAEA Safety guides, Tecdocs & other activities

P. Contri

(NS/NSNI/ESS)
IAEA

2nd Workshop on "Earthquake engineering for nuclear facilities. Uncertainties in seismic hazard assessment" ICTP - IAEA

ICTP, Trieste, February 14-25, 2005

IAEA Safety guides, Tecdocs & other activities

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Highlights of the presentation

- **Objectives**
  - Provide a framework for the PSHA in the NPP design and re-evaluation
  - Provide MS experience, trend and expectations
  - Provide a quick review of the IAEA activities/documents in relation to PSHA
- **Scope**
  - Seismic PSA. NPPs, RR and other nuclear facilities
- **Background**
  - General, basic procedures available in IAEA Safety docs, TECDOCS
- **Target group**
  - Advanced: knowledge of PSHA basics is a prerequisite

Content

1. Requirements for the PSHA in relation to its application
2. The operating experience
3. The reference PSHA methodology
4. The trend
5. The IAEA contribution
    1. A proposal for a CRP
    2. The directory of NCP contributions
    3. IAEA documents for PSHA
    4. IAEA documents for NPPs
    5. IAEA documents for research reactors

1) The use of PSHA

The PSHA for the deterministic design

- Safety objectives are defined in **probabilistic** terms
- Design and qualification are mainly **deterministic**, PSA aims at design confirmation
- A probabilistic hazard evaluation is the preferred way **to grade** safety requirements among facilities with different risk for workers, public and environment
- A probabilistic approach allows a control of the uncertainties in different **stages** of siting (and design)
- Earthquake: regional, near-regional, site vicinity, and site investigation. 10-4/y (SL-2) and 10-2/y (SL-1). Integration between historical and seismotectonic data. Stochastic model for magnitude -recurrence
- Flood: combination of deterministic and probabilistic. DBF around 10-4/y
- Human induced events: probabilistic screening (10-7/y) and deterministic evaluation of DBF (at 10-5/y)
- Meteorological events: probabilistic (<10-2/y)

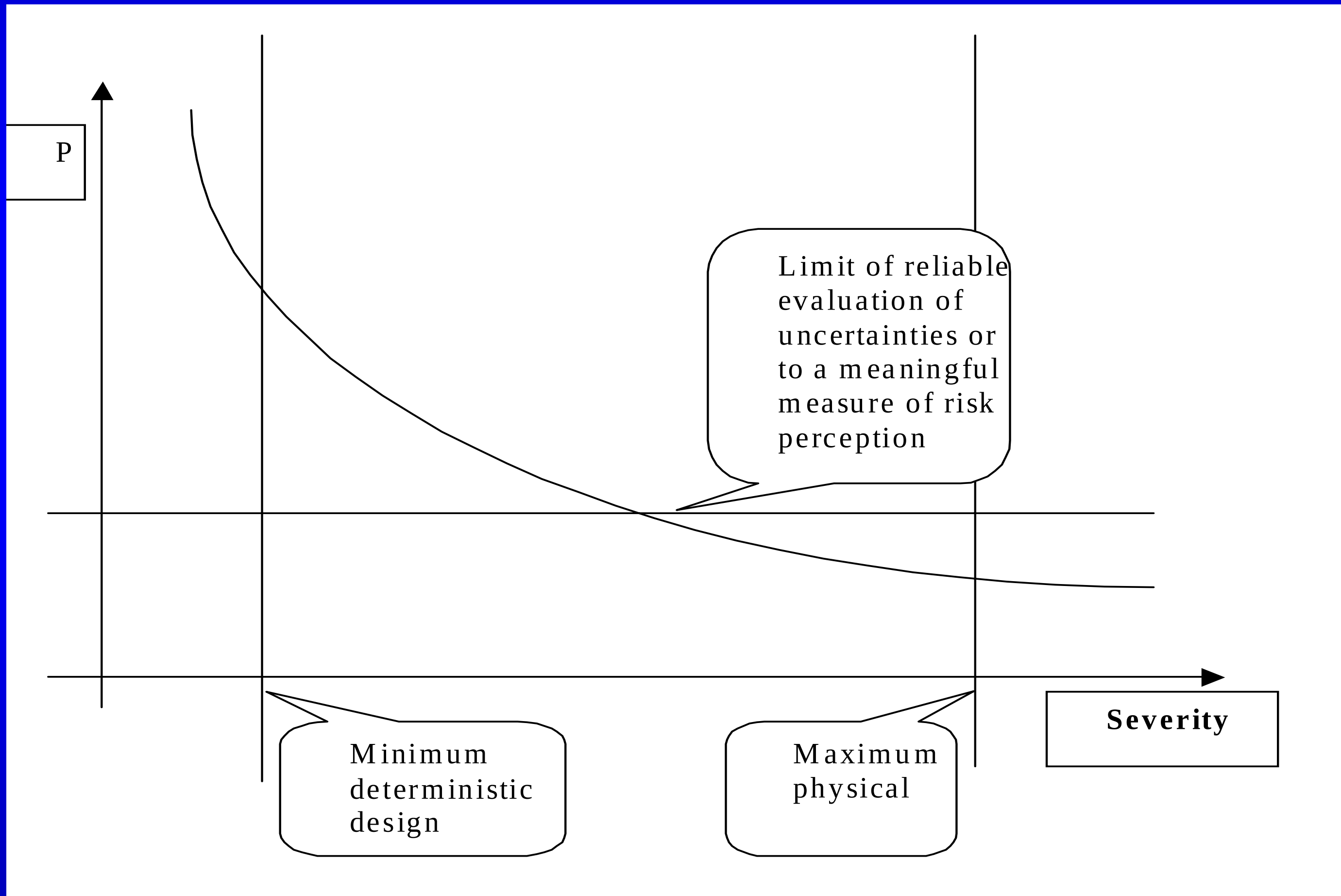
IAEA - Why a probabilistic hazard?

Advantages in the use of probabilistic techniques

- The risk can be better evaluated compared with a deterministic framework.
- A probabilistic approach can support a reduction of the chronic high level of uncertainty usually affecting the whole design process related to the external scenarios, allowing a quantification of the contribution of improved technologies in siting and design (investigations, monitoring, integration of different disciplines, etc.)
- Through probabilistic techniques, the best reduction of the uncertainties can be obtained in the siting phase, which still represents by far the highest contribution to the overall uncertainty level affecting the design process.

However, the application of probabilistic techniques, even though closer to the risk perception of the public, implies some intrinsic mathematical difficulties and some complicated coupling with some modules of the design process, still fully deterministic.

Some constraints…?



PSHA as input for the EEPSA

- Objectives of EE-PSA, its importance, connection with national programs (such as IPEEE, etc.), **required by the IAEA as a complement to the design**
- Interfaces with IE-PSA
- Involvement of different expertises: seismologists, structural engineers, hydrologists, etc.

- **Input data for a Seismic PSA**
  - Regional, near regional, etc. geology, seismology ,etc., including beyond national borders and off-shore!
  - Seismological data base
  - Soil data (dynamic properties)
- **Output data**
  - Hazard curve + engineering quantities
  - Uncertainties
  - Secondary effects evaluation

Use of EE-PSA results

Goals of EE-PSA

1. Cover design aspects: develop accident management programs, emergency planning, post-event operator actions, manage expenditure for upgrading, improve the knowledge of plant response, etc.
2. Provide input to EEPSA as a complement to design, for assessment of safety objectives
3. Support risk informed decision making (OLC, technical Spec, ISI, maintenance, etc.)

Quality requirements, frequency ranges, etc. are completely different!!!

Seismic upgrading issues, PSA oriented

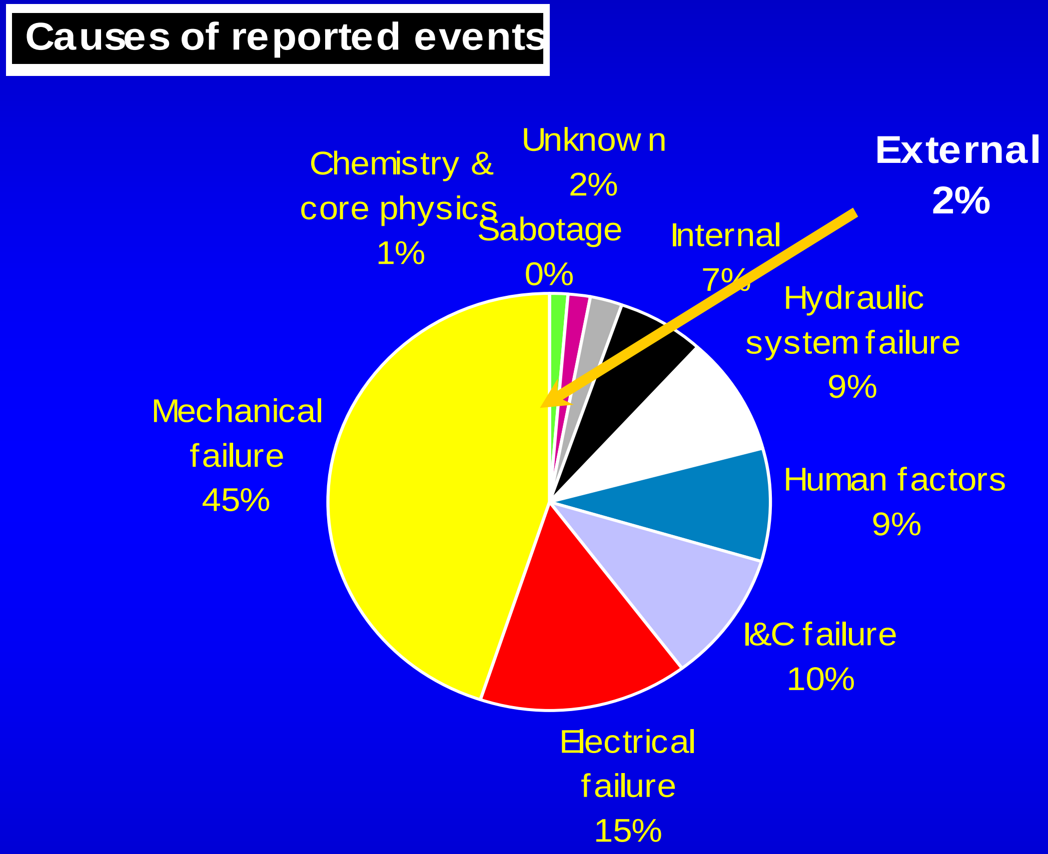
- Before upgrading, simulate better the fragility, which is usually the most critical contribution.
- In the upgrading, balance should be guaranteed between prevention and mitigation of accident; containment failure and core cooling, etc.
- Anticipated failure of mitigating systems can be a consequence of the classification.
- A comparison with EE-PSA results in similar plants should be carried out before taking corrective actions: unique vulnerabilities?

Seismic considerations

- PSHA is recommended by the IAEA SG for the design phase, not only for EE-PSA
- In case a PSHA is already available from the design phase, it has to be re-analysed and extended to the appropriate probability range
- Moreover, in the design phase the uncertainty on the hazard curve is not explicitly used, while in PSA is an essential part of the analysis

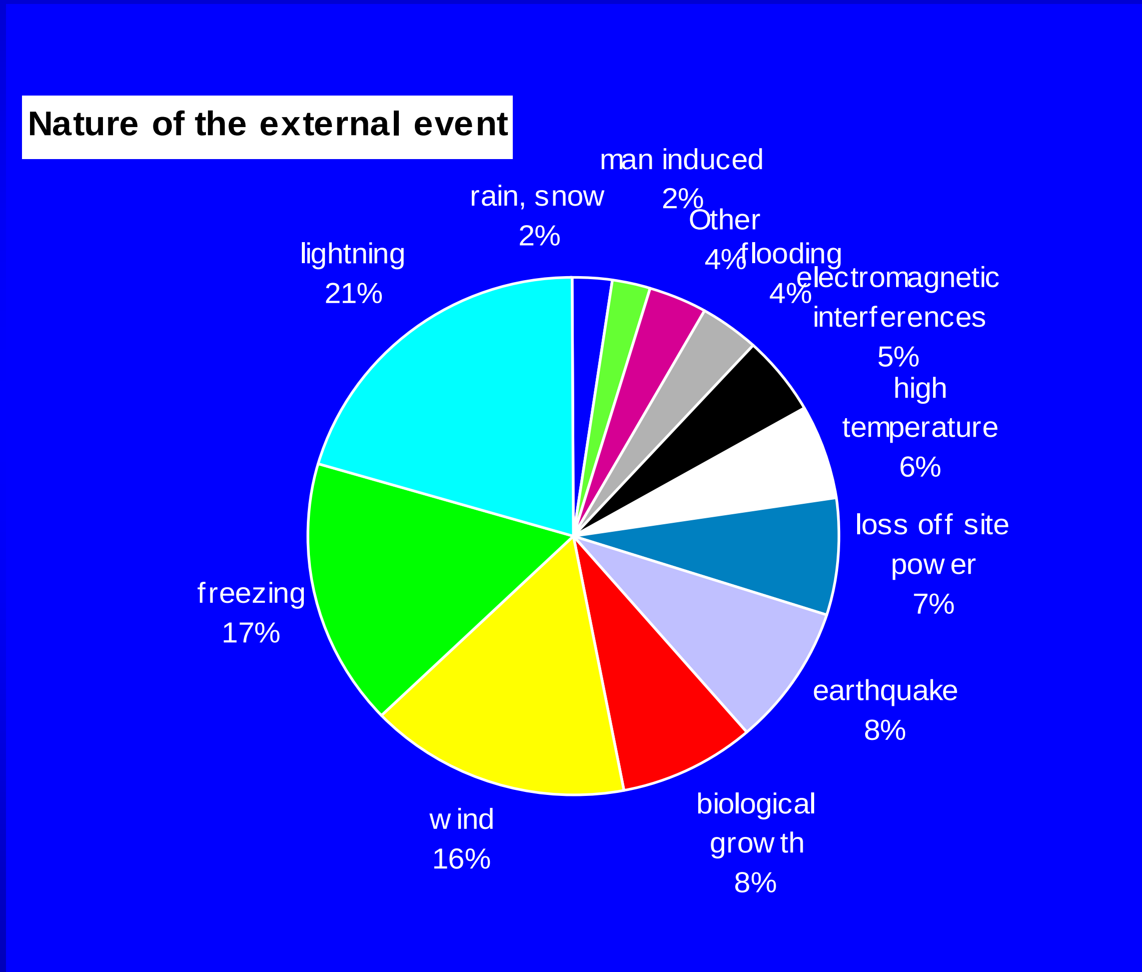
- **Alternative approaches:**
  - SMA: no hazard evaluation, only basic safety functions, simplified fragilities (HCLPF), etc. SMA cannot replace a PSA!
  - SMA techniques (fragility calculation and walkdown) can be used for PSA with advantages

2) The operational experience

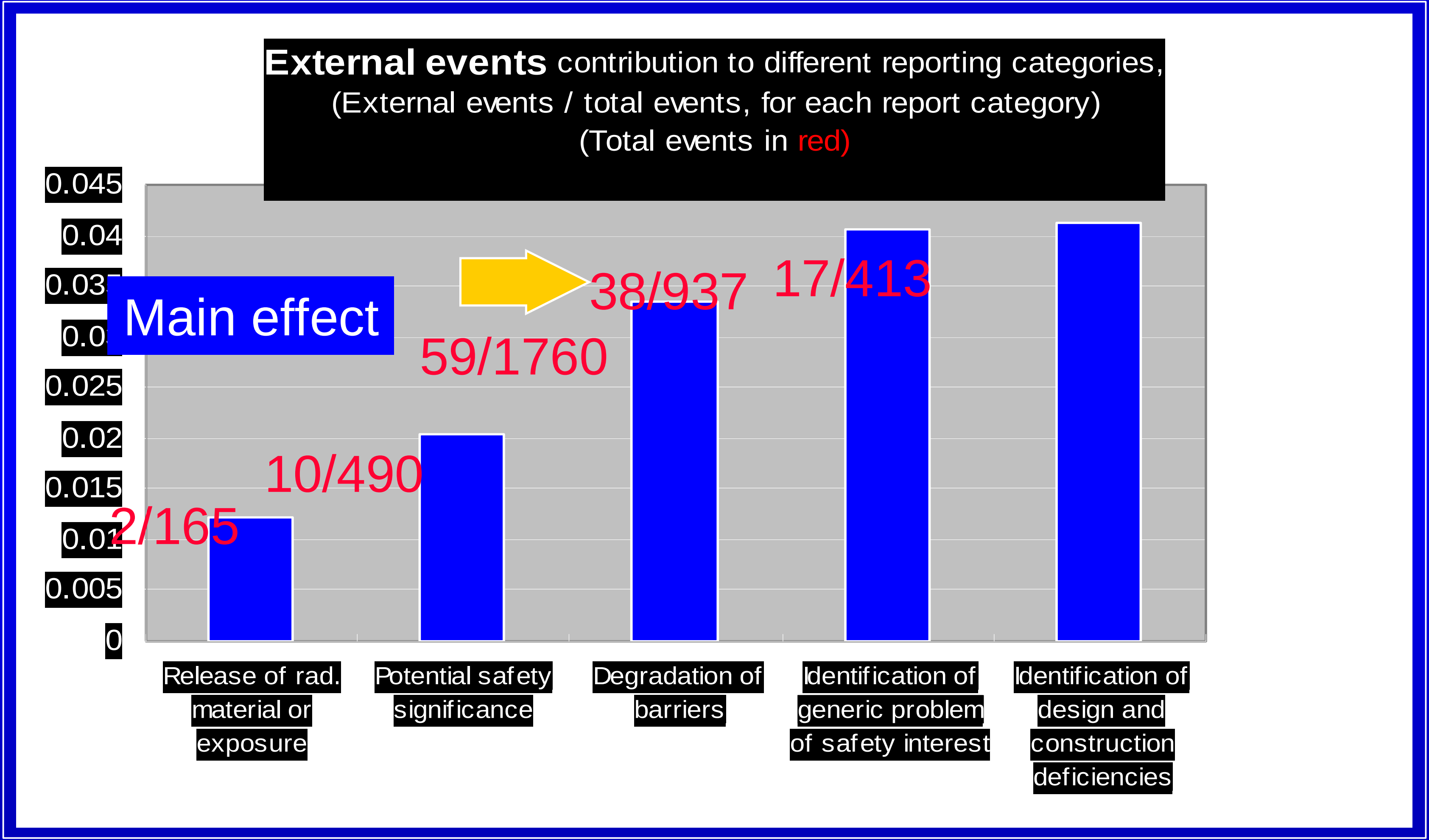


From IRS, after 1980, ~3000 events

Statistics (2)

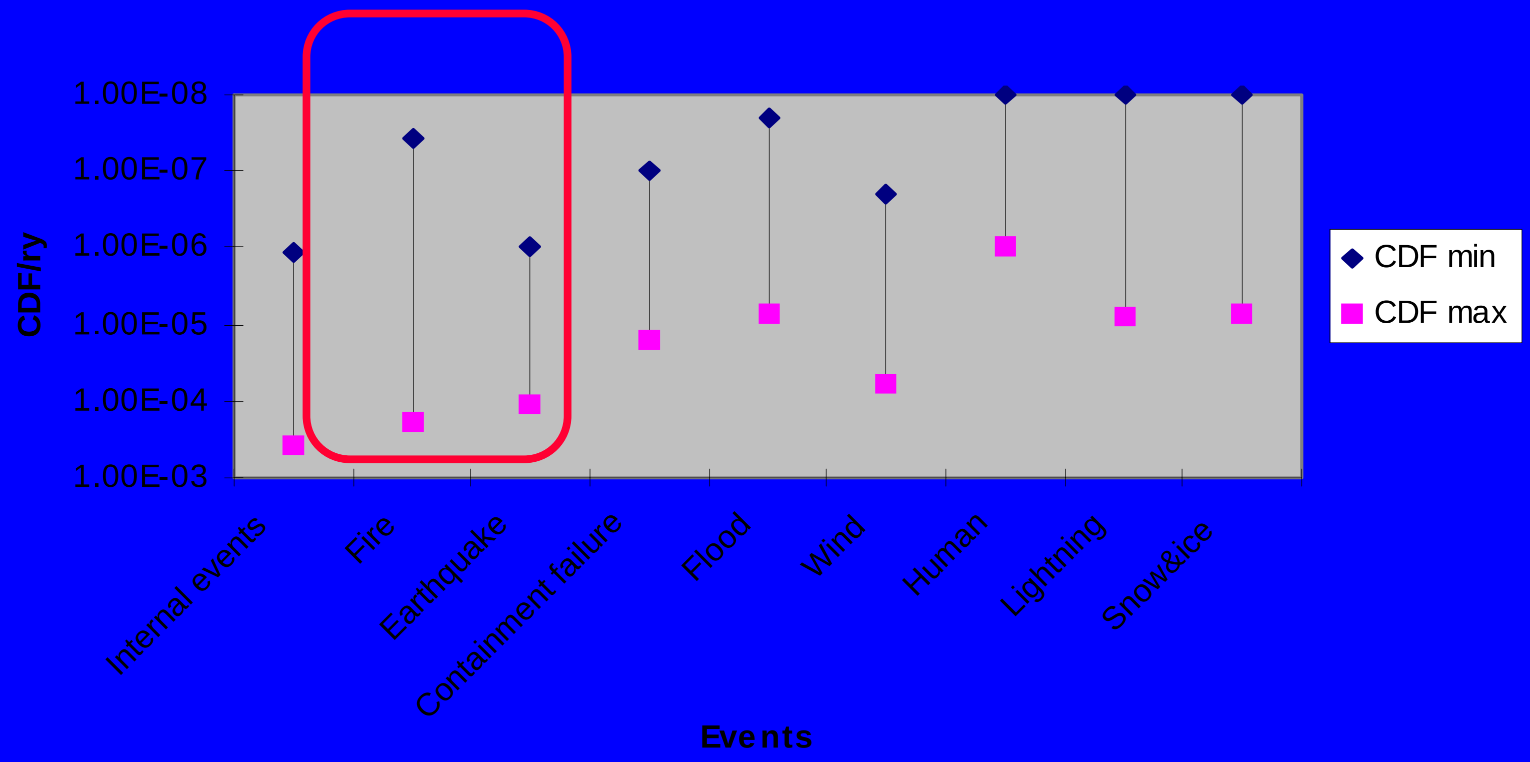


Statistics (3)



Contribution of EE and IE to the CDF

- Contribution to the CDF (from IPEEE)



General

From the experience in MS

- EE contribute between 10-50% to the core damage frequency depending mainly on the seismic design level of the plant
- For the innovative reactors it is going to affect the CDF much more!!
- Contribution from IE and EE: the radiological risk associated to EE should be lower. However, the comparison requires a level 3 PSA, it cannot be done on level 1. Moreover, the uncertainties are higher in EE-PSA!!
- In the seismic PSA the uncertainties on the Hazard usually dominate the final uncertainty associated to the seismic contribution to CDF (much higher than the uncertainties on the fragilities)

3) a) PSHA reference process

Objective: evaluate ground motion and fault displacement hazard at the site, evaluate the uncertainties and the secondary effects

Step 1 – Selection of the probability range to be considered

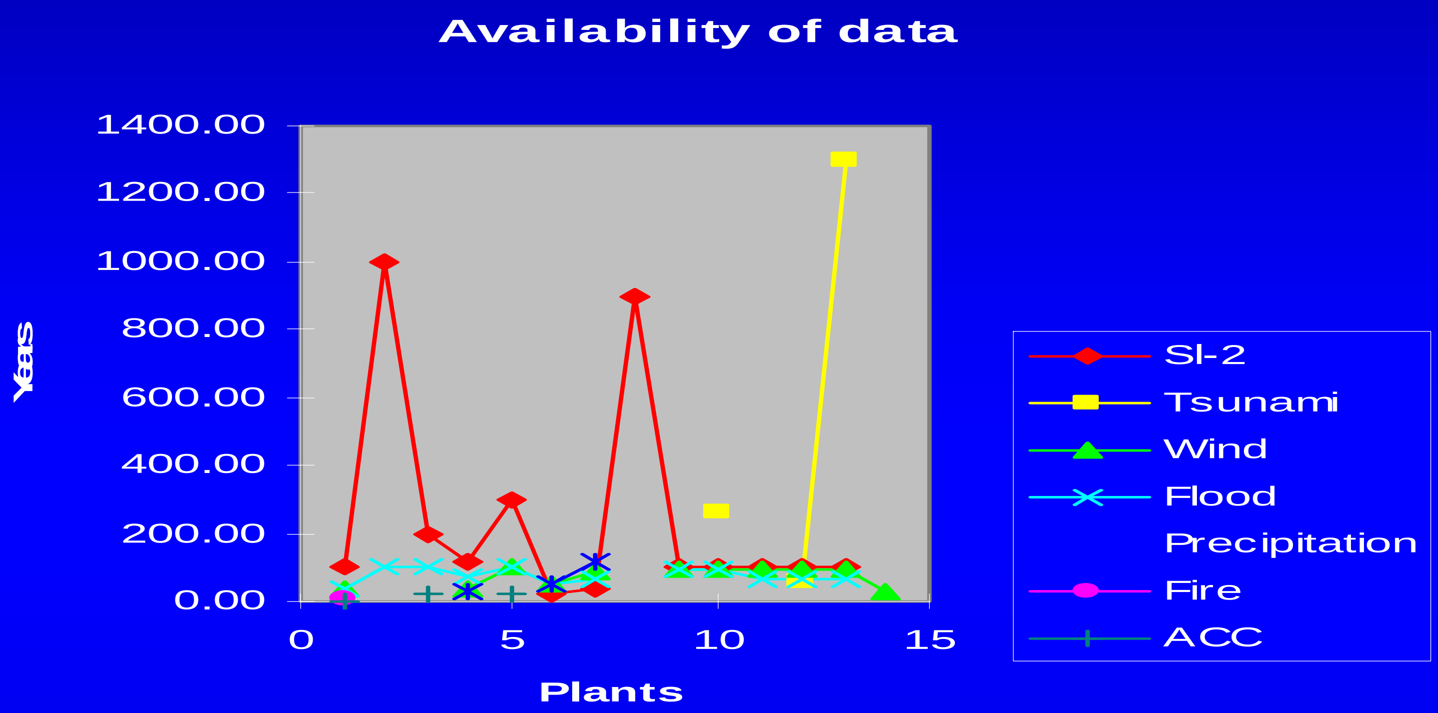
- The frequency range of interest is different from PSHA used for design considerations and therefore other methods are needed to extend its “window” to 10-4 - 10-8/y.
- The selection is the result of the evaluation of the product: event probability * conditional probability * release probability (which is the final safety objective!)
- The function CDF/intensity is not monotonic: this is also a criterion to check the proper range of integration!

Cont'd

Step 2 - Choosing the most appropriate parameter to represent the hazard

- Seismic hazard is a scenario (vibration, faulting, liquefaction, tsunami, landslides, etc.), not just a vibratory motion.
- The vibratory motion itself may need different parameters for a proper representation of the **consequences**:
    - Pga: for the maximum acceleration and brittle failures
    - Duration: for fatigue and ductile failures
    - Spectral content: for equipment failure
    - Phases distribution: for displacement and stress response field

Extrapolation issues – Practice in MS



SI-2	100	1000	200	120	300	25	33	900	101	101	101	101	101	
Tsunami										259		57	1300	
Wind	34			39	100	49	89		94	94	94	94	94	28
Flood	34	100	104	74	100	49	64		94	94	69	69	69	
Precipitation				30		49	116							
Fire	4													
ACC	2		21		20									

Interfaces with design and assessment

- PSHA is normally used for 1) design and 2) probabilistic assessment

- For both, two reference hazards should be considered:
  - SL-2: median value around 10-4/y. It represents the maximum level of ground motion to be used for design.
  - SL-1: median value around 10-2/y. It is a more likely earthquake used for load combinations and post-earthquake actions.

- Both may be referred to different sources and hazard curves (e.g. far and near field sources)

- In both design and PSA there is a screening process on consequences, but the target is different!! Some scenarios may have to be recovered for PSA

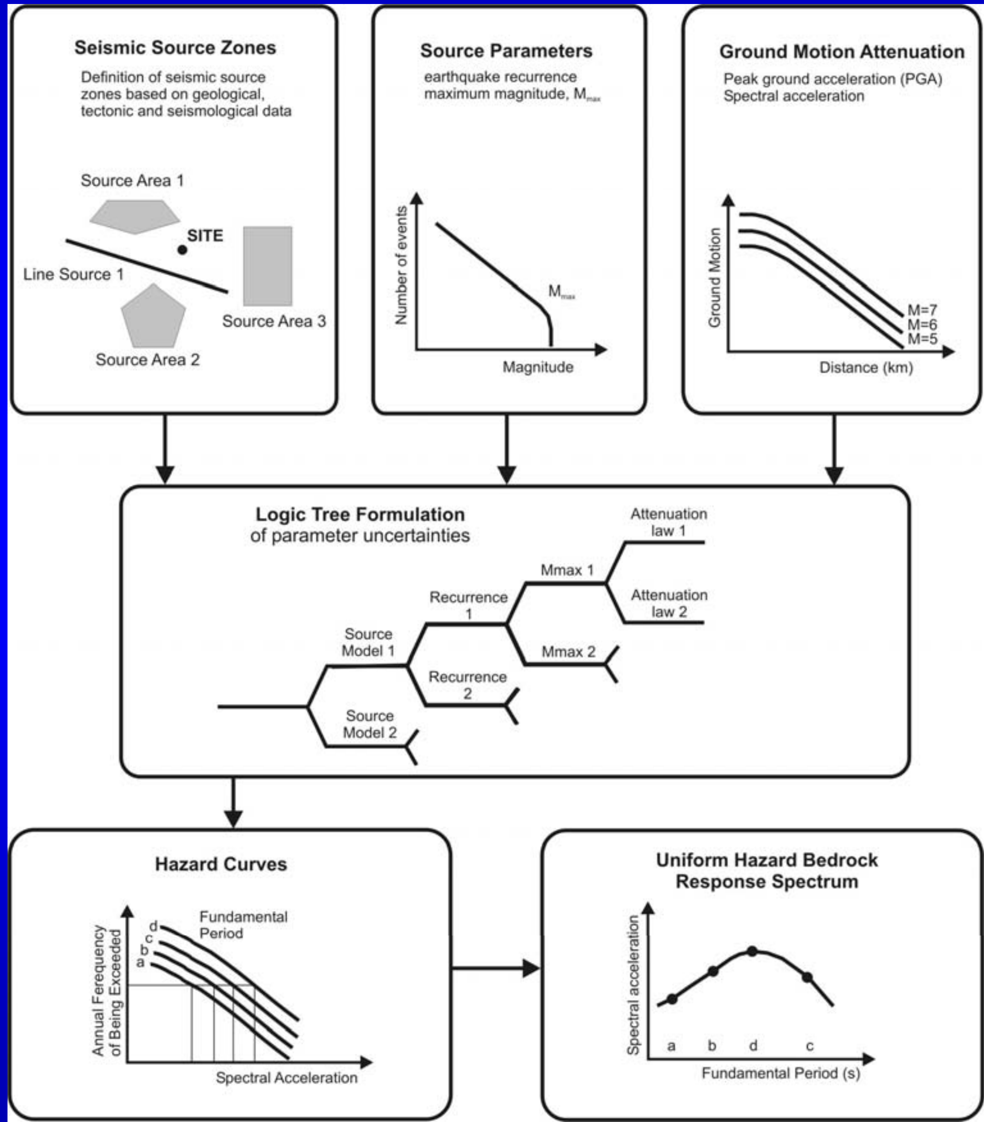
Cont'd

Secondary effects

- Surface faulting should be excluded, also in PSA, but other secondary effects may be excluded in design and recovered in PSA (liquefaction)
- Displacement field should be considered for underground structures
- Soil liquefaction, loss of bearing capacity, landslides, etc.
- System interactions, fire induced by earthquake, inadvertent actuation of fire protection system, etc.
- Dam failures, flood and other environment scenarios triggered by earthquakes.

The process

- See also IAEA Tecdoc n.724

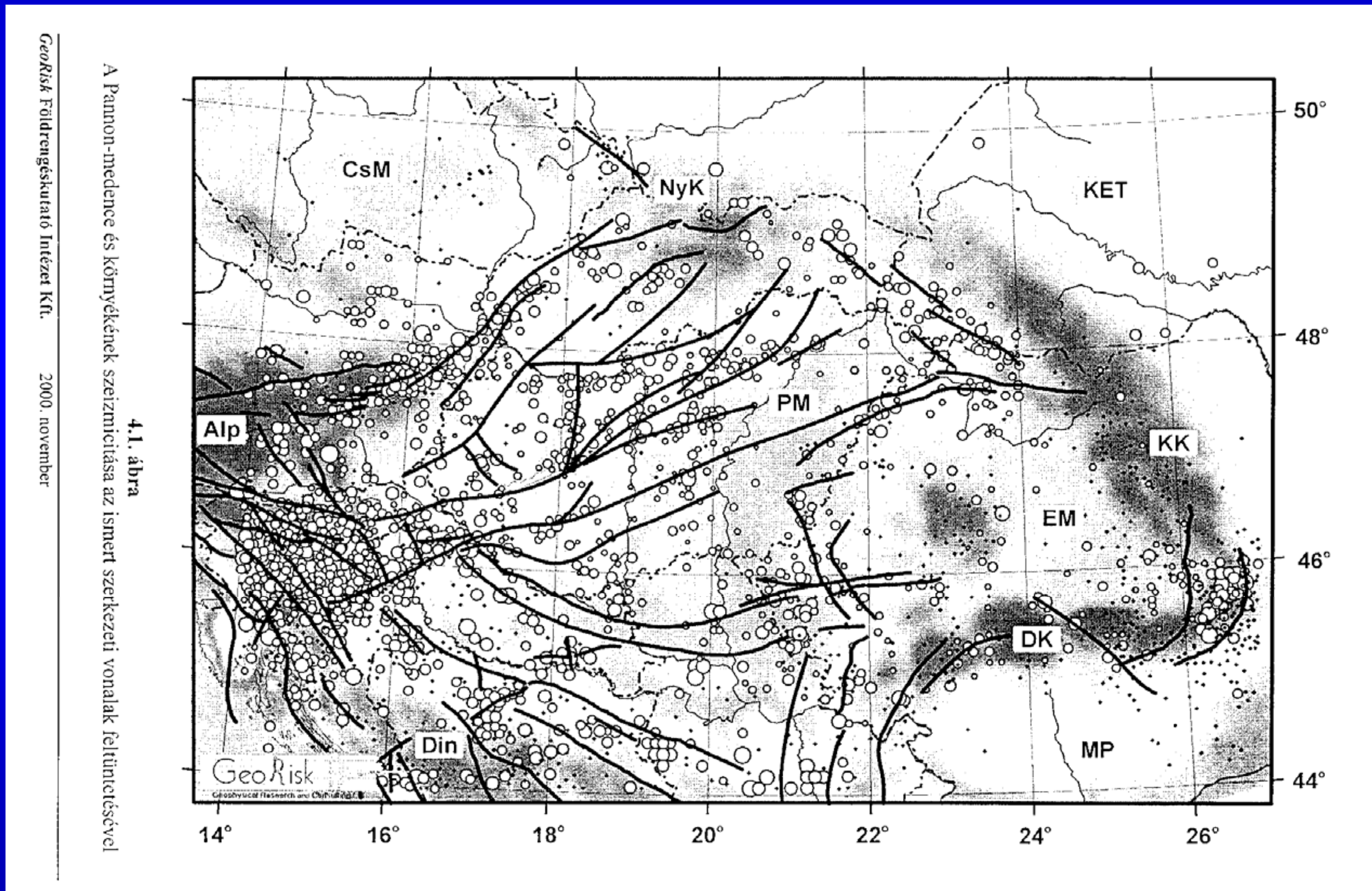


Investigations

Four steps (analysis levels) are mandatory:

- **Regional** (150 Km): focused on the geodynamic of the region, even asymmetric.
- **Near regional** (25 Km): focused on the understanding of local faults, their segmentation and activity. Needed: stratigraphy, geology, tectonic history. Data: geophysical investigations, heat flow, interferometric data and strain rate measurements, sedimentological studies and aerial pictures.
- **Site vicinity** (5 Km): focused on local neotectonic of faults, fault capability, potential for geological instability at the site. Data: geological, geophysical, bore-holes and trenching
- **Site area** (1 Km): focused on potential for permanent displacement, dynamic soil profile. Data: hydrological, geological, geophysical, geotechnical + lab testing

Example


4.1. ábra
A Pannon-medence és környékének szeizmicitása az ismert szerkezeti vonalak feltüntetésével
GeoRisk Földrengéskutató Intézet Kft.
2000. november
CsM
NyK
KET
PM
Alp
KK
EM
DK
Din
MP
GeoRisk
50°
48°
46°
44°
14°
16°
18°
20°
22°
24°
26°

Seismological data base

Three major contributions:

1. Pre-instrumental data: date, intensity, depth, effects, uncertainties, etc.
2. Instrumental data from available catalogues and local systems
3. Site specific instrumental data: from dedicated monitoring, operated also during plant operation for PSR, design confirmation and operator actions

- Data base extension, data availability
  - Holocene for interplate and Quaternary for intraplate.
  - Several years for site monitoring: analysis of the correlation with local seismotectonic, assessment of attenuation laws and local site effects.
- Data homogenization:
  - Small events are available only in recent years
  - Aftershocks should be included only if the seismotectonic does not use Poisson assumptions
  - Big events occurred in the past have higher uncertainty

DB improvement

- Use of Paleoseismology
  - Study of geological records of past earthquakes (faulting, liquefaction, coastline uplift) through age dating, displacement estimation
  - Evaluation of effects on ancient human constructions
  - It is the link between historical seismicity and neotectonics

Neotectonics → Paleoseismol. → Historical seism. → Instrumental

- Evaluation on completeness and reliability: attention to thresholds for recording on low and high excitation levels. The statistics can be biased!!

Large event n.1 → Large event n.2 → Many data from small earthquakes

Seismotectonic model

A seismotectonic model as composed of a discrete set of seismogenic sources (areas, lines, segments), composed of:

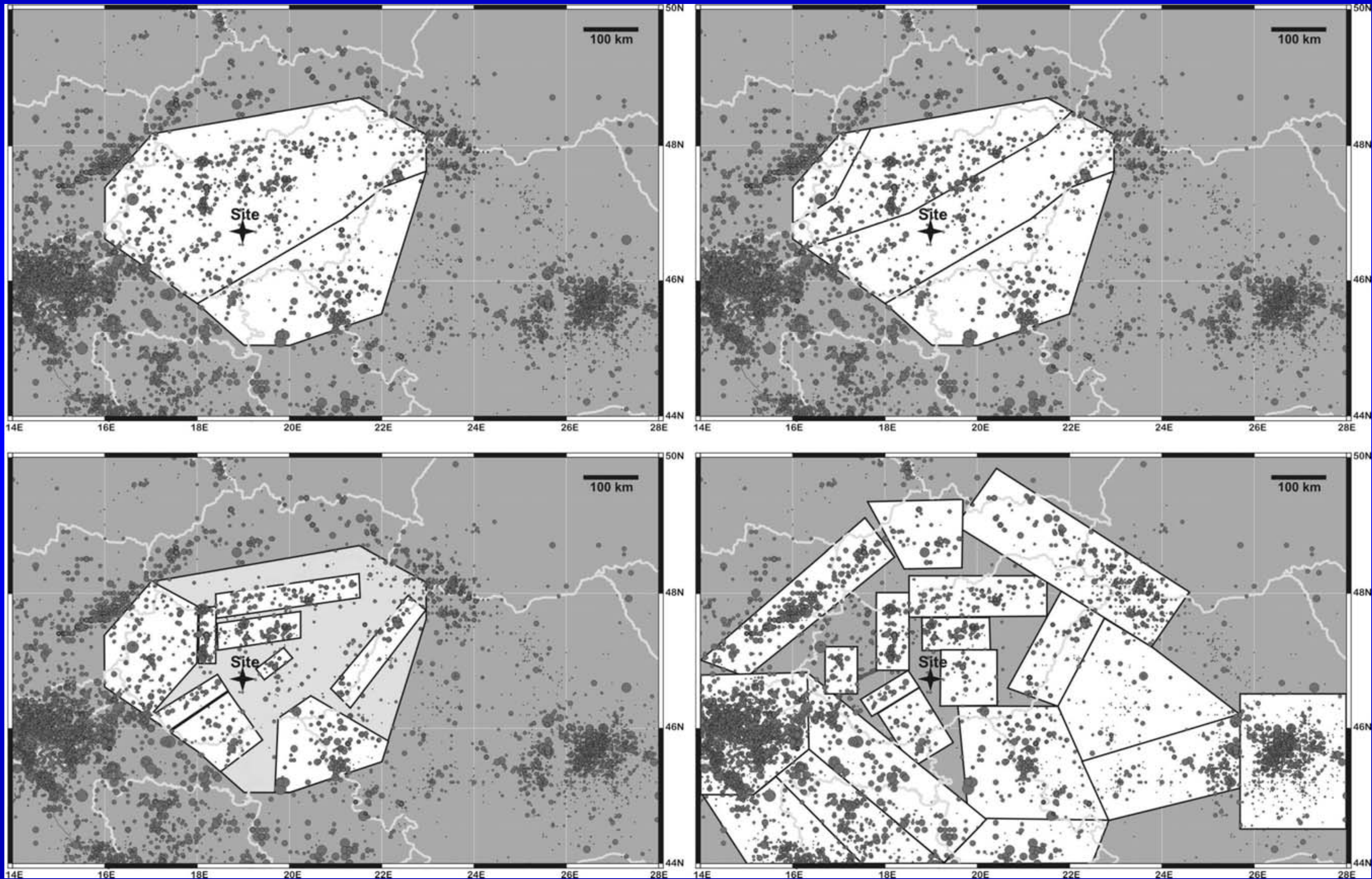
  - The seismogenic sources identified in the DB
  - Diffuse seismicity

- Characterisation:
  - Dimension of the structure, amount and direction of displacement, max hist. earthquake, paleo data, source depth.
  - Segmentation, average stress drop, fault width

Comments

- Higher uncertainty level for diffuse seismicity
- Sensitivity studies are needed with comparison of different models (not less than three)
- Special care in the identification of areas with deep/ shallow earthquakes (no/yes superficial faults)
- Far field/near field special aspects

Model uncertainties



Magnitude/recurrence models

- The estimation of maximum magnitude potential can be carried out through:
  1. Direct empirical relationship based upon source dimension (segmentation, fault width) and stress drop
  2. In case these quantities are not available, a statistical model for magnitude/statistical recurrence should be developed (Poisson?). Statistical models should be:
     - Consistent with geological and geomorphological evidences
     - Structure specific and fault specific
  3. In case of high rate of occurrence, from site monitoring data. The distribution and the uncertainties can be evaluated using catalogues

Comments

- **It is preferable to combine all of them**
- **A Cut off** in magnitude sometimes is applied: they should be substantiated with detailed historical analysis (“reasonable” duration) and seismotectonic evidences

Diffuse seismicity models

- May be uniform or not in a seismic province.
- Should be located in the brittle to ductile transition zone of the earth's crust
- Zones may be identified by depth and/or rates of earthquakes

- The estimation of maximum magnitude potential can be carried out through:
  1. Comparison with similar regions
  2. Assuming the same "b" value of the whole tectonic region

- If the site is in the zone, the distance should be in the range 5-20 Km, according to the best estimate of the focal depth. The dimension of the source is relevant
- For neighbor zones, the assumed location should be at the closest distance from the site

Attenuation curves

- Should be assessed and validated on the data base
- The uncertainty of the mean attenuation and the variability about the mean should be a function of the magnitude and source distance
- Attenuation curves: their variability is of a different nature than the randomness of the phenomena.

$$Y = A * f(M)\, g(D)\, h(S)\, \varepsilon$$

M=magnitude: source size, energy, depth, mechanism

D=distance: epicentral, hypocentral, of the closest point of fracture, projected distance, seismotectonic context

S=site: thickness, Vs

ε=uncertainty

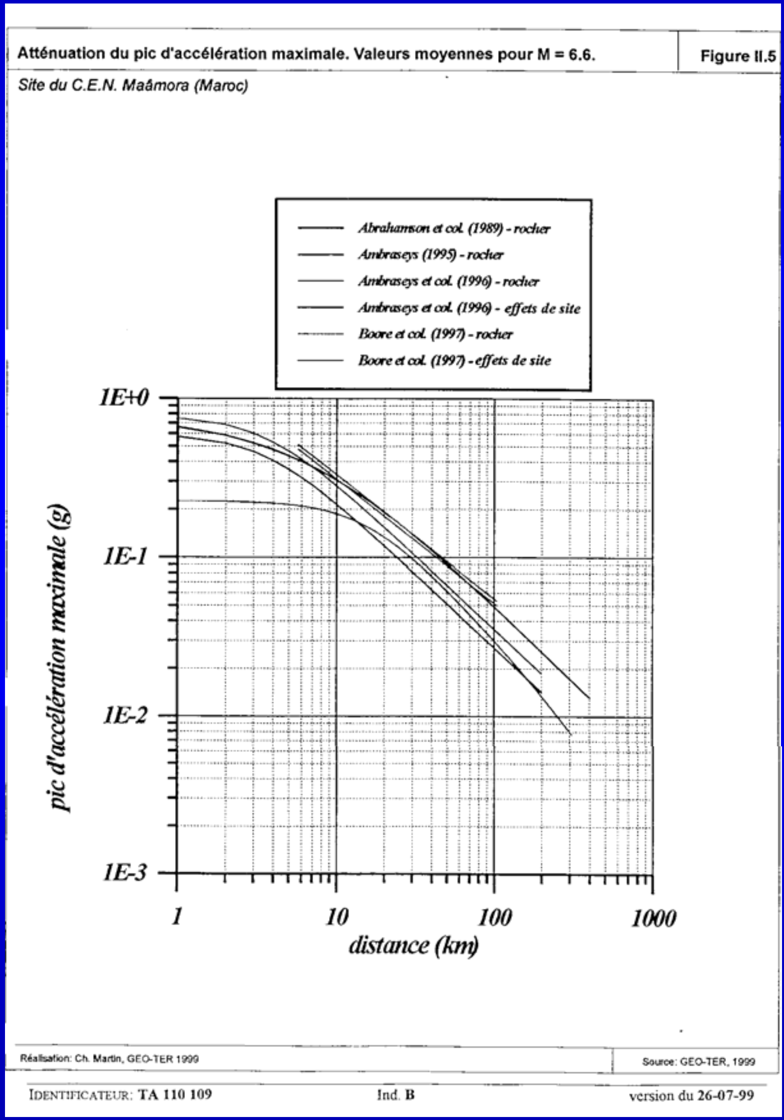
Cont'd

- **How many curves should be considered?** Their number deeply affect the uncertainty of the result. Therefore: as many as it is reasonable, including, according to the DB, the geology, the isoseismical maps of the region, the bibliographic studies, the characteristics of the source (deep/shallow, diffuse, frequency content, etc.). Most of them has already an uncertainty parameter in the formulation itself

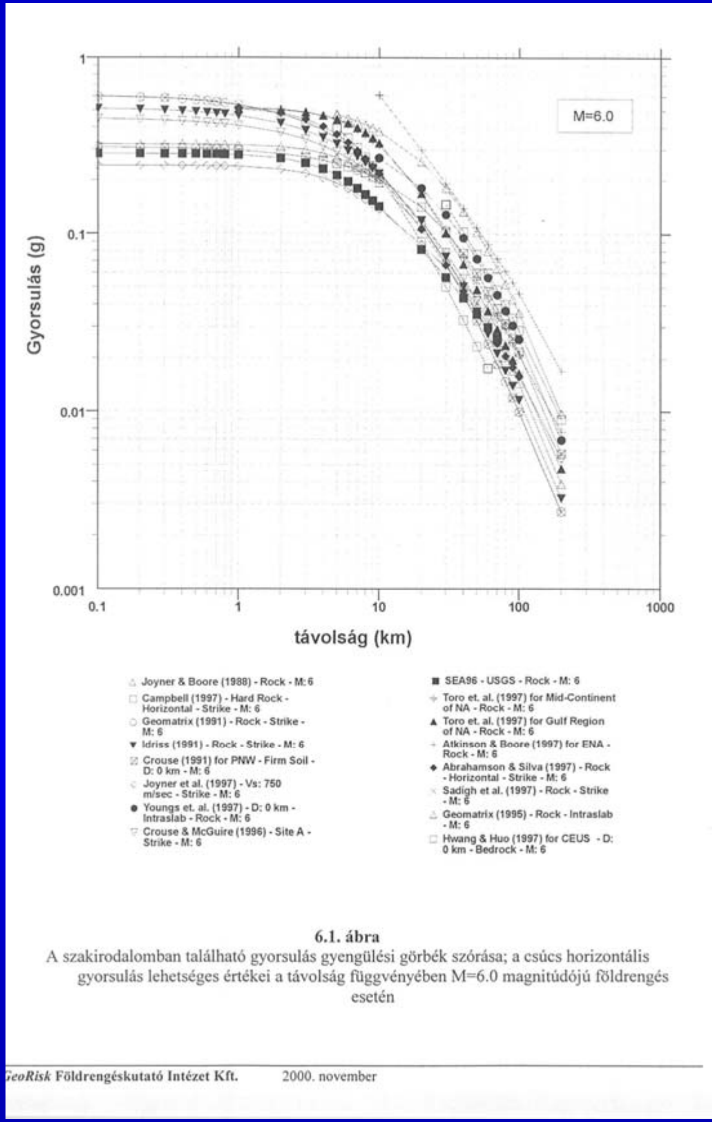
- Attenuation can be applied to:
  1. Attenuation of Pga
  2. Attenuation of spectral acceleration (frequency and damping dependent)

- Usually they represent the <u>highest</u> contribution to the uncertainty in PSHA !

Examples



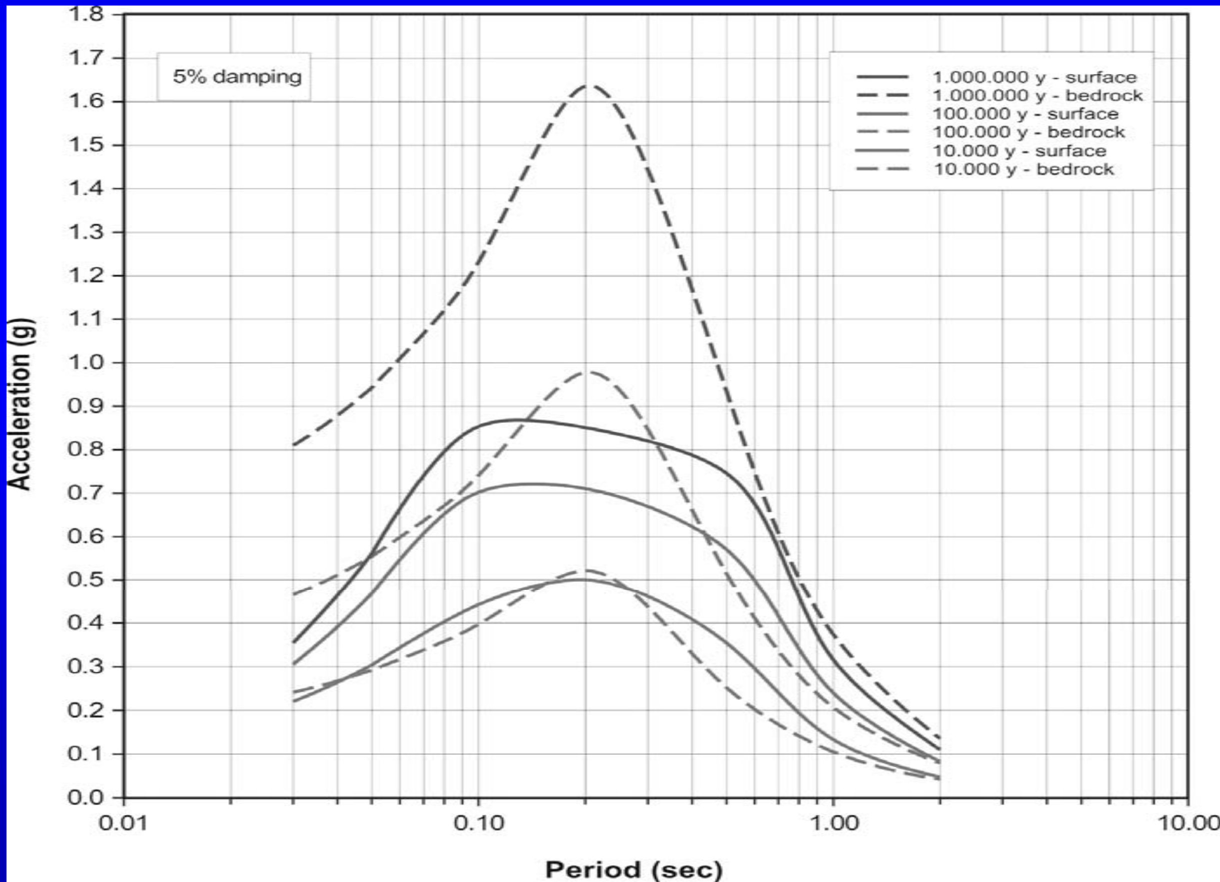
Atténuation du pic d'accélération maximale. Valeurs moyennes pour M = 6.6.
Figure II.5
Site du C.E.N. Maâmora (Maroc)
Abrahamson et col. (1989) - rocher
Ambraseys (1995) - rocher
Ambraseys et col. (1996) - rocher
Ambraseys et col. (1996) - effets de site
Boore et col. (1997) - rocher
Boore et col. (1997) - effets de site
1E+0
1E-1
1E-2
1E-3
pic d'accélération maximale (g)
1
10
100
1000
distance (km)
Réalisation: Ch. Martin, GEO-TER 1999
Source: GEO-TER, 1999
IDENTIFICATEUR: TA 110 109
Ind. B
version du 26-07-99



M=6.0
1
0.1
0.01
0.001
Gyorsulás (g)
0.1
1
10
100
1000
távolság (km)
Joyner & Boore (1988) - Rock - M: 6
Campbell (1997) - Hard Rock - Horizontal - Strike - M: 6
Geomatrix (1991) - Rock - Strike - M: 6
Idriss (1991) - Rock - Strike - M: 6
Crouse (1991) for PNW - Firm Soil - D: 0 km - M: 6
Joyner et al. (1997) - Vs: 750 m/sec - Strike - M: 6
Youngs et. al. (1997) - D: 0 km - Intraslab - Rock - M: 6
Crouse & McGuire (1996) - Site A - Strike - M: 6
SEA96 - USGS - Rock - M: 6
Toro et. al. (1997) for Mid-Continent of NA - Rock - M: 6
Toro et. al. (1997) for Gulf Region of NA - Rock - M: 6
Atkinson & Boore (1997) for ENA - Rock - M: 6
Abrahamson & Silva (1997) - Rock - Horizontal - Strike - M: 6
Sadigh et al. (1997) - Rock - Strike - M: 6
Geomatrix (1995) - Rock - Intraslab - M: 6
Hwang & Huo (1997) for CEUS - D: 0 km - Bedrock - M: 6
6.1. ábra
A szakirodalomban található gyorsulás gyengülési görbék szórása; a csúcs horizontális gyorsulás lehetséges értékei a távolság függvényében M=6.0 magnitúdójú földrengés esetén
GeoRisk Földrengéskutató Intézet Kft. 2000. november

Uniform Hazard spectra

- Hazard curves: aggregation and deaggregation of sources.
  - Usually it is done for the target frequency of exceedance.
  - It is done for two spectral frequencies (1 and 10 Hz) at least



Engineering quantities

- Usually: response spectra for three orthogonal directions and damping values.
- Uniform hazard spectra (spectral amplitudes wit the same annual exceedance frequency for the range of structural period of interest). It has to be constructed for any target hazard level. It is often criticised because of the unrealistic shape and instability of the estimate
- Standard response spectra: scaled at the Pga. They are different for near and far field
- Uniform confidence RS: ordinates have the same confidence values for all periods
- T-H should be typical of the region. They may be derived from the UHS or at least adapted to it

Time histories

- Phases distribution of T-h: it is non-stationary and therefore it should be taken from records

- Duration of T-h: influenced by geology (trapped waves in deep basins), by the length and velocity of fault rupture. Different durations may be selected according to the objective of the analysis: liquefaction is sensitive to low signals but long-lasting!

Mandatory checks on T-H

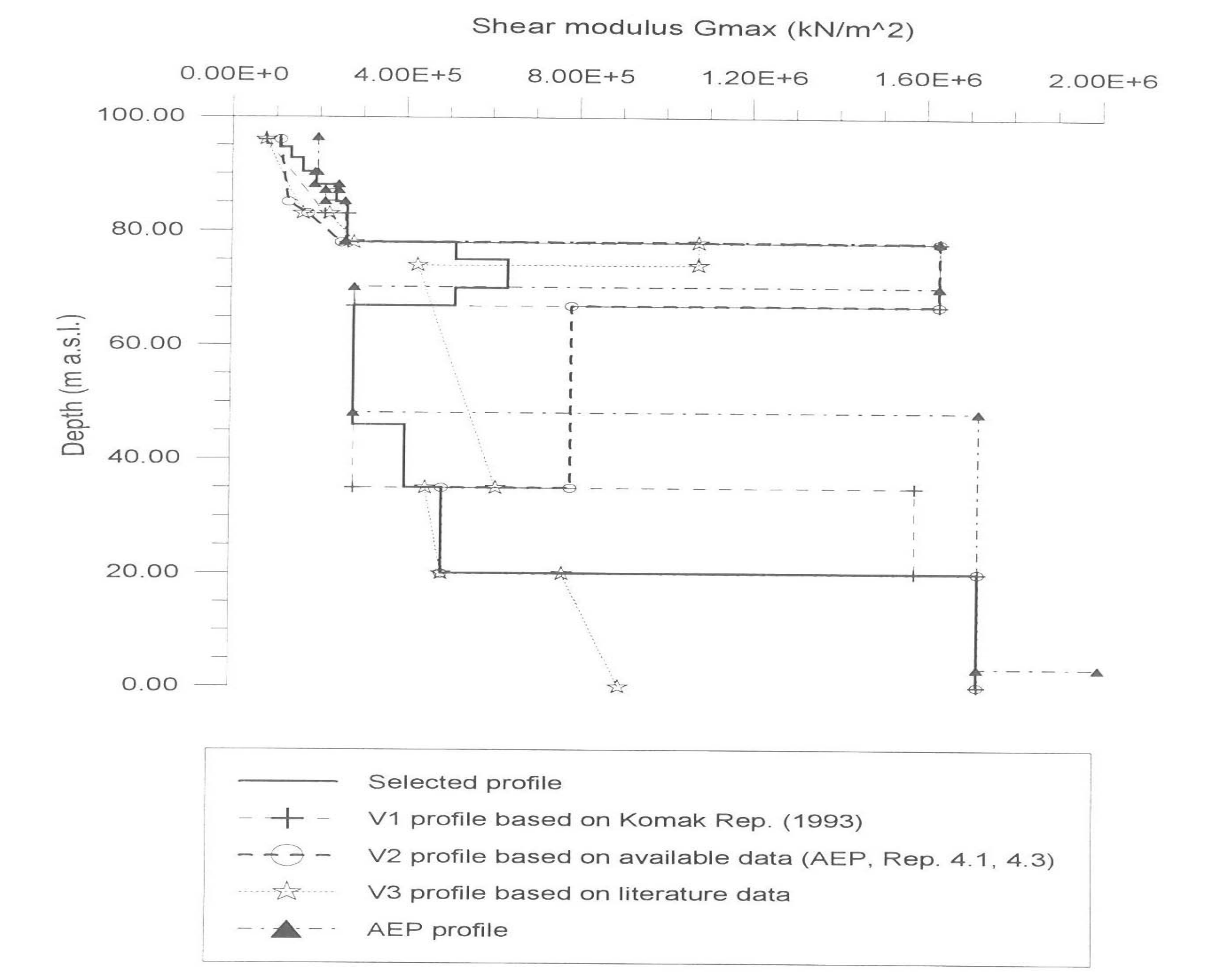
- Power spectral density
- Ratio between vertical and horizontal directions: from 0.5 up to 1 in the near field

Local site effects

- A dedicated simulation should be carried out, possibly in the frequency domain. It is impossible to predict the equivalent overall damping, frequency shifting and RS modification without an explicit simulation.
- Soil effects depending upon:
  - Bedrock location
  - Shear modulus, as a function of frequency and strain
  - Radiation damping, as a function of frequency and strain
  - Hysteretic damping, as a function of strain
  - Poisson modulus (or E)
  - Preloading (mainly for SSI)
- Variation in soil parameters, water table, etc.:large uncertainties to be included in the final model. Highest contributions from the non-linearity of the soil parameters.

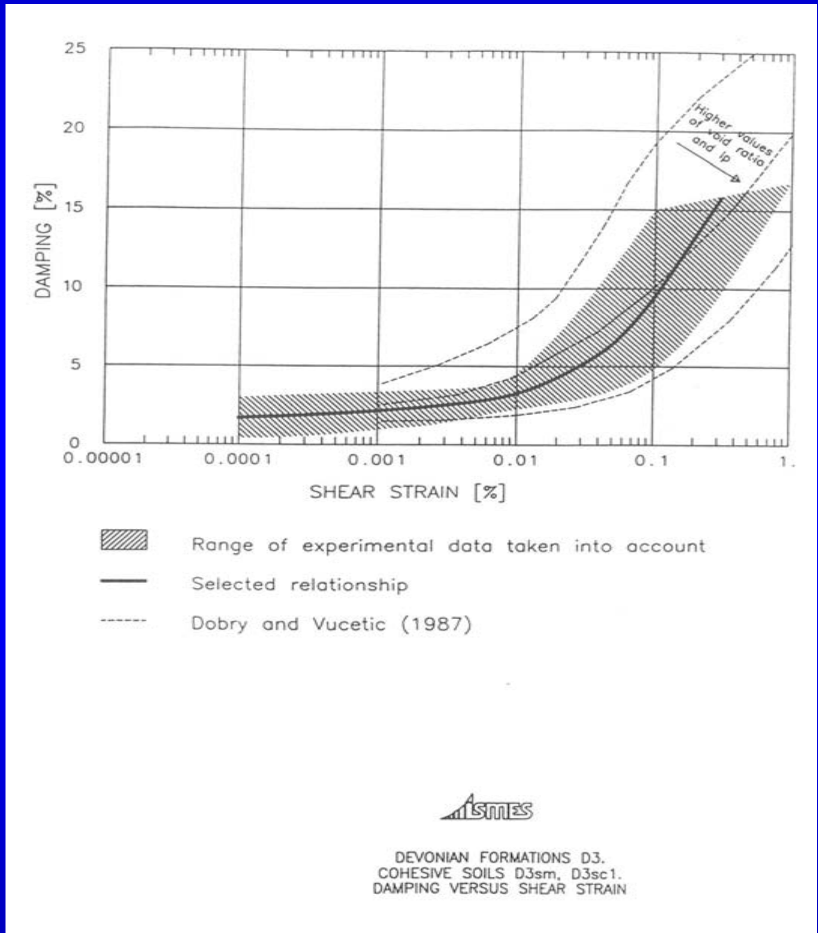
Attention: site conditions affect the structural response through two different mechanisms: 1) the modification of the seismic input and 2) the SSI. Soil properties are used in both!

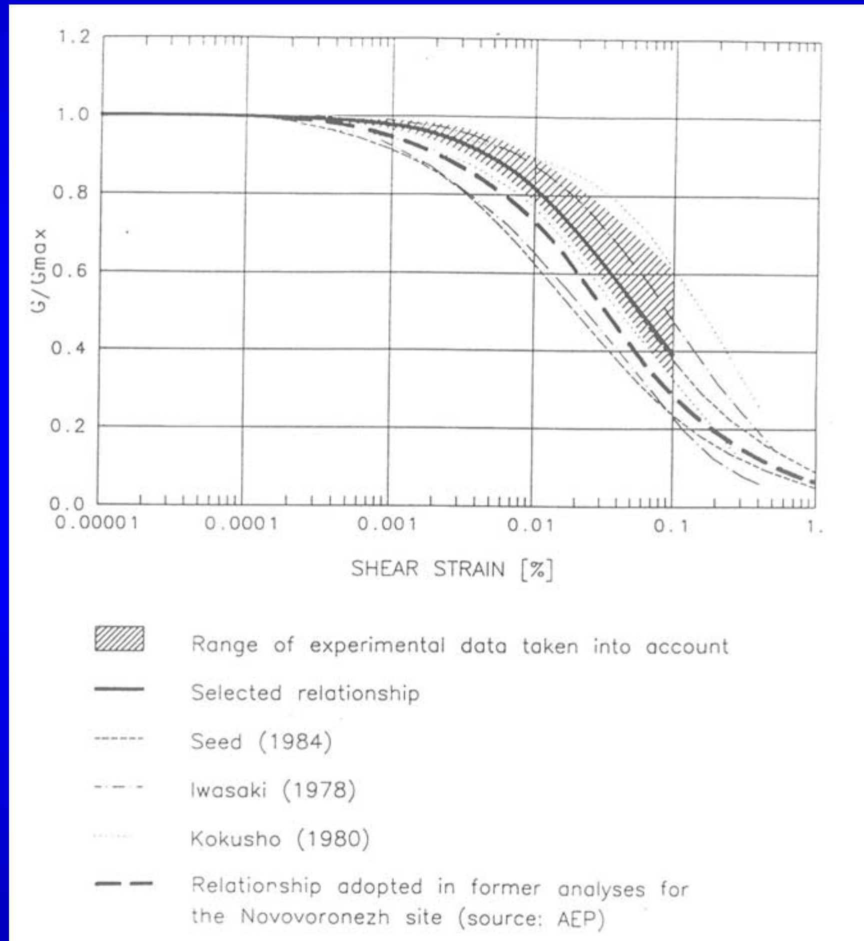
Example



Shear modulus Gmax (kN/m^2)
0.00E+0
4.00E+5
8.00E+5
1.20E+6
1.60E+6
2.00E+6
100.00
80.00
60.00
40.00
20.00
0.00
Depth (m a.s.l.)
Selected profile
V1 profile based on Komak Rep. (1993)
V2 profile based on available data (AEP, Rep. 4.1, 4.3)
V3 profile based on literature data
AEP profile

Examples


25
20
15
10
5
0
DAMPING [%]
0.00001
0.0001
0.001
0.01
0.1
1.
SHEAR STRAIN [%]
Higher values of void ratio and Ip
Range of experimental data taken into account
Selected relationship
Dobry and Vucetic (1987)
ismes
DEVONIAN FORMATIONS D3.
COHESIVE SOILS D3sm, D3sc1.
DAMPING VERSUS SHEAR STRAIN

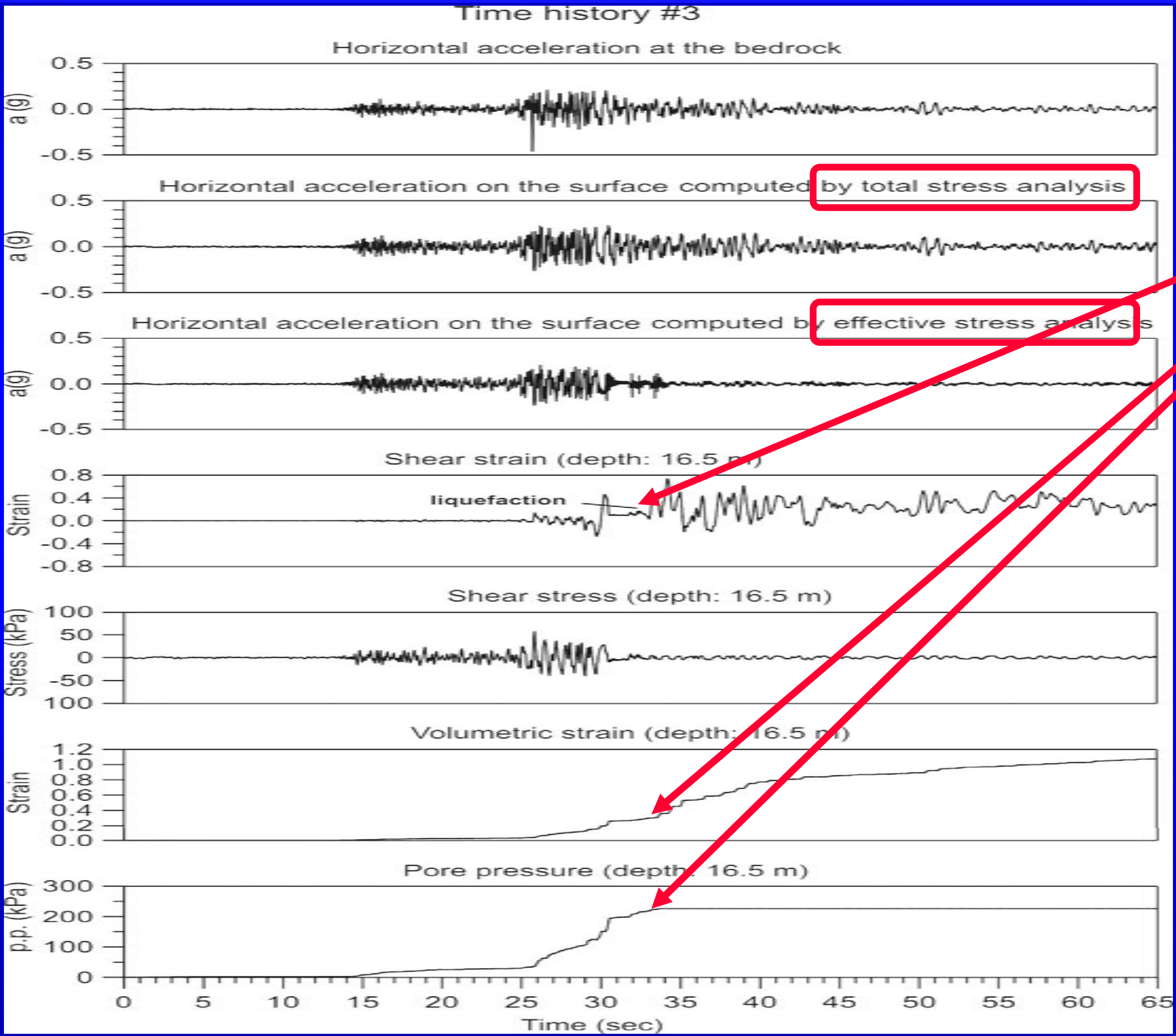

1.2
1.0
0.8
0.6
0.4
0.2
0.0
G/Gmax
0.00001
0.0001
0.001
0.01
0.1
1.
SHEAR STRAIN [%]
Range of experimental data taken into account
Selected relationship
Seed (1984)
Iwasaki (1978)
Kokusho (1980)
Relationship adopted in former analyses for the Novovoronezh site (source: AEP)

Secondary effects

- Faulting at the site. It should be checked at the siting stage. The criterion is: 1)evidence for ~10.000 years (or longer for low seismicity areas), 2) relationship with known capable faults, 3) connection with seismogenic sources that can induce surface rupture. It can be influenced by fluid injection or other.
- Other secondary effects
  - Soil liquefaction, slope instability, ground collapse, faulting, damage to power lines, dam failure and tsunami, damage to pipelines, etc.
  - Time aspects (aftershocks)
  - Distance aspects (dam failure)
  - Probability of simultaneous occurrence (e.g.: earthquake and dam break)
  - Combination as per event tree
- They are approached either by a deterministic evaluation or screened out by probability, looking at the consequences

- Liquefaction simulation: effective stress and total stress

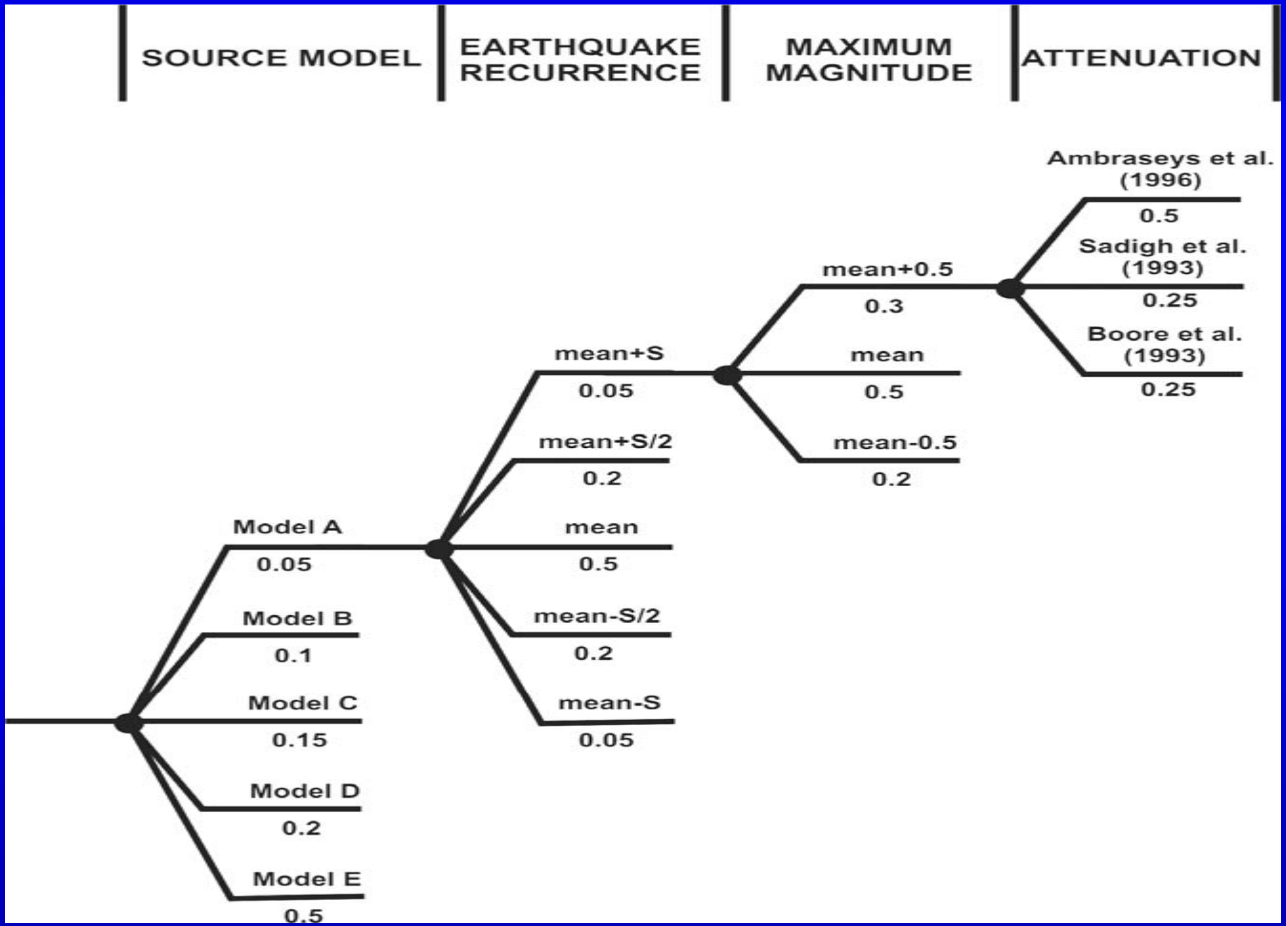
Example



- Liquefaction analysis

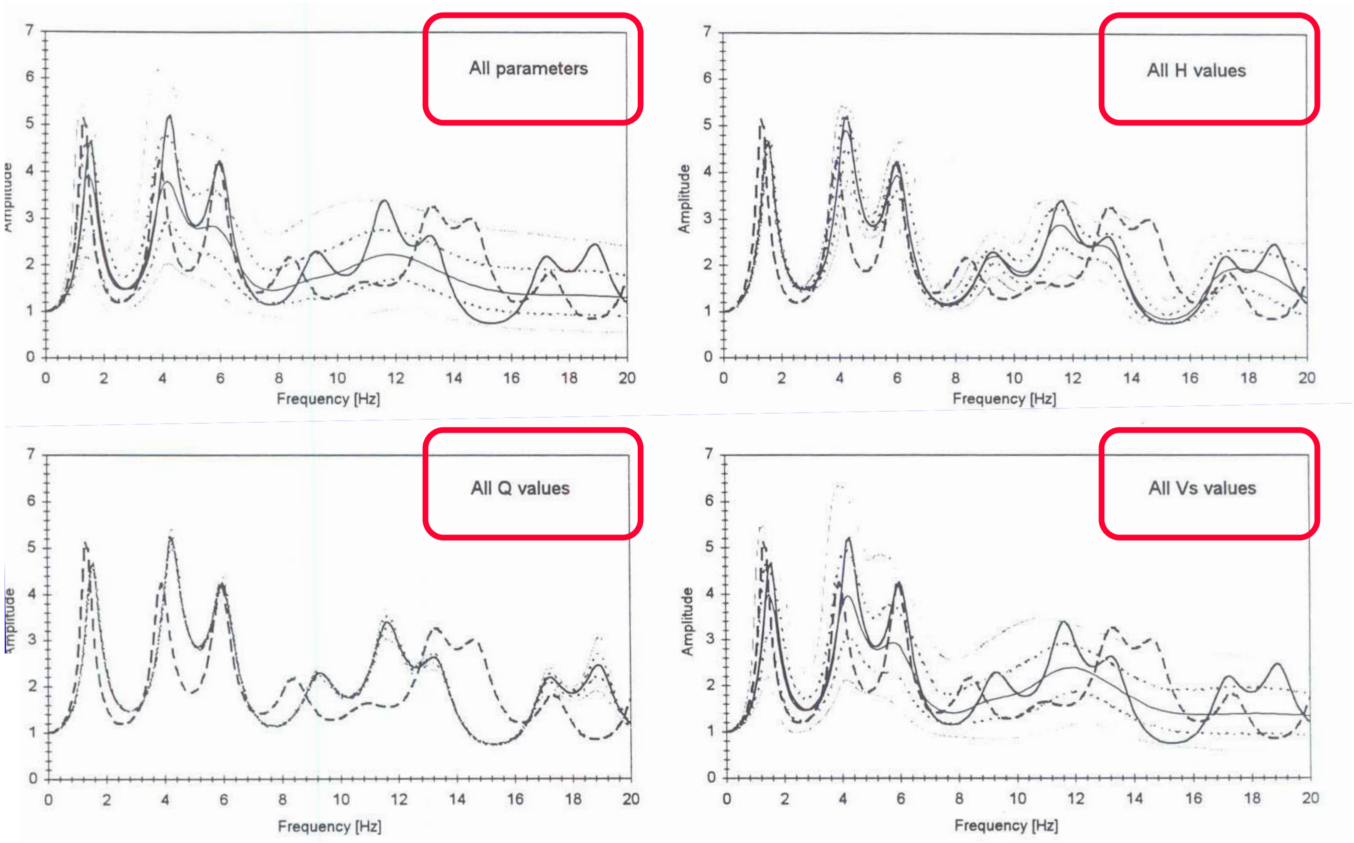
Management of uncertainties

- Logic tree: combination of random effects (from the physical reality) and uncertainties (from the simulation)



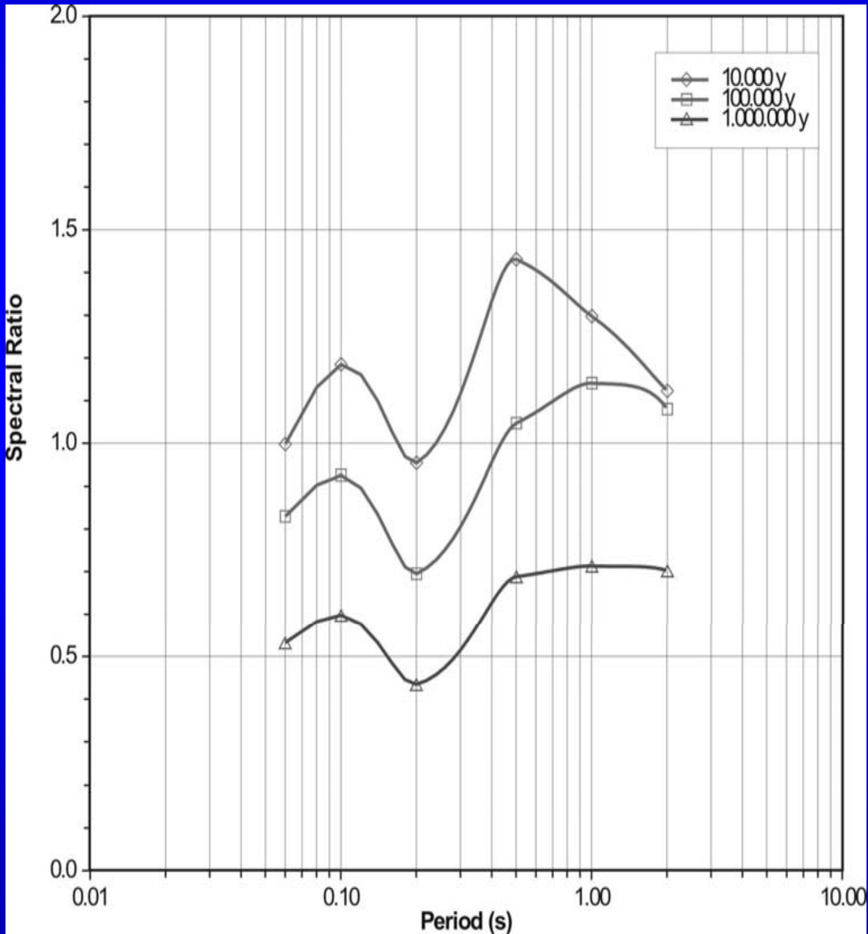
Cont'd

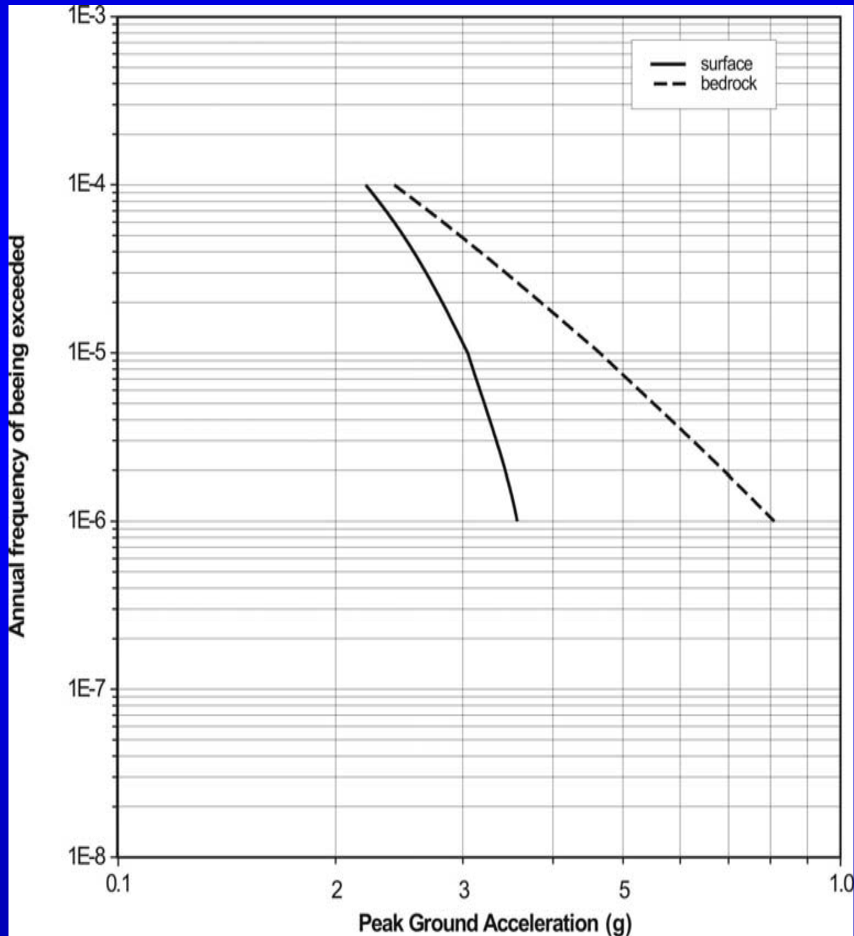
- Through convolution



Assessment of results

- Final assessment with spectral ratios comparison, comparison of UHRS at bedrock and surface, etc.





b) Fragility evaluation

Reference steps:

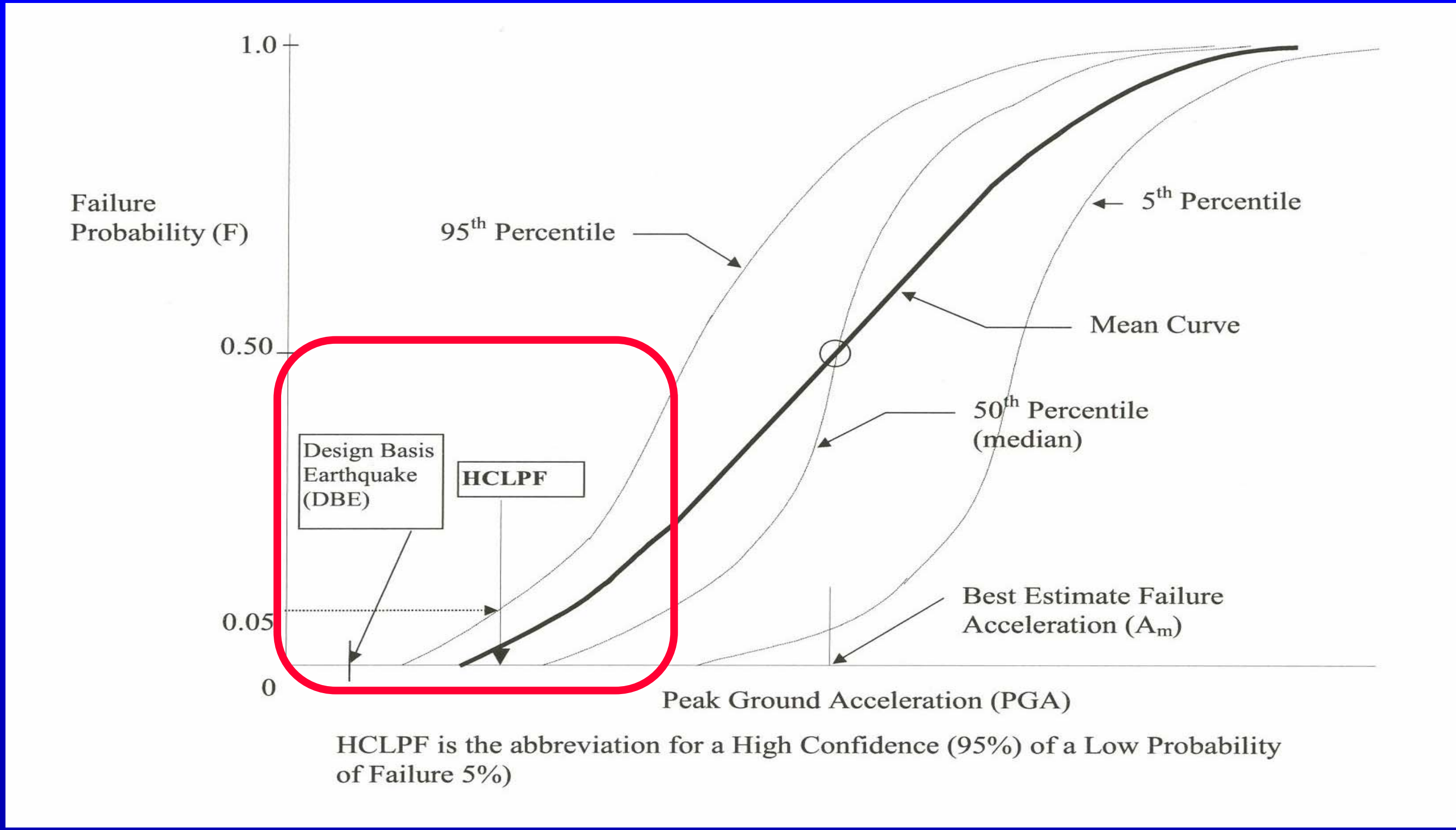
1. Selection of SSEL as a spin-off of the seismic classification.
2. Evaluation of seismic response: structures, cabinets, supports
3. Selection of the reference failure mode (relevant parameter)
4. Fragility evaluation

Comments

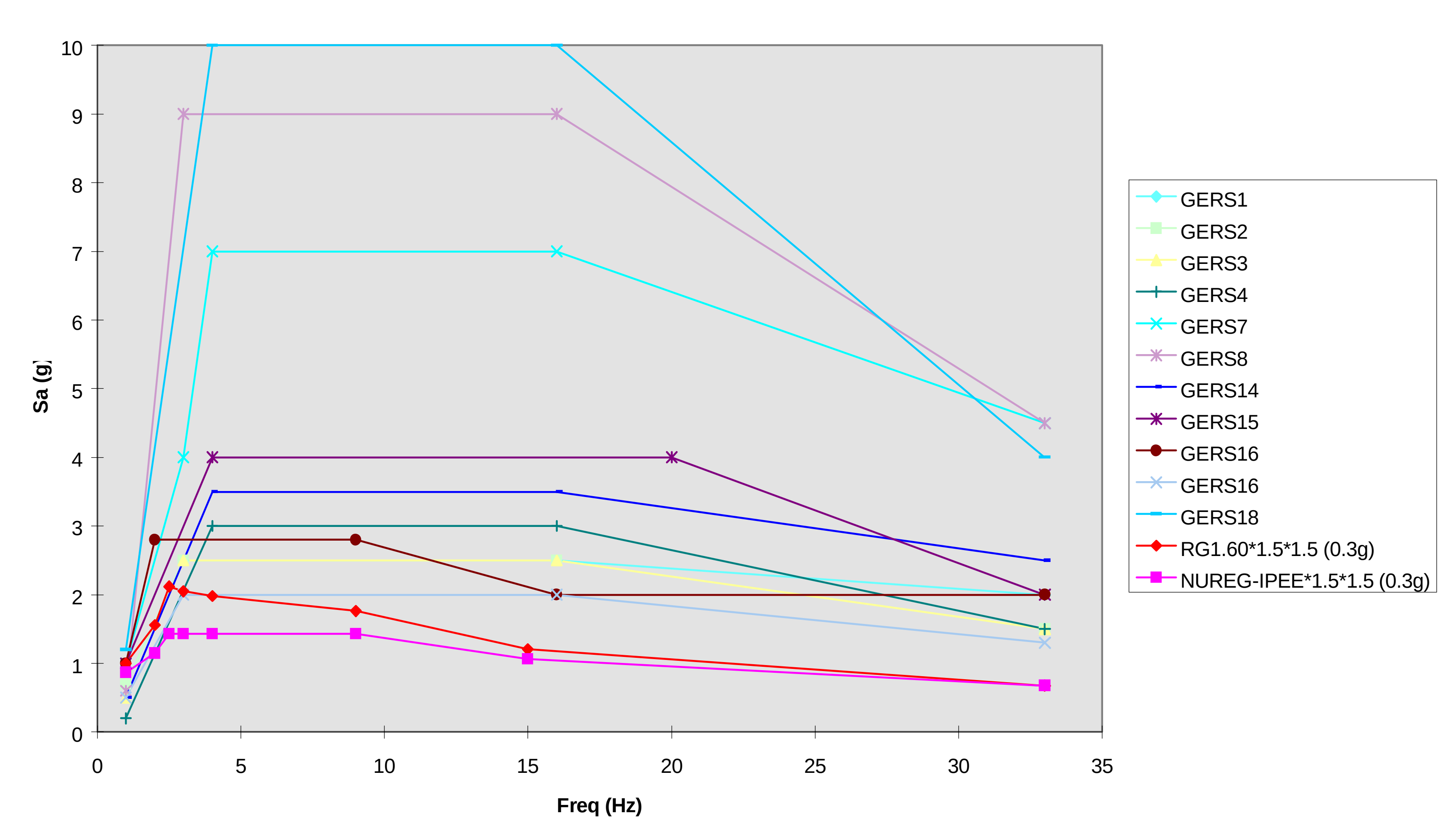
- Design in relation to any EE, including seismic, should be accommodated into level 1 of the defence in depth. All levels of DID should be seismically qualified, as DBE is a design basis!
- In some MS emergency systems have a lower seismic class than pressure retaining systems: consequences on failure mode should be evaluated with care
- Screening can be carried out on “robust components”: borrowed techniques from SMA.
- Simplified evaluations (HCLPF) can rely on the fact that the contribution of the beta on the CDF uncertainty is hidden by the uncertainty on the hazard (but it has to be checked!)

Definition of the objectives

- Definition of the curve: $A=A_m\varepsilon_r\varepsilon_U$ (inherent randomness and uncertainty in the median). A_m is usually the best estimate of the median Pga
- Use of best estimate fragility: $\beta_c=(\beta_r^2+\beta_U^2)^{1/2}$ (therefore the curve is known only with one beta and the median value!)
- A fragility curve is for ONE failure mode only!!



From SMA



- Attention should be paid to the modalities of derivation of GERS!!

Management of uncertainties on fragility

- Variation in input motion
- Phasing of earthquake components
- Vertical/horizontal acceleration ratio
- Soil stiffness
- Soil damping
- Structural stiffness
- Structural damping
- Non linearities
- Soil structure interaction
- Material strength
- Ductility
- Instability point
- Load combination (seismic + live + dead + DBA)

Inherent **randomness**

Uncertainties can be managed through calculation of derivatives of the CDF

Uncertainties can be reduced with higher efforts in investigations and simulations: trade off!!

Other consequences from earthquakes

- Effects on emergency planning (for severe consequences)
- Effects on availability of external services (power, cooling water, fire brigades, etc.)
- Effects on availability of shift operators and their attitude
- Effects on neighbour destructions and radiological dispersion in case of release
- Do not forget seismic induced fire, flood, missiles and other interactions!!

4) The trend – A questionnaire (2000)

Recent operation experience shows:

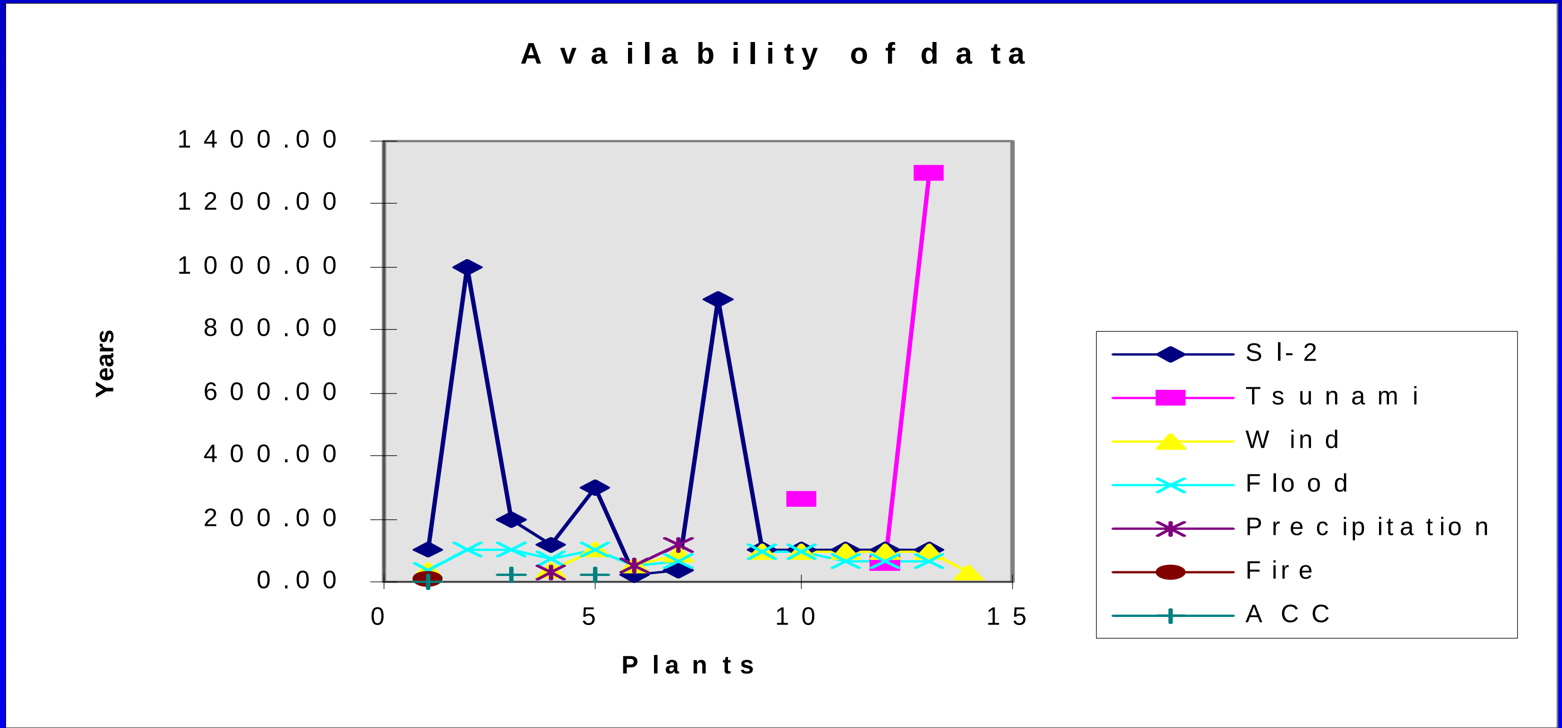
- many "**unexpected**" events: wrong deterministic screening
- significant contributions from wrong probabilistic evaluations of design basis loads, particularly in **combinations** of different effects from the same scenario and in combination of different scenarios

- General tendency towards **probabilistic approach** in design basis evaluation, however, most of MS still adopt a mixed deterministic-probabilistic approach both in screening and DB evaluation
- Few countries show a regulatory limit to the **risk** of radiological hazard, usually selected at 1E-6 (it is like a limit on the result of PSA level 3)
- Hazard definition is very different between general design and **PSA** and it had to be re-evaluated very often
- Very different **record length** used for extrapolation at low probability levels
- **Low correlation** between hazard evaluation procedures and nature of data record (e.g: "temperature" could be probabilistic and "tsunami" could be historical). Difference between **rare** and **frequent** phenomena is more and more common

Experience (cont'd)

- Very common use of **graded hazard levels** for wind, earthquake, temperature, snow
- Very often some **minimum** values (earthquake, ACC, wind) are deterministically defined even in a probabilistic context
- Total disagreement on the selection of the probabilistic targets (flood, temperature, wind, snow could reach 1E-2) and **uncorrelation** with population density and industrial installations.
- Very different safety margin values added to the **historical data** (e.g. for floods: 0.3 - 2 m, for earthquake: 0 +1MSK)
- Mixed standards, nuclear and non nuclear in the selection of the hazard
- Probabilistic targets (usually 1E-6,7) on the probability of event **combination** among external events and between external and internal events (80% combine LOCA and SL-2)
- Total independency of the data accuracy between site evaluation and design phase. **No control of the uncertainties**

Extrapolation



SI-2	100	1000	200	120	300	25	33	900	101	101	101	101	101	
Tsunami										259		57	1300	
Wind	34			39	100	49	89		94	94	94	94	94	28
Flood	34	100	104	74	100	49	64		94	94	69	69	69	
Precipitation				30		49	116							
Fire	4													
ACC	2		21		20									

Target levels in different Countries

EVENT/COUNTRY	a	b	c	d	e	f	g	h	i	l	m	n	o	p	q	s	t
Explosion		1E-5 - 1E-7	1.E-07	1.E-07	1.E-06	hist		NA	det.	standard		1.E-07		1.E-07	1.E-04	NA	1.E-07
Fire	2.7E-3 in10 Km		1.E-07	1.E-07	1.E-06	hist		NA	site dep.	site dep.		NA		1.E-07	1.E-04	NA	1.E-07
Asphyxiant gases			1.E-07	1.E-07	det	hist		NA	site dep.	site dep.		NA		1.E-07	1.E-04	NA	1.E-07
corrosive substances			1.E-07	1.E-07	det	hist		NA	site dep.	site dep.		NA		1.E-07	1.E-04	NA	1.E-07
ACC	1E-6 in0.2 Km	1E-6 - 1E-7	1.E-07	6.E-08	1.E-06	hist		1.E-08	site dep.	1.0E7 or det.		1.E-06	1.E-07	1.E-07	1.E-04	det.	det.
ground collapse			NA	NA	excl	hist		NA	site dep.	site dep.					1.E-04	det.	site dep.
slope insatbility	NA		NA	NA	excl	hist		NA	site dep.	site dep.					1.E-04	NA	site dep.
settlements			1.E-04	NA	excl	hist		2.E-05	site dep.	site dep.					1.E-04		site dep.
groundwater			1.E-04	NA	excl	hist		NA	site dep.	site dep.					1.E-04	NA	site dep.
water intake	NA		1.E-07	NA		hist		NA	NA			NA			1.E-04	NA	site dep.
damage by ships	NA		1.E-07	NA	NA	hist		NA	NA		NA	NA			1.E-04	NA	site dep.
biological phenomena	NA		1.E-07	NA	NA	hist		NA	NA		NA	NA			1.E-04	NA	site dep.
electromagnetic		NA	NA	NA		hist	NA	NA	NA	site dep.	NA			NA	1.E-04	NA	site dep.
extreme temp	NA	Conv. standard	1.E-07	NA	hist	hist		NA	1.E-04	1.E-04	1.E-02	NA		1.E-05	1.E-04	hist.	hist.
floods	1.E-08	1.E-04	1.E-07	7.E-06	1.E-3, 1E-2	1.E-02	1.E-03	NA	site dep.	1.E-04	1.E-03	1.E-06	1E-2, 1E-3	1.E-05	1.E-04	hist.	hist.
drought	NA		1.E-07	NA	hist	hist		NA	site dep.	1.E-04	excl	NA		1.E-07	1.E-04	hist.	
wind	5.E-06		1.E-07	3.E+06	conv. standard		1.E-02	1E-4, 1E-2	1.E-04	1.E-04	1E-4,1E-3	1.E-07	1.E-07	1.E-06	1.E-04	hist.	
tornadoes	4.E-06		NA	5.E-06	conv. standard	2.E-07		1E-7, 1E-4	1.E-04	1.E-04	1E-4,1E-3	1.E-07	1.E-07	1.E-06	1.E-04	hist.	NA
dust	NA	NA	NA	NA	NA	hist		NA	site dep.		excl	NA		NA	1.E-04		NA
site instability	NA		1.E-07	NA	excl	hist	NA	NA	site dep.			NA			1.E-04	NA	site dep.
lightning			1.E-07	NA		hist		NA	site dep.			NA			1.E-04		site dep.
tsunami	NA	NA	NA	NA	NA	hist		NA	NA			1E-3-1E-4		1.E-04	1.E-04	NA	NA
snow	NA		1.E-07	NA	1.E-02	hist		1.E-02	1.E-04	1.E-04	NA	NA		1.E-04	1.E-04	NA	site dep.
earthquake	yes	1E-4 - 1E-6	1.E-04	6.E-05	hist	1.E-04	1.E-04	1E-4, 1E-2	1.E-04	1E-4 or 5E-3 in 50 Years	1E-4, 1E-2	1E-3, 1E-4	1.E-04	1.E-04	1.E-04	site dep.	prob.
volcanism	NA	NA	NA	NA	excl	hist		NA	NA		NA			NA	1.E-04	NA	

The trend - Issues from a CS 2003

- Use of probabilistic hazard assessment in deterministic design and probabilistic safety assessment: special needs according to the engineering use. **Choice of reference probability ranges**. Reference to internal event probability of occurrence. Grading according to the facility hazard
- Lower probability levels **for PSA** than those used for design; need for whole range hazard curves. Need to re-consider initiating events screened out in the deterministic design. Need to correlate initiating events and secondary effects.
- Use of historical and instrumental data: **extrapolation** to low probability levels, data homogenisation
- **Integration** of historical data with other considerations
- **Propagation** models: from the potential sources to the site
- Development of site specific design basis: choice of suitable parameters
- Management of the **uncertainties** in all the phases of the hazard evaluation. Reliability of the final result
- Evaluation of **secondary effects**
- **Combination** among scenarios: evaluation of complex scenarios

To be improved...

- Uncertainties, randomness, conservatism
- Extrapolation models
- Models for extreme and rare events
- Models for combinations of events
- Methods for uncertainty evaluation and minimisation
- Data acquisition methods from monitoring and assessment of data significance
- Evaluation of reliability of administrative measures and protection systems

The trend – Issues from a TM 2003

A Technical Meeting (2003) on EE hazard and PSA left the following conclusions to the IAEA Secretariat for further consideration and action

- The hazard development and the PSA are strongly **influenced by the application** that is expected to be carried out with them: safety assessment and re-evaluation, prioritization of the upgrading, risk informed review of the technical specifications and of the inspections, etc. and even non safety related tasks (public acceptance, re-insurance, etc.).
- The effects of the **hazard change** and in general of the improved knowledge of the hazard characteristics as a consequence of the scientific research and site monitoring should be better understood.
- It is recognised the importance of an improved **communication exchange** among the few groups who developed some experience in this field, as preliminary to an improvement of the consensus in the engineering community.

5) IAEA proposals - A CRP

1.	Basic research	Knowledge "per se"
2.	Strategic research	Understanding potential benefits on socio-economic problems
3.	**Applied research**	**Develops the applicability concepts**
4.	Adaptive research	Tuned to the beneficiaries

The research must

- Be related to the needs of the IAEA and to the MS ("RELEVANT")
- Be applicable elsewhere ("TRANSFERABLE")
- Be problem driven and result oriented
- Lead to verifiable (indicators!) outputs in 3-5 years
- Be coordinated within a network of Organisations
- Develop new or improve existing knowledge

Background of the CRP

- The CRPs are **the only (applied) research** activities of the IAEA, and this is the only one in our Engineering Section.
- It will last **3-5 years**
- It will involve 5-15 research contracts
- It will **propose standards, strategies, advice to MS in the field of interest and will also foster an appropriate dissemination of the results**

- The **title** has been chosen after
  - Analysis of the IAEA program (priorities, tasks, etc.)
  - Recent Technical Meetings at the IAEA
  - Feedback from MS

Technical background (1)

The IAEA policy (BB)

- J.5.03. "To enhance MS capabilities to re-evaluate seismic and other external/internal hazards in view of implementation of related upgrades/safety enhancements and to evaluate new sites and relevant hazards"

The NS "Vision"

- First Focal point: "Approximately 20% of the Standards must be reviewed annually if the Departmental goal for maintaining them current and viable is to be achieved. This will require a continued concentration of resources for "in office" as opposed to "in field" tasks

The IAEA Design Requirements

- "…A probabilistic safety analysis of the plant **shall be carried out** in order…to provide assessments of the probabilities of occurrence and the **consequences of external hazards**, in particular those unique to the site…"

Main actors

- **IAEA Project Officer**
- **Network of 5-15 Research Institutions** (and representatives of the end-users)
- **End-users**
  - Scientists
  - Organisations in charge of research (TSOs)
- **End-beneficiaries**
  - Plants
  - Reg.Bodies
  - International community at large

Funded by

- Research contracts
- Research agreements

Some “provocations” on task title

1. Probabilistic hazard definition: frequency range, multi-parameter description, either probabilities of effects or probabilities of scenarios, different probabilistic models, combination of scenarios, probabilistic description of human induced scenarios
2. PSA assumptions in case of external events: major destruction in the vicinities, impairment of access to the site, lack of supply of oil power water rescue etc., reliability of the weather forecast and preventive operator actions
3. Human reliability models suitable for external event scenarios
4. Common cause failure models suitable for scenarios affecting “large” site areas (ACC, fire, seismic, flood, etc.)
5. Component fragilities to shock, humidity, smoke, toxic agents, etc. Their evaluation by test, experience, etc. Their sensitivity to component ageing

Tasks

Area n.1

- 1. To develop methodologies and event screening procedures suitable to support risk informed applications of EEPSA;
- 2. To develop conceptual methodologies for EE-PSA level 2 (modelling of the containment behaviour) and 3 (modelling of the off-site emergency planning) in relation to external event initiators;
- 3. To develop conceptual methodologies to extend EE-PSA level 1,2,3 to operational modes other than full power and to include other sources of radioactivity, such as fuel pool, fuel storage, waste storage, etc.

Area n.2

- 4. To characterise the sensitivity of the component fragilities to the hazard level and characteristics, structural response and soil properties;

5. 5. To determine the sensitivity of EEPSA results to component screening criteria based on their capacity;

Cont'd

Area n.3

- 1. To develop a methodology for uncertainty propagation including coupling between different sources of uncertainty;
- 2. To develop models for human reliability analysis covering operator actions following emergency operating procedures (skill or rule based actions) as well as for accident management actions which might be knowledge-based and may not be supported by formal procedures;
- 3. To develop models for the common cause failure of redundant components allocated to different safety trains during external events due to direct challenge by the event, development of harsh environmental conditions (including EE induced fire and flood) or induced by the failure of safety related electrical equipment.

IAEA proposal - The directory of NCPs

The Directory of the Organisations involved in Prob. Hazard and EE-PSA

- The IAEA/NSNI was suggested at the TM 2003 to compile and circulate a simple database/directory of the groups and plants with some experience in both probabilistic hazard development and external event PSA in order to foster the bilateral communication (phase 1 of the project). Such a directory/data base could also support more significant IAEA initiatives in the long term (phase 2 of the project), trying to develop a synthesis of the most important scientific and application issues for the nuclear community at large. Current application problems that prevent a broad use of EEPSA should be re-solved with an appropriate research effort.

- 20 Countries nominated a National Contact Point (NCP) by July 2004
- 7 NCP have been nominated at the TM
- 16 NCP-Organisations have been selected by the Secretariat

In total 43 NCP are now part of the network!!

IAEA proposal – Technical documents

Reference IAEA documents

- NS-G-3.3 Hazard evaluation for seismic events
- Safety Report n.xx – Safety of new and existing research reactor facilities in relation to external events, 2004
- Safety Practice P-7 Treatment of external hazards in probabilistic safety assessment for NPPs
- TECDOC 711, “Use of probabilistic safety assessment for nuclear installations with large inventory of radioactive material”, 1992
- TECDOC 724 Probabilistic safety assessment for seismic events
- TECDOC 1267 “Procedures for conducting probabilistic safety assessment for non-reactor nuclear facilities”, 2002
- TECDOC-1341 Extreme external events in relation to design or assessment of NPPs
- TECDOC 1347 ”Design of nuclear facilities other than NPPs in relation to external events, with emphasis on earthquakes”, 2002
- TECDOC xx “Probabilistic hazard development for external events”, 2005
- WM from Workshops (China (1999), Bulgaria (2000), Romania (2001), etc.)