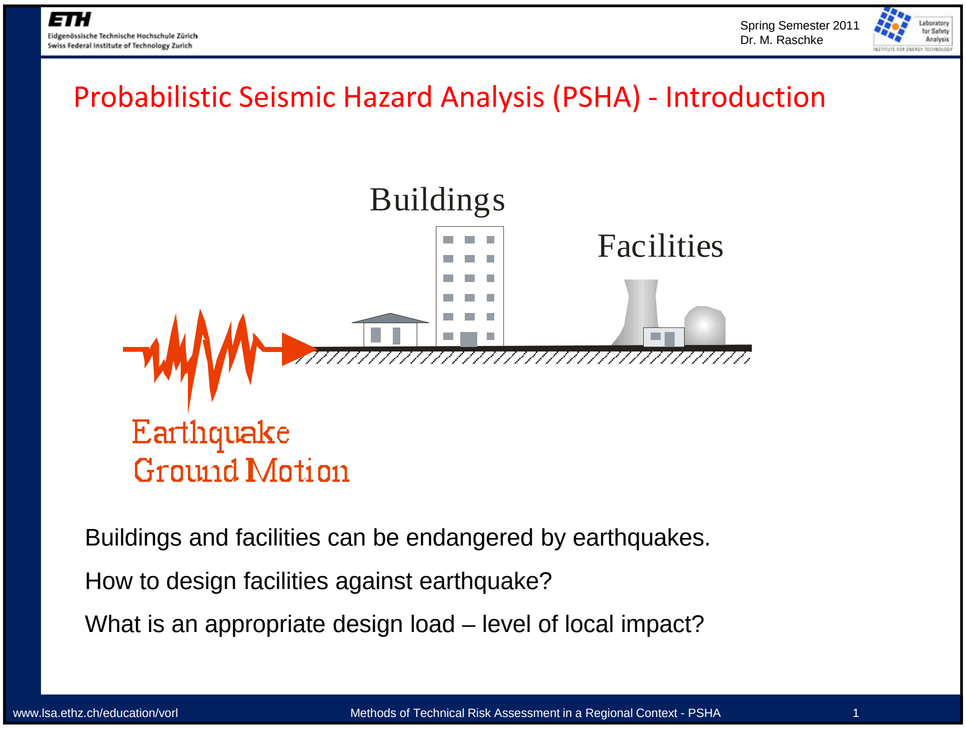


Probabilistic Seismic Hazard Analysis (PSHA) - Introduction

Buildings

Facilities

Earthquake
Ground Motion

Buildings and facilities can be endangered by earthquakes.

How to design facilities against earthquake?

What is an appropriate design load – level of local impact?

Seismic resistance design

"Earthquakes Don't Kill People, Buildings Do"
S. Hough and L. Jones, USGS

Dwellings are designed for an impact with a return period of 475 years according to modern design codes. The safety level has to be defined by the entire society.

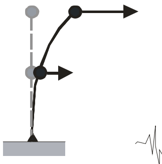
**Seismic resistance design is part of engineering science.
The estimation of the level of local ground motion is part of seismology and earthquake engineering.**

Seismic resistance design

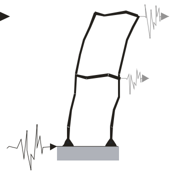
Seismic impact:
- simple load factor: factor*weight; without consideration of dynamic interaction; NOT STATE OF THE ART
- response spectrum: maximum response values form SDOF for computation of replacement load; dynamic of the system can be simply considered or more in detail
- time history analysis: complex model of dynamic system and interaction

Design details:
- linear or non-linear behaviour of the structural response

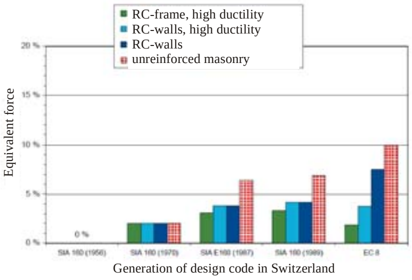
The load/impact level for the seismic resistance design is provided by PSHA, independent on design details.



Response force for system with two degree of freedoms



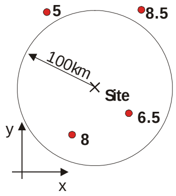
Time history analysis and a system of moment frames



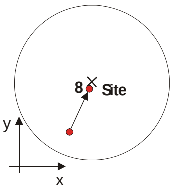
Probabilistic Seismic Hazard Analysis - Approaches

Deterministic approach

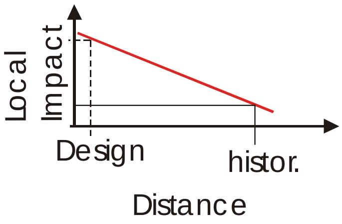
- simple rules, e.g.: The largest observed earthquake within a radius of 100 km being placed near the site is the design earthquake.
- older codes
- design load depends on historical records (settlement history)
- No statements about frequency or probability.
- simple and straightforward



Selection of histor. earthquake



Change of position



Resulting impact (design load)

Probabilistic Seismic Hazard Analysis - Approaches

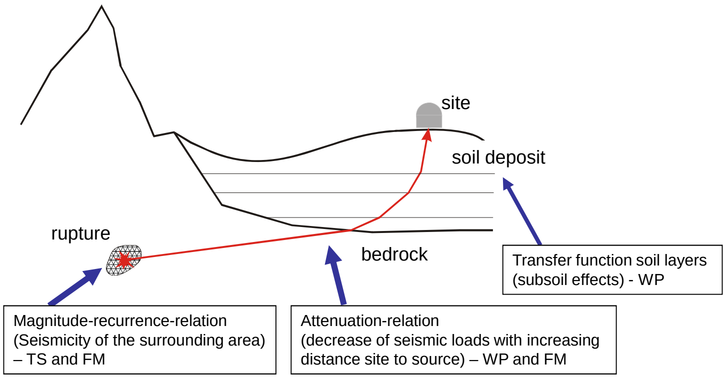
Probabilistic approach

- state of the art of seismic hazard assessment
- statements about frequency or probability
- earthquake hazard can be compared with other hazards
- modeling and computation is much more complicate

Probability integral for the occurrence frequency

$$\lambda(Z(\mathbf{s}) \geq z) = \sum_i \nu_i \int\int f_{mi}(m) f_{ri}(r) \overline{F}_i\left[z \middle| m, r\right] dm dr$$

Components of the Model and functional chain of the earthquake process



Transfer function soil layers (subsoil effects) - WP

Magnitude-recurrence-relation (Seismicity of the surrounding area) – TS and FM

Attenuation-relation (decrease of seismic loads with increasing distance site to source) – WP and FM

Scheme of earthquake process (side view)

source: Habenberger, 2007

The probability integral

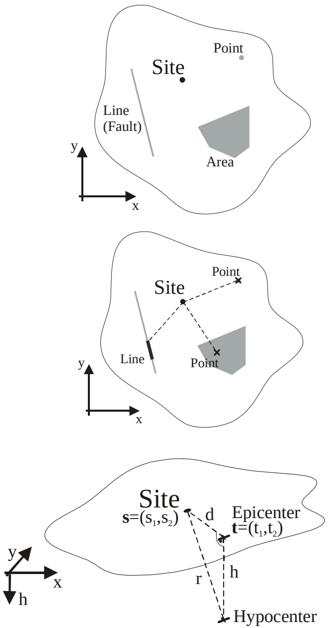
$$\lambda(Z(\mathbf{s}) \geq z) = \sum_i \nu_i \int\int f_{mi}(m) f_{ri}(r) \overline{F}_i\left[z \middle| m,r\right] dmdr$$

$$\lambda(Z(\mathbf{s}) \geq z) = \kappa \int\int\int\int f_m(m) f_h(h) \overline{F}\left[z \middle| m,r\right] dxdydhdm$$

$$r = \sqrt{d^2 + h^2}$$

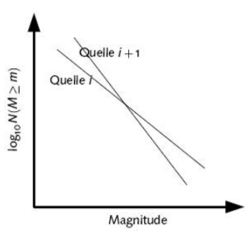
$$d = \sqrt{(t_1 - s_1)^2 + (t_2 - s_2)^2}$$

$Z(\mathbf{s})$	Local shaking levle, random variable
$\lambda(Z(\mathbf{s}) \geq z)$	Annual frequency of exceedance of Z
ν	Annual frequency of occurrence (M>mmin)
κ	Annual intensity of occurrence (M>mmin)
$f_m(m)$	PDF of M
$f_h(h)$	PDF of H
$\overline{F}\left[z \middle| m,r\right] = P(Z(\mathbf{s}) \geq z \mid m,r)$	Conditional probability of exceedance

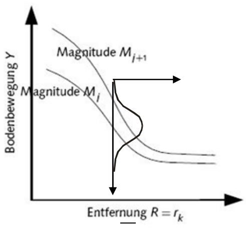


PSHA – Details of some Components

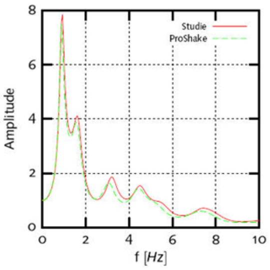
Magnitude-recurrence-relation



Attenuation-relation



Transfer function soil layers



Seismic sources (faults, regions)
Magnitude-recurrence-relation:
e.g.: Gutenberg-Richter

$$\log N(M \geq m) = a - bM$$

$$\log N(M \geq m) = \kappa \overline{F}_m(m)$$

M: magnitude (e.g.: M_w, M_s, M_l)
N: number of magnitudes m>=M per year
a, b: regression parameters of the Gutenberg-Richter-law

Attenuation relation for spectral accelerations or intensities
e.g.:

$$\log Z = C_1 + C_2 M + C_3 \log(R) \quad + \varepsilon\sigma$$

σ: aleatoric uncertainty
C_n: regression parameters
R: distance site-hypo-/epicentre
ε: coefficient (deviation from average)

Site response:
damping or amplification of seismic waves due to soft soil layers

-analytical (e. g. frequency domain)
-numerical (e.g. FEM)

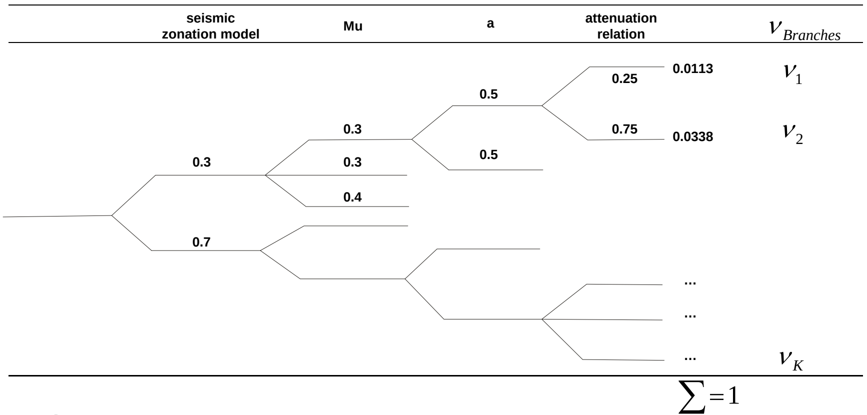
source: Habenberger, 2007

PSHA – Uncertainties

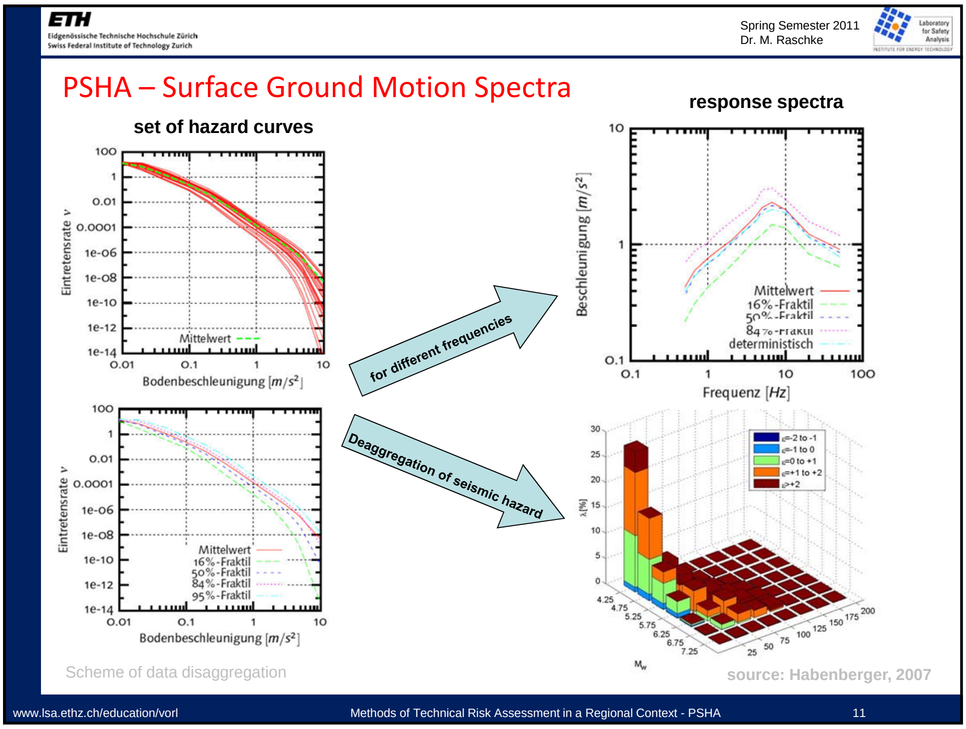
Uncertainty in PSHA	**Analogy in Stochastic and Statistic**
epistemic uncertainty: incomplete knowledge (lack of data)	estimation error, confidence interval or residual variance
aleatory uncertainty: inherent randomness of ground motion generation	spreading of random variables

PSHA – Logic Tree Approach

- •It is an approach to estimate the epistemic uncertainty.
- •It can be a simple mixture of models (probability distributions).
- •Weighting factors based on expert opinions or special approaches.
- •It is not an event (fault) tree!



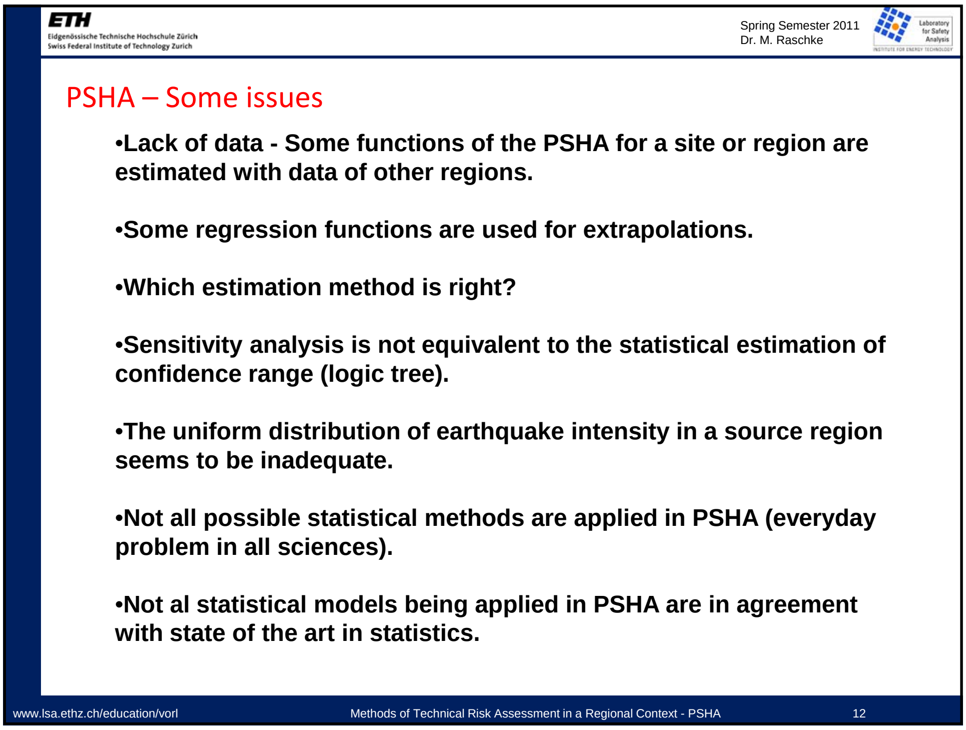
Logic tree



PSHA – Surface Ground Motion Spectra

Scheme of data disaggregation

source: Habenberger, 2007



PSHA – Some issues

•Lack of data - Some functions of the PSHA for a site or region are estimated with data of other regions.

•Some regression functions are used for extrapolations.

•Which estimation method is right?

•Sensitivity analysis is not equivalent to the statistical estimation of confidence range (logic tree).

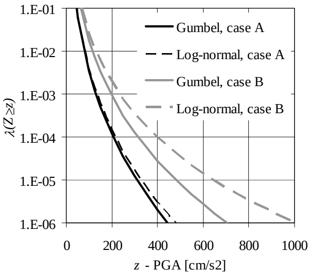
•The uniform distribution of earthquake intensity in a source region seems to be inadequate.

•Not all possible statistical methods are applied in PSHA (everyday problem in all sciences).

•Not al statistical models being applied in PSHA are in agreement with state of the art in statistics.

PSHA – The conditional Probability of Z

- **The distribution type of Z|m,h influences the hazard estimation.**
- **If Z is an extreme value, an extreme value distribution should be appropriate.**
- **But it is often assumed that Z |m,h is log-normal distributed.**



A: $\mathrm{Var}(\ln(Z)\,|m,h)=0.46^2$
B: $\mathrm{Var}(\ln(Z)\,|m,h)=0.69^2$

Example I – Model for Switzerland of SED (2004)

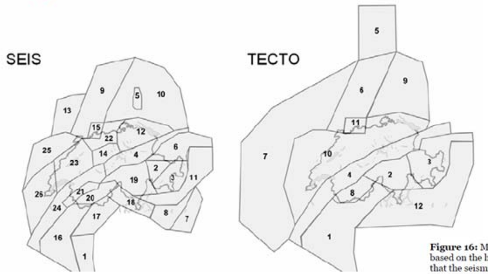


Figure 16: Maps of Switzerland. (Left): source zones of model 1, SEIS, which is largely based on the historical seismicity. (Right): source zones of model 2, TECTO, which assumes that the seismicity follows broad tectonic regions. The numbers refer to the names of source zones, as listed in Appendix 2 in Table A3.

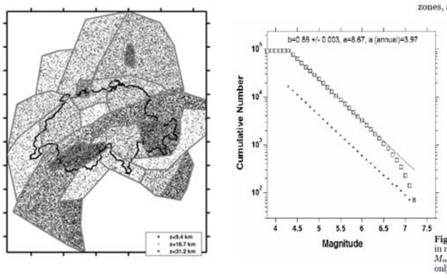


Figure 27: Example of a synthetic catalog. (Left) Map of epicenters and sources zones used in model SEIS. (Right) Cumulative frequency-magnitude distribution of events. In this case, M_{max} was assumed 7.2. Note that for plotting purposes, the catalog in this figure contains only 50'000 years, and the map only displays events with $M \geq 5$.

Example I – Model for Switzerland

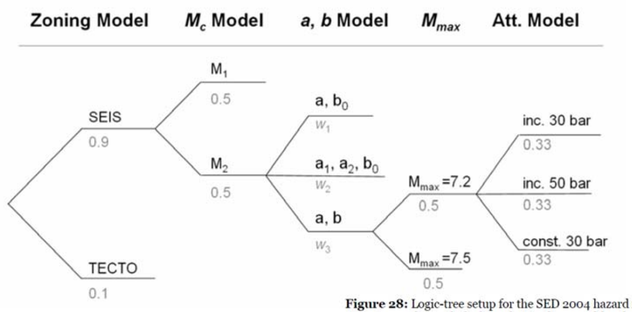


Figure 28: Logic-tree setup for the SED 2004 hazard model. Weights for each branch are given in gray beneath the branch. For the *a*- and *b*-value estimation, the weight (*w*) is zone dependent, as explained in Chapter 4.

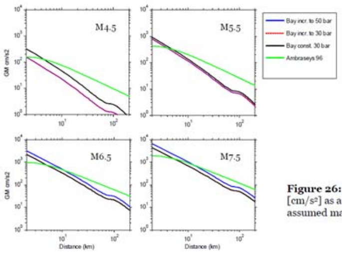
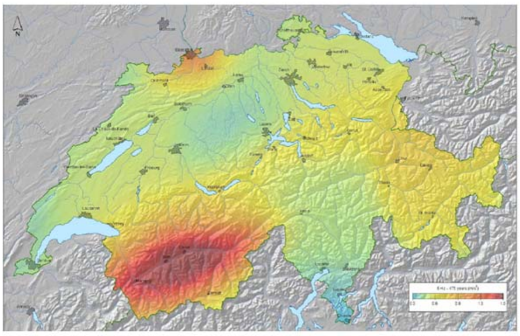


Figure 26: Predictive ground-motion relations at 5 Hz. Shown is the ground-motion in [cm/s²] as a function of distance for four ground-motion relationships. Each frame shows one assumed magnitude.

source: SED

Example I – Model for Switzerland



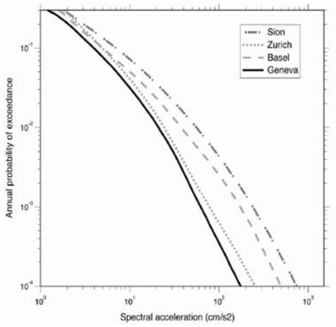
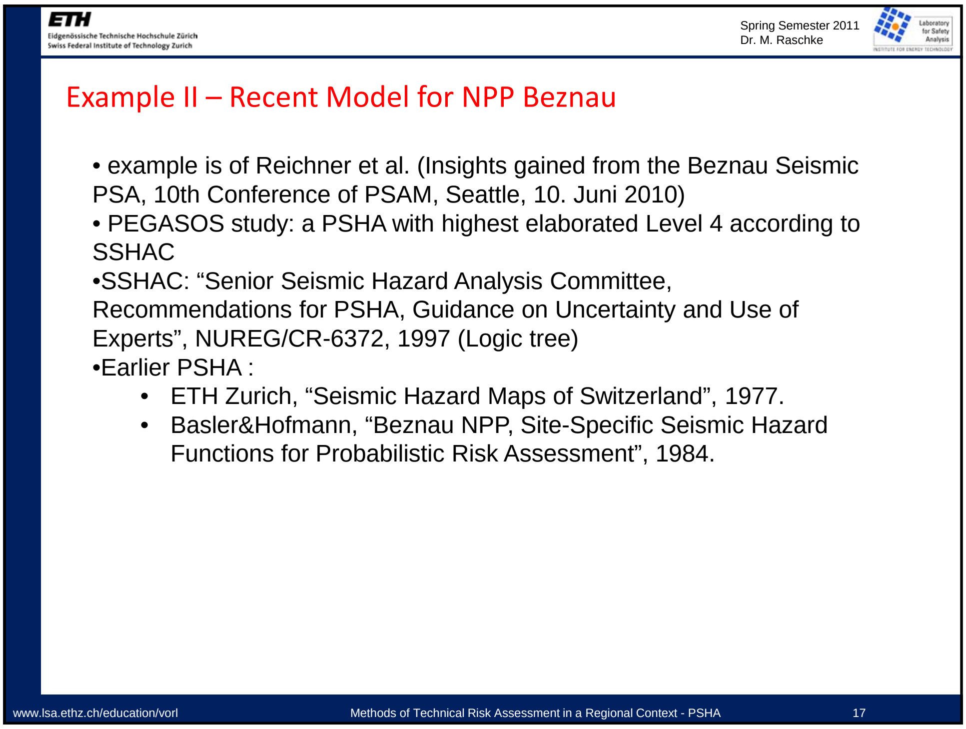


Figure 30: Comparison of hazard curves for four cities in Switzerland, taken from Figure 29.

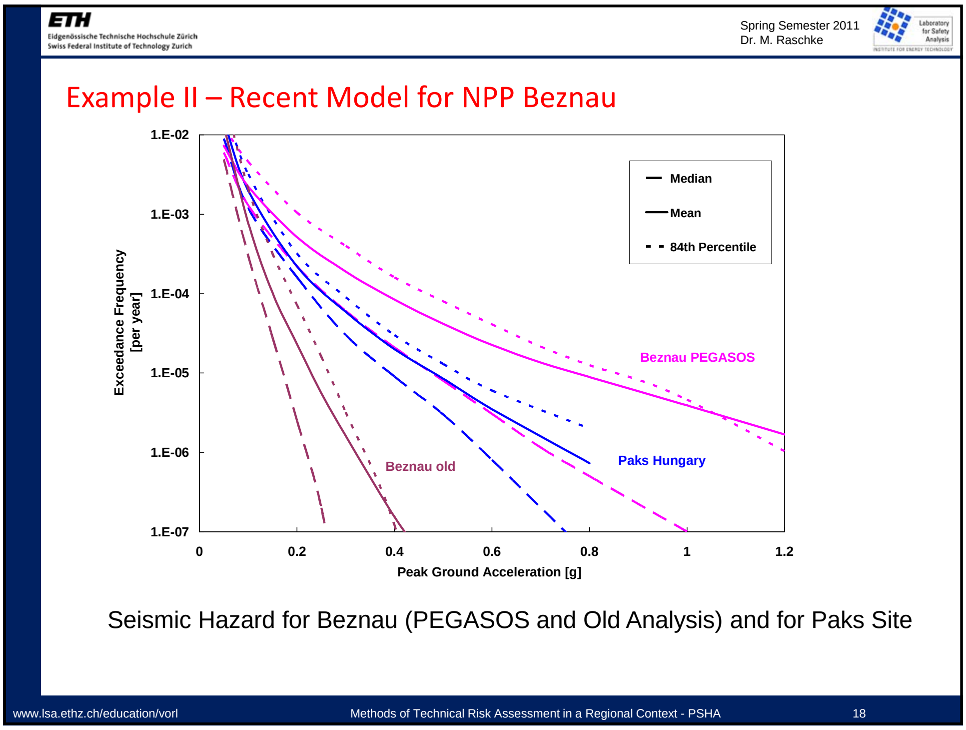
Recent hazard map

Recent frequency functions for λ>0.0001



Example II – Recent Model for NPP Beznau

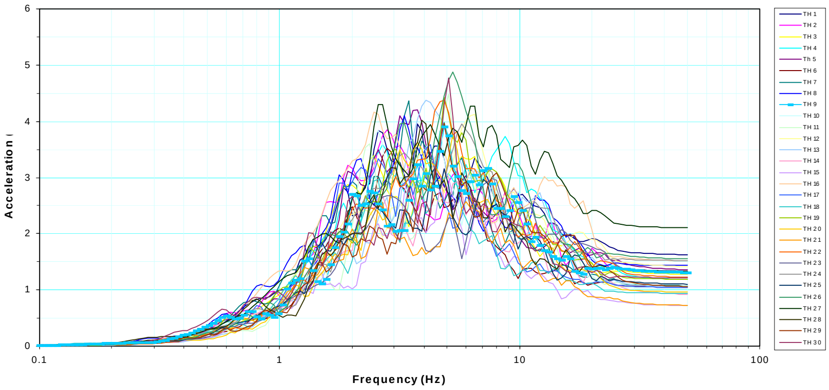
• example is of Reichner et al. (Insights gained from the Beznau Seismic PSA, 10th Conference of PSAM, Seattle, 10. Juni 2010)
• PEGASOS study: a PSHA with highest elaborated Level 4 according to SSHAC
•SSHAC: “Senior Seismic Hazard Analysis Committee, Recommendations for PSHA, Guidance on Uncertainty and Use of Experts”, NUREG/CR-6372, 1997 (Logic tree)
•Earlier PSHA :
- ETH Zurich, “Seismic Hazard Maps of Switzerland”, 1977.
- Basler&Hofmann, “Beznau NPP, Site-Specific Seismic Hazard Functions for Probabilistic Risk Assessment”, 1984.



Example II – Recent Model for NPP Beznau

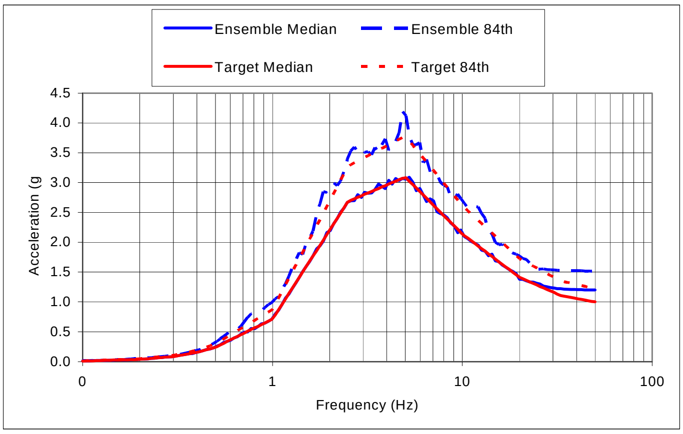
Seismic Hazard for Beznau (PEGASOS and Old Analysis) and for Paks Site

Example II – Recent Model for NPP Beznau

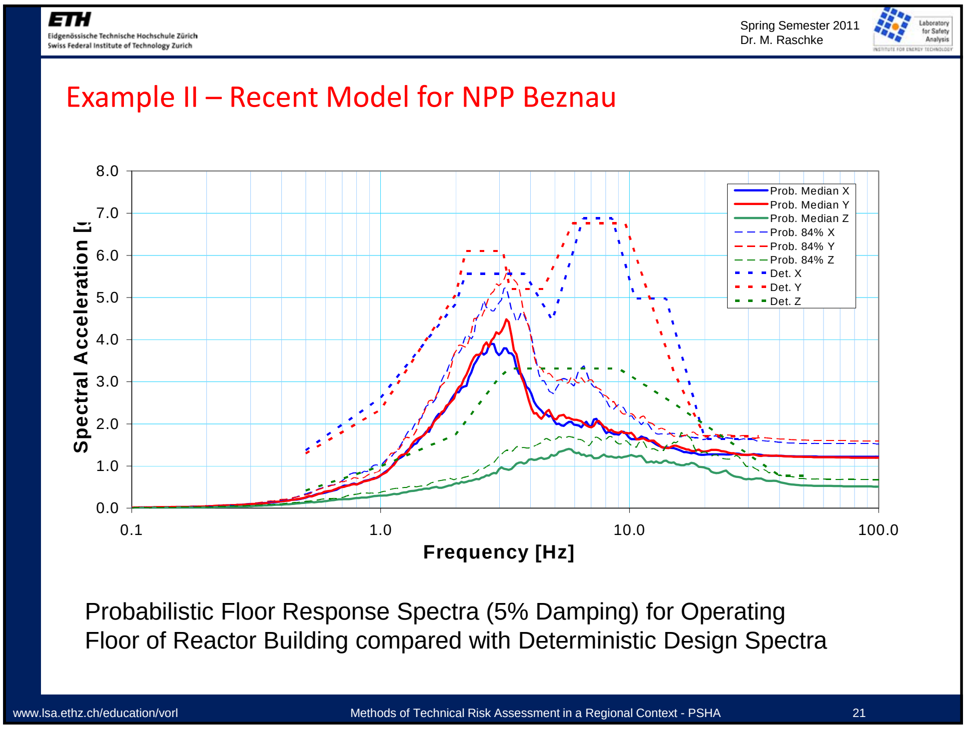


Summary of Spectra of 30 Time Histories Used

Example II – Recent Model for NPP Beznau

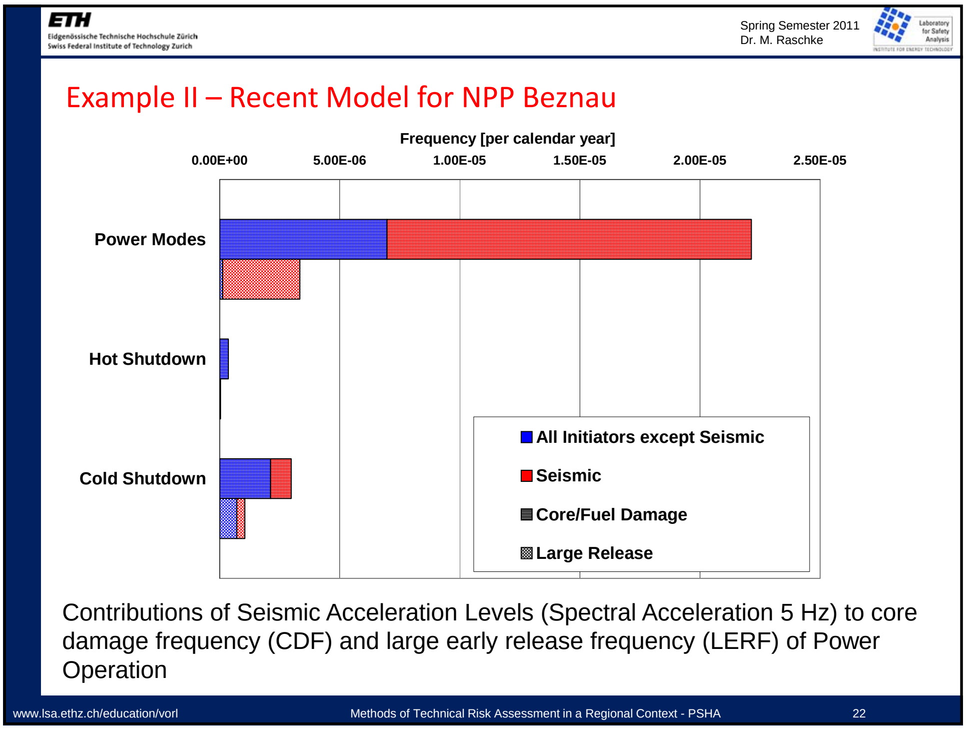


Resulting Median and 84th-Percentile UHS from Time Histories compared to PEGASOS Target



Example II – Recent Model for NPP Beznau

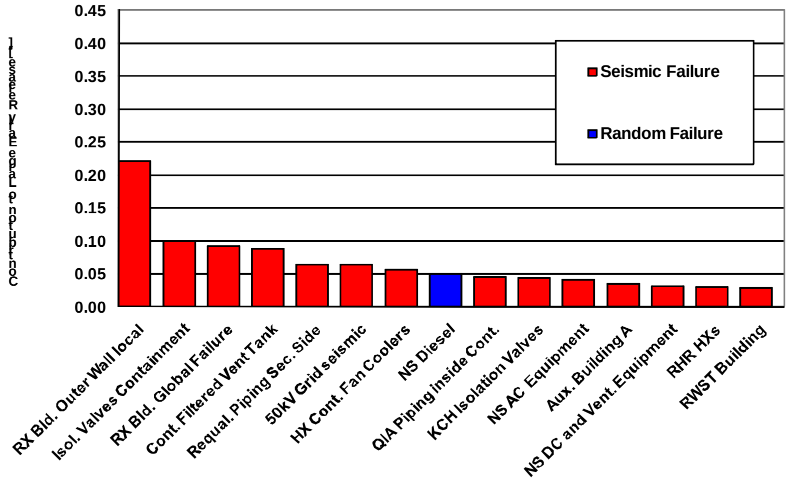
Probabilistic Floor Response Spectra (5% Damping) for Operating Floor of Reactor Building compared with Deterministic Design Spectra



Example II – Recent Model for NPP Beznau

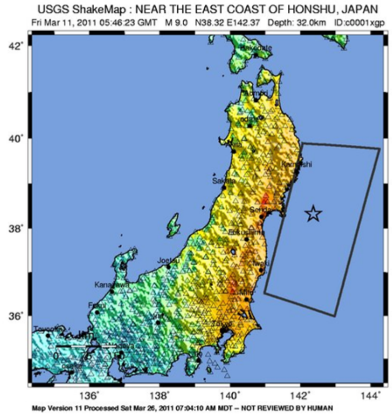
Contributions of Seismic Acceleration Levels (Spectral Acceleration 5 Hz) to core damage frequency (CDF) and large early release frequency (LERF) of Power Operation

Example II – Recent Model for NPP Beznau

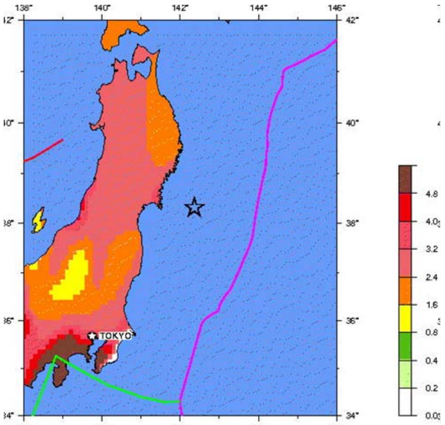


Contributions of SSCs to LERF of Power Operation

The large earthquake near Honshu and the impact on Fukushima

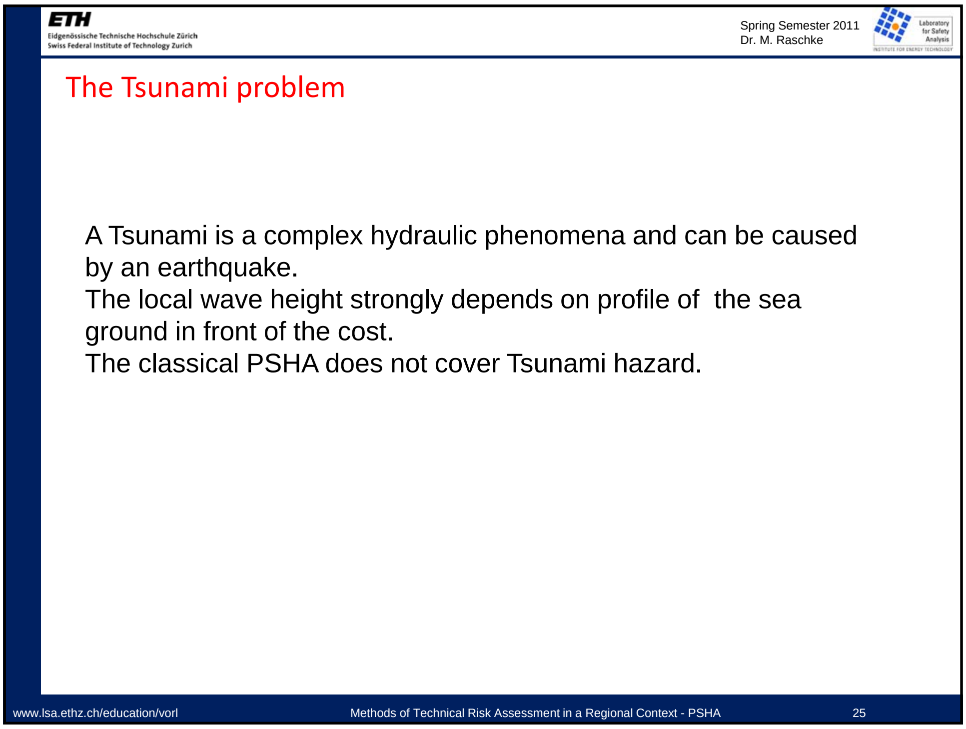


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



NEAR EAST COAST OF HONSHU, JAPAN
2011 03 11 05:46:23 UTC 38.32N 142.36E Depth: 32.0 km
Peak Ground Acceleration (m/s²) with 10% Probability of Exceedance in 50 Years

The energy magnitude is 8.6, the moment magnitude is 9.0. The locale shaking level has a return period of around 475 years. This is the design level of simple buildings. (source: USGS)



The Tsunami problem

A Tsunami is a complex hydraulic phenomena and can be caused by an earthquake.
The local wave height strongly depends on profile of the sea ground in front of the cost.
The classical PSHA does not cover Tsunami hazard.