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

14 - 25 February 2005

Site Specific Data - Treatment of Uncertainties according to SSHAC Level 4 Methodology

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IAEA/ICTP Workshop on
Earthquake Engineering for Nuclear Facilities - Uncertainties in Seismic Hazard Assessment

"Site specific data- Treatment of uncertainties according to SSHAC Level 4 Methodology"

Trieste, Italy, 14 – 25 February 2005

Unit 15 - Sener Tinic-Kizildogan

Content of the Presentation

- Introduction
- SSHAC Level 4 Methodology
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  - Methodology
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- Supporting Computations
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- Summary of the Presentation
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Introduction

- First PSHA's for Swiss NPP's are performed between 1984 – 1996
- PSA's have shown that earthquakes are a significant contributor to the estimated core damage frequency
- HSK required a state-of-the-art hazard evaluation and issued methodological guidelines which closely resemble the Study 4 Level methodology in NUREG/CR-6372 (SSHAC, 1997)
- Swiss NPP's planned the PEGASOS- Project based on the SSHAC recommendations.
- The first phase of the PEGASOS is performed in 2000 – 2004.
- The second phase will be completed by the end of 2006.

SSHAC Level 4 Methodology

- The differences between the LLNL (1989) and EPRI (1989) hazard results led to establish the SSHAC to provide methodological guidelines on the PSHA.
- SSHAC concluded that the main reasons for the differences were procedural rather than technical.
- SSHAC Report (NUREG/CR-6372) provides technical advice and procedural guidance at 4 different "levels of complexity" of a PSHA- Study.

Table 3-1 Degrees of PSHA Issues and Levels of Study

ISSUE DEGREE	DECISION FACTORS	STUDY LEVEL
A Non-controversial; and/or insignificant to hazard		1 TI evaluates/weights models based on literature review and experience; estimates community distribution
B Significant uncertainty and diversity; controversial; and complex	•Regulatory concern •Resources available •Public perception	2 TI interacts with proponents & resource experts to identify issues and interpretations; estimates community distribution
C Highly contentious; significant to hazard; and highly complex		3 TI brings together proponents & resource experts for debate and interaction; TI focuses debate and evaluates alternative interpretations; estimates community distribution
		4 TFI organizes panel of experts to interpret and evaluate; focuses discussions; avoids inappropriate behavior on part of evaluators; draws picture of evaluators' estimate of the community's composite distribution; has ultimate responsibility for project

NUREG/CR-6372

SSHAC Level 4 Methodology

Important Characteristics of SSHAC Level 4 PSHA

- Sampling the state of knowledge of the informed scientific community by expert elicitation and the using the aggregated views

- Distinguishing between

  - Epistemic uncertainty – knowledge-based (e.g., lack-of-knowledge) or informational uncertainties (e.g. associated with a limited data)
    Epistemic uncertainty results from imperfect knowledge about earthquakes and their effects and can be reduced with advances in knowledge and collection of additional data.

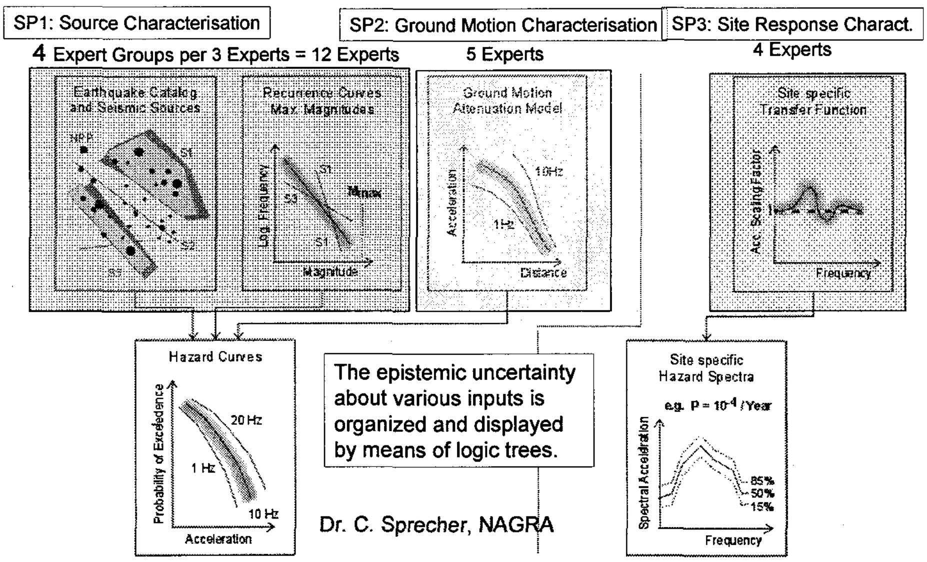
  - Aleatory variability (Randomness)- probabilistic variability that results from natural physical process (the size, location and time of the next earthquake and the resulting ground motion)
    Aleatory variability is irreducable without the inclusion of additional predictive parameters.

PEGASOS-Project (2000 – 2004)

- PEGASOS is the Probabilistic Seismic Hazard Assessment for four Swiss Nuclear Power Plant Sites according to SSHAC Level 4 Methodology
  - Worldwide second project after Yucca Mountains
  - Worldwide first project for existing NPP's
  - Worldwide first project with site-specific soil response evaluation fully integrated to the soil hazard evaluation
  - Added values to the "state of the art" of seismic hazard anayses regarding to max. ground motions and some other aspects
- Deliverables of the Project:
  - Seismic hazard curves at three depths for peak (100 Hz) and spectral accelerations for probabilities of exceedance between 10^{-1} and 10^{-7} with the epistemic uncertainties
  - Uniform hazard specta for the 10^{-3} to 10^{-7} annual probabilities of occurance with associated uncertainties
  - Deaggregation of hazard results with respect to magnitude and distance

PEGASOS-Project Methodology

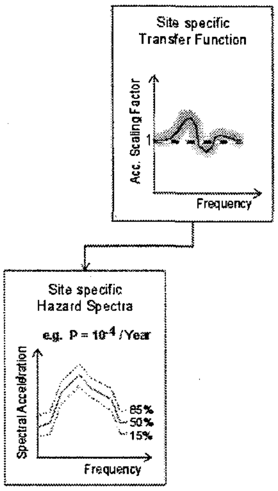
Rock Hazard ⟶ Site Specific Soil Hazard



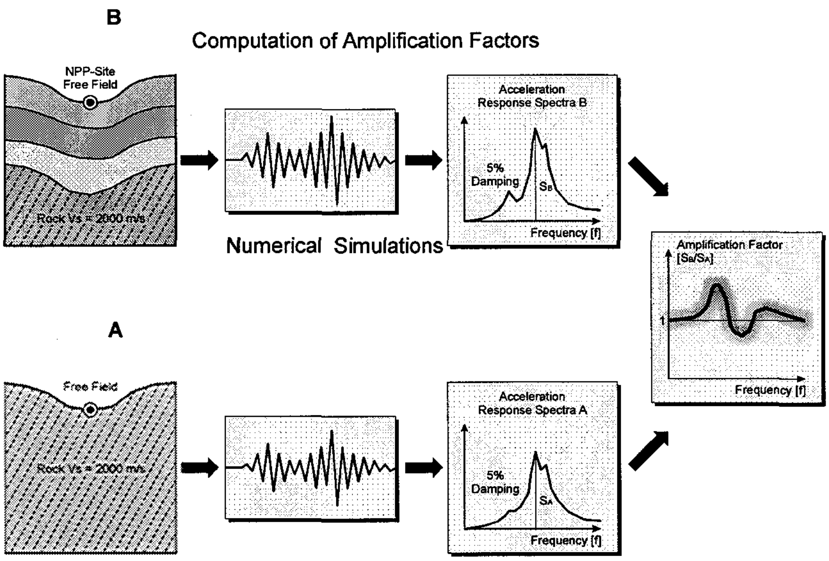
PEGASOS - Site Response Characterisation

- Objective: To quantify the surficial geology effects on the characteristics of the earthquake ground motion

- Results: A set or several sets of scale factors given as function of frequency at the surface, foundation level of the reactor building and the safety-relevant buildings



PEGASOS - Site Response Characterisation Methodology



PEGASOS - Site Response Evaluation Process

- Generation of Geological and Geotechnical Models
- Workshop 1: Key Issues and Data Needs
- Additional Site Investigations
- Elicitation Meeting on Properties of Soil Profiles
- Supporting Computations
- Workshop 2: Evaluation of Models
- Elicitation Interviews, Development of Initial Logic trees
- Workshop 3: Initial Feedback on Experts' Estimates
- Model Revisions
- Model Implementation
- Workshop 4: Feedback on Expert's Estimates
- Expert Model Revisions
- Expert Meeting on Maximum Ground Motion
- Development and Review of Final Expert Models

Experts
Project Management, TFI

Uncertainties in Site Response Characterisation

- Epistemic uncertainty is due to
  - Imperfect knowledge of material properties (uncertainties in the shear wave velocities, G-modulus and damping curves, unknown variation of the material properties over the site)
  - Inappropiate or too simple modeling (1-D or 2-D instead of 3-D modelling, simplifed material modelling, equivalent linear instead of true non-linear)
- Aleatory variability is due to
  - S-PV Waves
  - 2D – effects

?

Geological and Geotechnical Data Assessment

- Collecting all available and relevant geological and geotechnical data
- Digitalizing all available data, generating a document database
- Evaluation of the quality of all basis geotechnical data
- Compilation of all available geological and geotechnical data
  - Integration of data in the GIS
  - Generate geological models
  - Store the data in the Project Database

- Submit data information to experts prior to Workshop 1
- Discussion at the Workshop
  - Is the data quality acceptable for site-specific evaluations ?
  - Is additional data needed ?
  - Can uncertainty be reduced through additional investigations?
  - Are resources available in the framework of project deadlines and budget constraints?

Geol. and Geotechn. Data Asessment (cont.)

Evaluation of the Quality of Former Geotechnical Investigations at the NPP-Sites

- Evaluation criteria
  - Accepted standard procedure at the time of data gathering
  - Acceptance of these procedures today
  - Experience of the organization performing the investigations and interpretation results
  - Properties in expected, reasonable range for these geological formations

Geol. and Geotechn. Data Asessment (cont.)

Evaluation of the Quality of Former Geotechnical Investigations at the NPP-Sites (cont.)

- Field tests
  - Geophysical borehole tests
  - Hydrostatic test
  - Plate test
  - Standard penetration test
  - Load-settlement tests
  - Surface refraction tests
  - Up-hole tests
  - Cross-hole tests
  - Down-hole tests

Evaluation of the Quality of Former Geotechnical Investigations at the NPP-Sites (cont.)

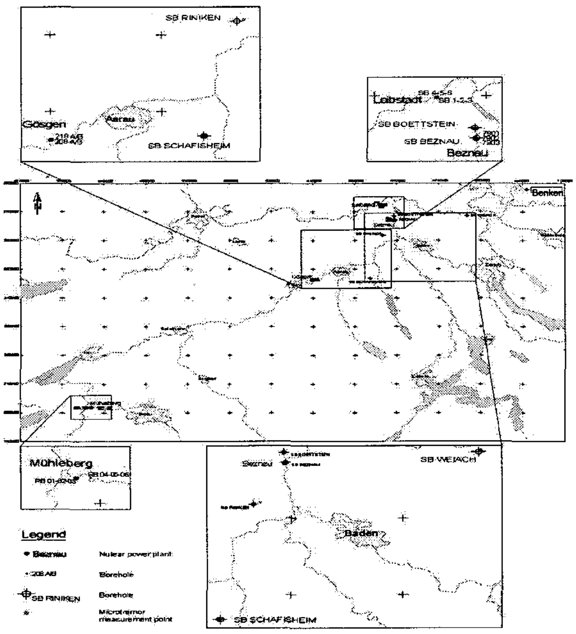
- Laboratory tests
  - Classification
  - Specific weight
  - Grain size distribution
  - Direct shear test
  - Compression test
  - Triaxial test
  - Resonant columns tests
  - "Stress controlled dynamic tests"
  - "Strain controlled dynamic tests"
  - Cylic triaxial tests

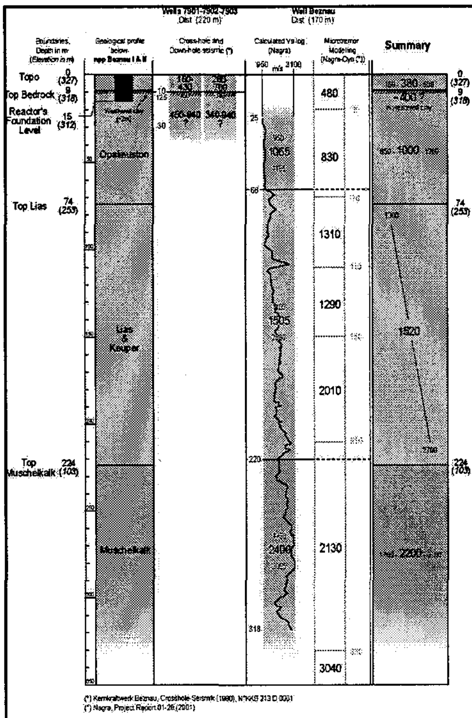
Geol. and Geotechn. Data Asessment (cont.)

Compilation of all available Site Geology Data

- Geological information from all the boreholes drilled on the four NPP sites
- All available well data in a radius of some two kilometers around each site.
- Additional regional geological data (maps, deep boreholes, seismic reflection data, digital elevation models, etc.)

Location map

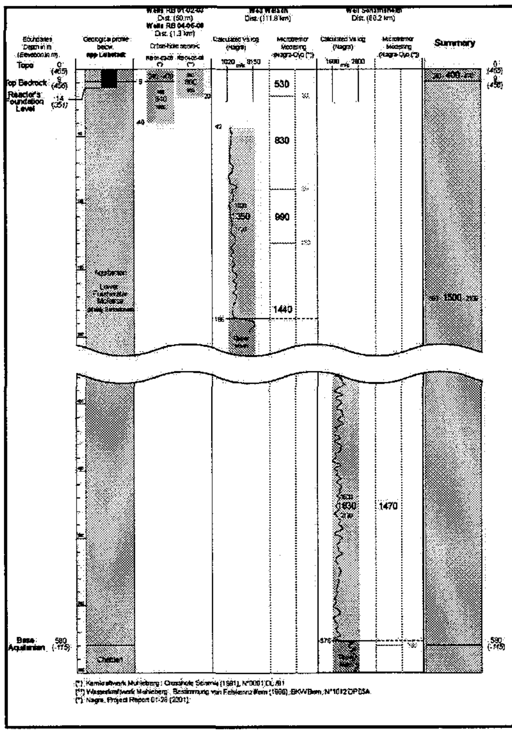




Site 1 **Vs Profile**

Formation	Depth Below Surface (m)		Vs Range		
	Fro m	To	Min	Average	Max
Unconsolidated Rocks	0	9	150	**380**	500
Weathered Opalinuston	9	~11		**400 ?**	
Opalinuston	~11	74	850	**1000**	1200
Lias & Keuper	74	224	1300	**1520**	2700
Muschelkalk	224	End of Model	1750	**2200**	3100

PROSEIS, Switzerland



Site 4 **Vs Profile**

Formation	Depth Below Surface (m)		Vs Range		
	Fro m	To	Min	Average	Max
Unconsolidated Rocks	0	9	240	**400**	470
Aquitanian	9	580	800	**1500**	2100
Chattien	580	End of Model			

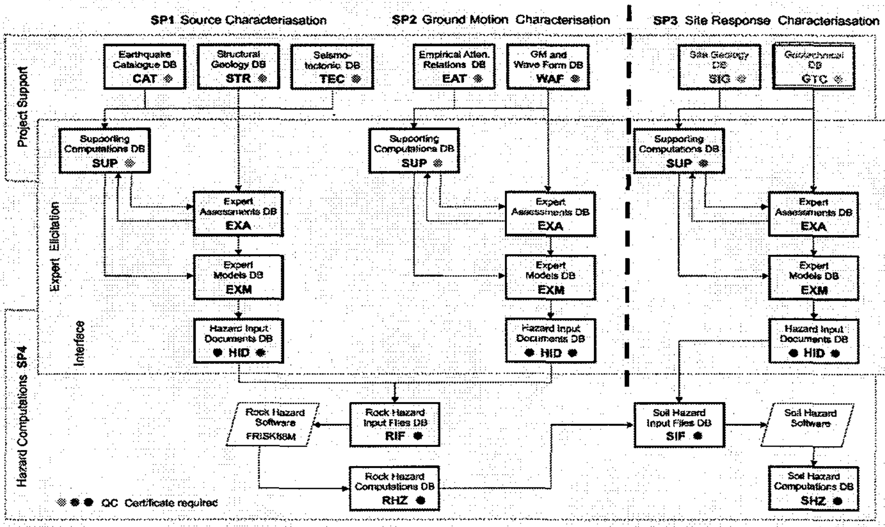
PROSEIS, Switzerland

Geol. and Geotechn. Data Asessment (cont.)

Geological and Geotechnical Database

PROJECTDATA DB & DATA FLOW

PEGASOS

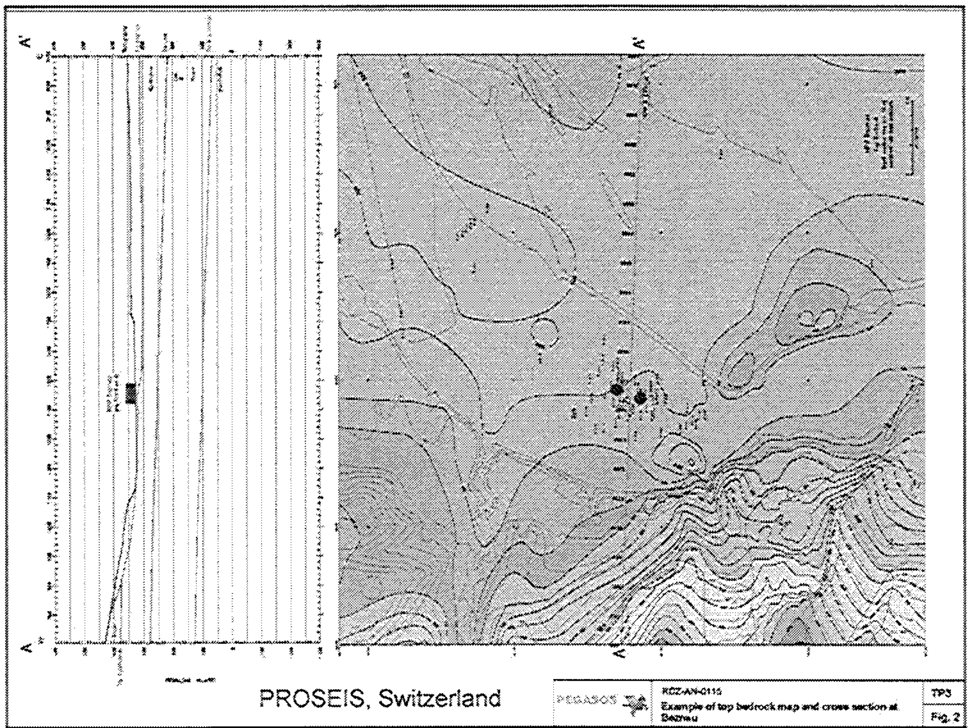


Geol. and Geotechn. Data Assessment (cont.)

Site Geology Database

- Maps of the bedrock geometry using a GIS software package.
- Contour maps of depth to additional deeper geological units
- Selected vertical geological profiles
- Additional vertical profiles computed along any expert-defined cross section.

Bedrock Map:	NPP 2 x 2 km		1:5,000
Subsurface Map:	Top Opalinuston		1:5,000
Subsurface Map:	Top Lias		1:5,000
Subsurface Map:	Top Muschelkalk		1:5,000
Geological Section:	NPP_Centre	1:5,000	
Geological Section:	NPP-C	1:5,000	



PROSEIS, Switzerland

Geol. and Geotechn. Data Asessment (cont.)

Site Geotechnical Database

Using the same boreholes as used for the collection of the geological data, several categories of SP3 relevant rock physical properties have been gathered and integrated in the Geotechnical Database. The physical properties collected were:

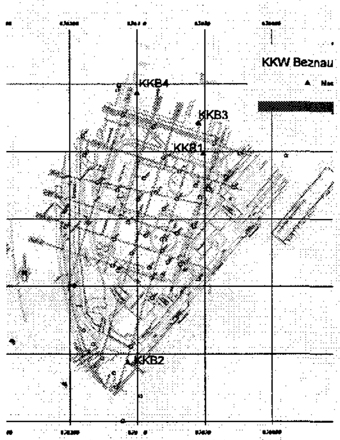
•P wave velocity
•S wave velocity
•Grain size distribution (grain size and sediment type)
•Atterberg consistency limits
•Density
•Water content
•Porosity
•Elastic properties
•Non linear material properties (shear modulus and material damping as a function of shear strain)

Geol. and Geotechn. Data Asessment (cont.)

- Geological, geotechnical data together with related quality assessments were presented at WS-1 to the experts
- Experts required additional investigations:
  - Ambient vibration measurements to elaborate possible Vs Profiles based on Dr. Donat Fäh's inversion technique
  - Additional ambient vibration measurements (H/V data processing to determine the fundamental frequencies according to Nakamura-Method)
  - Spectral Analysis of Surface Wave (SASW) to check the older crosshole data at one site

Geological and Geotech. Data Asessment (cont.)

Measurement of S-Wave Velocity Profiles, Donat Fäh, Johann Wössner, SED



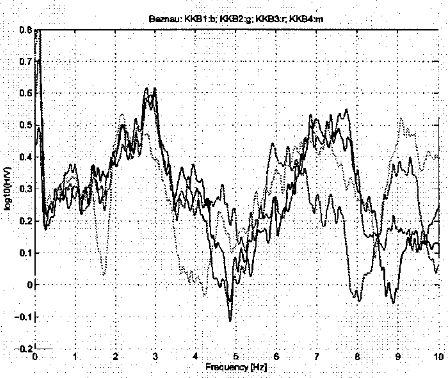


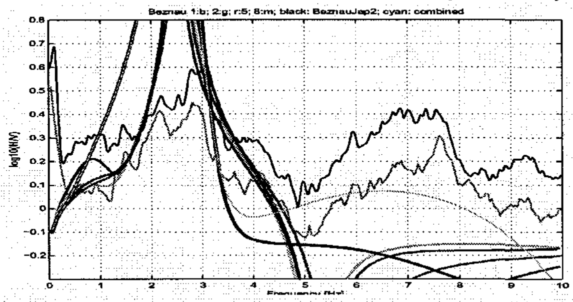
Figure 1. Sites of the ambient vibration measurements at NPP site Beznau, and derived H/V ratios.

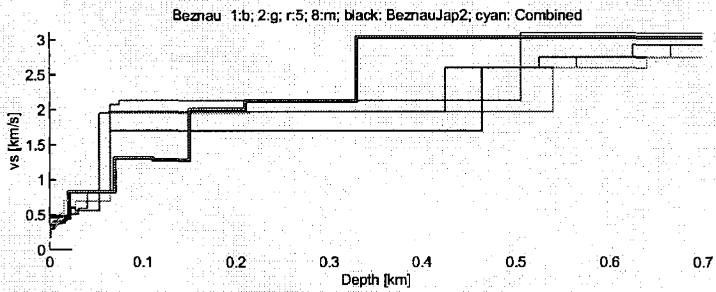
2

Geological and Geotech. Data Asessment (cont.)

Conclusions:

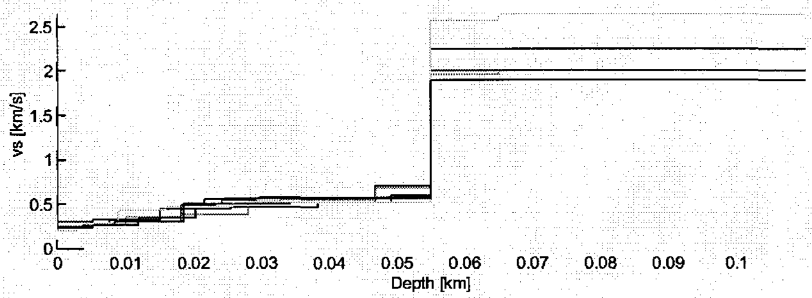
The structure can not be approximated by a one soil-layer – over-bedrock structure. Since other velocity measurements are available at the site the combined VS profile (in cyan) is proposed.





Geological and Geotech. Data Asessment (cont.)

Measurement of S-Wave Velocity Profiles, Donat Fäh, Johann Wössner, SED

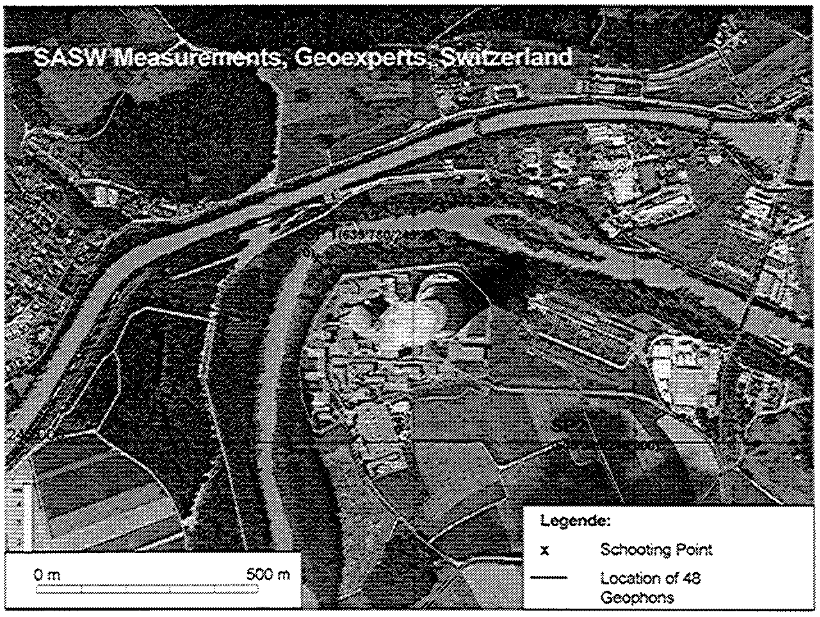


Structural models obtained from the different inversions.

Conclusions:

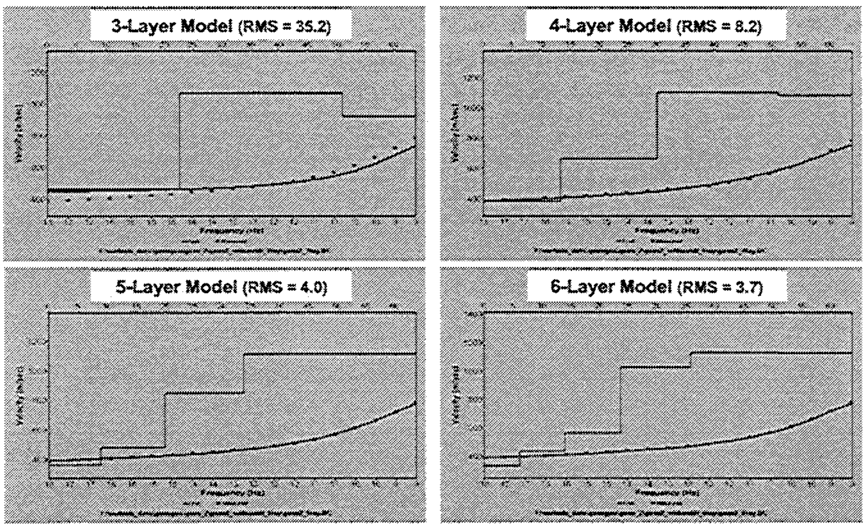
The structure can be approximated by a one soil-layer – over-bedrock structure.
Inversions from H/V ratios in such case are considered to be reliable.

Geological and Geotech. Data Asessment (cont.)



Geological and Geotech. Data Asessment (cont.)

Gösgen 2: SASW Inversion with 3 to 6 Layers



PEGASOS SP3: SASW Gosgen   14 March 2002   2

Geolog. and Geotech. Data Assessment (cont.)

Results of additional geological Investigations were presented at the Expert Meeting on "Validation of Soil Profiles"

NPP Site 1	NPP Site 2	NPP Site 3	NPP Site 4
Cross-hole, down hole,1980	Refraction Seismic, 1967	Cross-hole, 1975	Cross-hole and up-hole 1980, 1981
Microtremor, Oyo-Corp. 2000	Cross-hole and down-hole, 1972	Micotremor Fäh, 2001	Nakamura, Résonancé,2001
Microtremor, Fäh 2001	Microtremor Fäh, 2001	Nakamura, Résonancé,2001	
	SASW, Résonance, Geoexperts 2001		

(shaded) In the Framework of PEGASOS-Project

Geolog. and Geotech. Data Assessment (cont.)

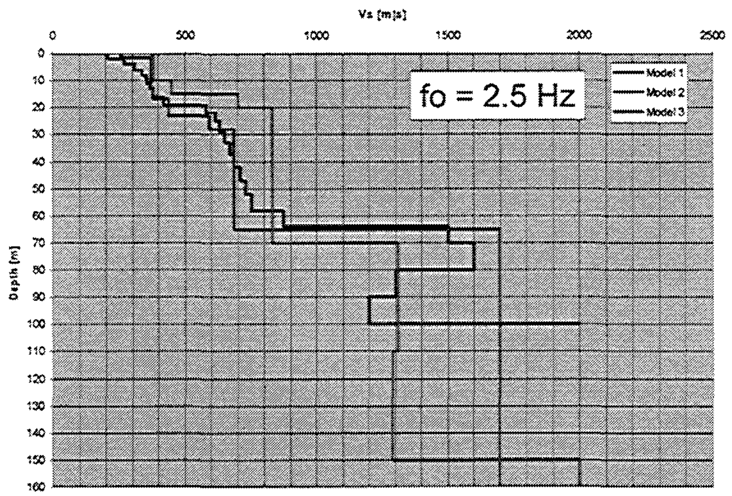
- Experts discussed potential value of additional S-Wave reflection measurements. According to different contacts it was not possible to execute such measurements in the given time and budget frame of the PEGASOS-Project. It was also questionable if these measurements can give a clear statement for the typical nuclear plant environment because of the typical geological conditions and the availability of the adequate shear wave source on the market at that time.
- Based on all compiled information experts decided on the control values of the shear wave velocities for each site and requested to introduce a$z^{1/4}$dependency within the uncohesive loose soil and to check the transfer functions for weak motion and adjust the velocities so that the fundamental frequencies obtained from H/V ambient vibration measurements are matched.
- Further experts specified soil profile randomization constraints.

Geolog. and Geotech. Data Assessment (cont.)

- Soil Profile Randomization Constraints
  - A bound on the uncertainty of 30% of the median velocity is imposed. This represents ± 2 σ.
  - G/G_{max} (γ) and D(γ) are randomized about the base case values. A log normal distribution is assumed with σ_{ln} of 0.35 at a cylic shear strain of $3x10^{-2}$. An upper and lower bound truncation of 2 σ is used
  - An inverse correlation between G/Gmax and D(γ) curves is assumed. In developing the randomized equivalent linear properties, full correlation is assumed between the G/G_{max} (γ) and D(γ) curves
  - The fundamental natural frequencies must be within the site specific frequencies (e.g. for Beznau 1.8 Hz and 3.0 Hz)
  - No randomization will be undertaken for the bedrock
  - Site specific constraints about layer thicknesses

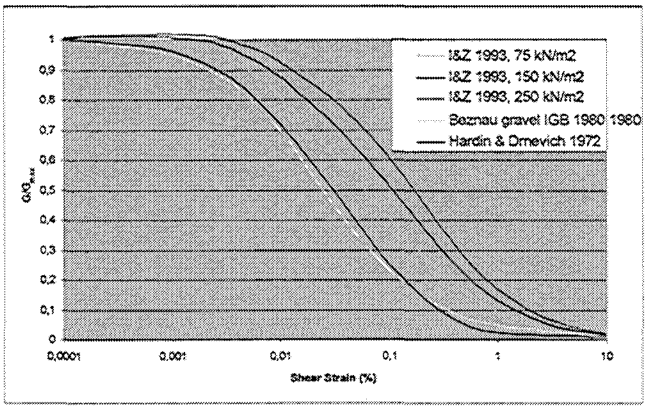
Geol. and Geotechn. Data Assessment (cont.)

Shear Wave Velocity Profiles at Site 1



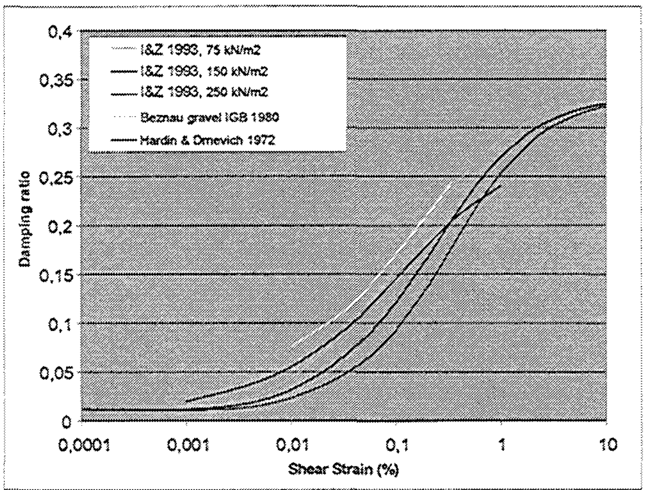
Geolog. and Geotech. Data Assessment (cont.)

Dynamic Material Properties for 1-D Site Simulations
G/G$_{max}$ (γ)

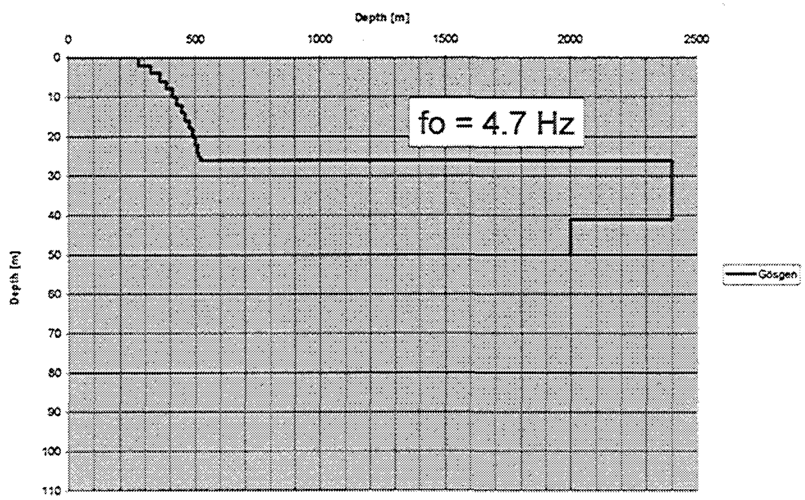


Geolog. and Geotech. Data Assessment (cont.)

Dynamic Material Properties for 1-D Site Simulations
D (γ)

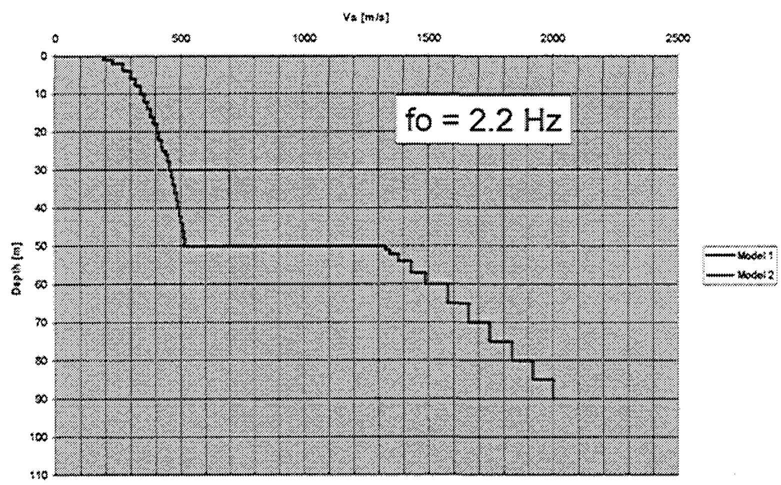


Vs profile for Site 2, elicitated on the Meeting, February 4, 2002



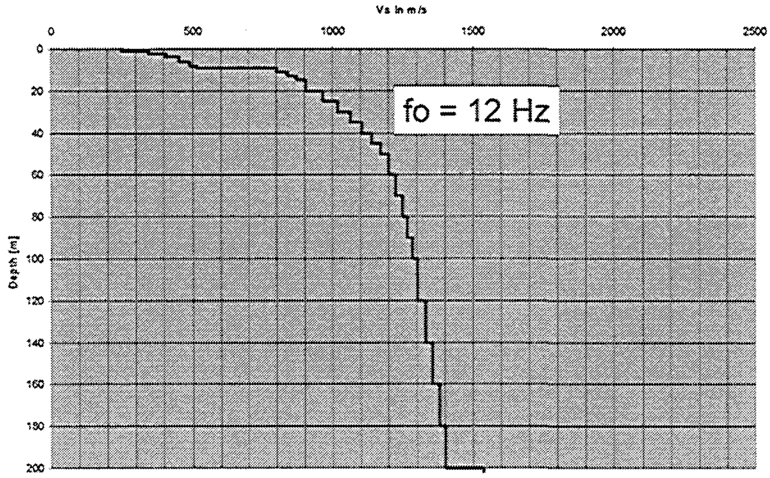
4. Geological and Geotechical Data (cont)

Vs-Profiles for Site 3, elicitated on the Meeting, February 4, 2002



4. Geological and Geotechical Data (cont)

VS-Profile for Site 4, elicitated on the Meeting, February 4, 2002



Supporting Computations

- 1-D Equivalent-Linear Site Response Computations
  - Time History Methode (SHAKE) each case with 15 TH's
  - Random Vibration Theory Method (RVT) with and without soil profile randomization (Silva, 1972)
- 1-D True Non-Linear Site Effect Computations (Modaressi,GDS, Geodeco using SUMDES and DYNAFLOW)
- 1-D Site Effect Computations for Oblique Wave Incidence (Bard, Fäh)
- 2-D Site Effect Computations
  - Aki-Larner Technique (Bard)
  - 2D SH computations (Fäh)

Supporting Computations (cont.)

Overview of the supporting computations for the horizontal component of ground motion

Site	RVT with soil randomization		Shake	1-D true non-linear	2-D	SH-PSV
	number of cases	number of runs*	number of runs	number of runs		
NPP Site 1	90	4'590	225	30		yes
NPP Site 2	60	3'060	225	35		yes
NPP Site 3	120	6'120	270	30	2-methods	yes
NPP Site 4	60	3'060	180	0		
TOTAL	**330**	**16'830**	**900**	**95**		

** 51 runs per case*

Supporting Computations (cont.)

1- D Site Response Simulations according to the RVT-method (Silva)

NPP	Number of Velocity Soil Profiles	Number of Dynamic Material Properties	Number of Magnitudes (Mw)	Number of ground motion levels
Site 1	B1 B2 B3	M1	3 (5, 6, 7)	10 (0.05 to 1.5 g)
Site 2	G1	M1 M2	3 (5,6,7	10 (0.05 to 1.5 g)
Site 3	L1 L2	M1 M2	3 (5,6,7)	10 (0.05 to 1.5 g)
Site 4	M1	M1 M2	3(5,6,7)	10 (0.05 to 1.5 g)

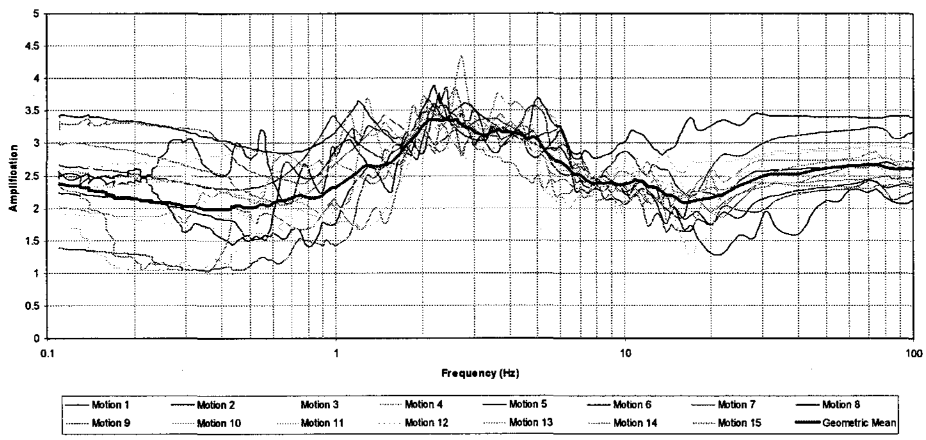
Supporting Computations (cont.)

- Visualisation and Comparison of RVT and SHAKE Results
  - Effect of different Time Histories (SHAKE runs)
  - Effect of Ground Motion Level (RVT runs)
  - Comparison of RVT and SHAKE runs
  - Effect of Input Level (RVT runs)
  - Effect of Soil Randomization
  - Effect of Magnitude (RVT runs)
  - Maximum Strains

Supporting Computions (cont.)

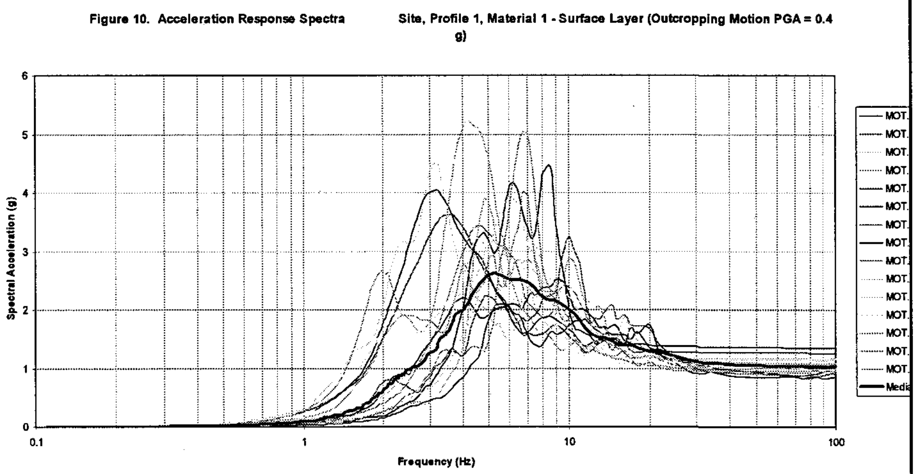
- **Effect of Different Time Histories**

Figure 21. Amplification Spectra | Site, Profile 1, Material 1- Surface Layer (PGA = 0.4 g)



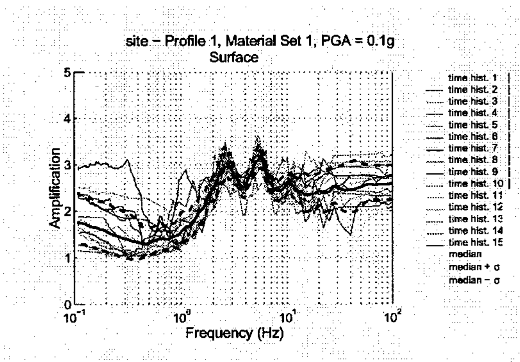
Supporting Computions (cont.)

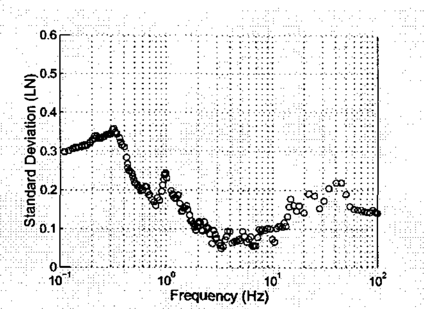
- **Effect of Different Time Histories**



Supporting Computions (cont.)

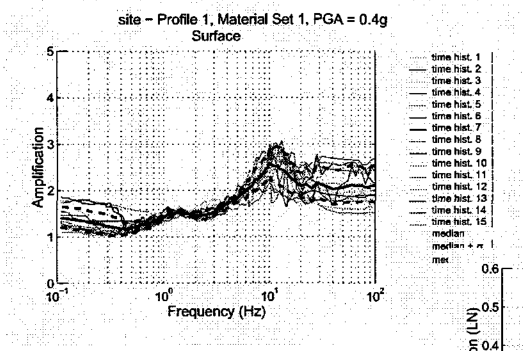
Effect of Different Time Histories

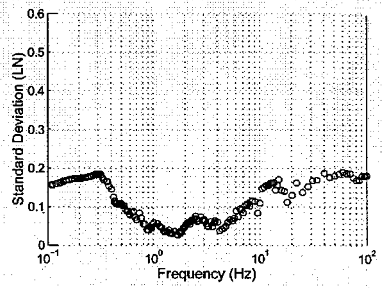




Supporting Computions (cont.)

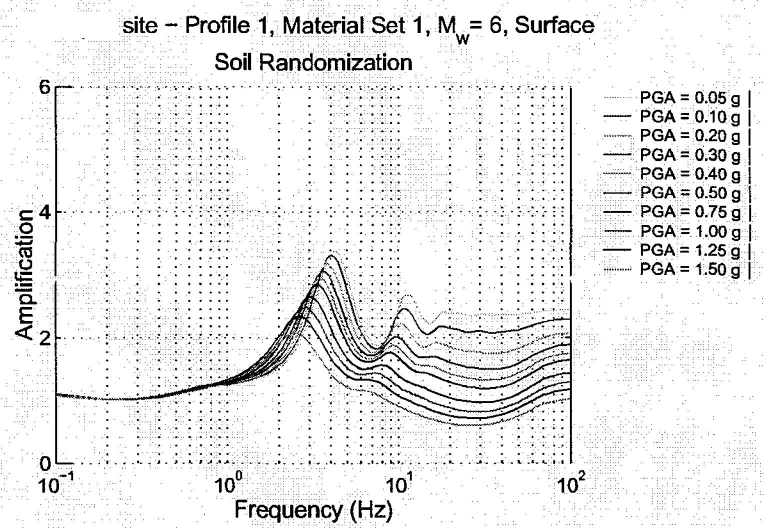
Effect of Different Time Histories



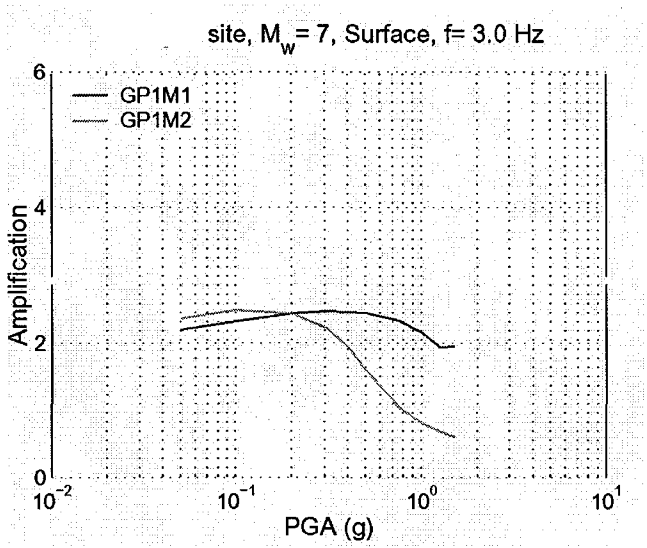


Supporting Computions (cont.)

•Effect of Ground Motion Levels



Effect of Input Level (RVT runs)

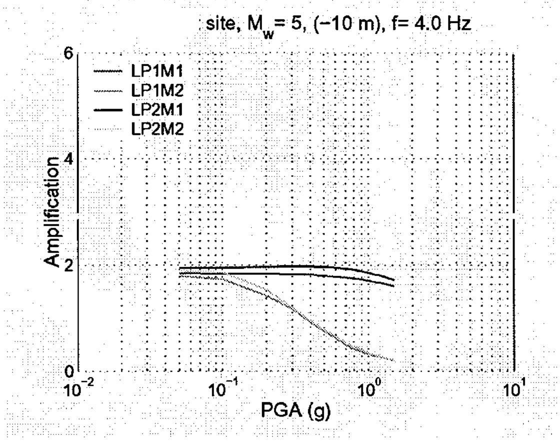


GP1M1: Median Amplification Factors Soil Profile 1, Material 1

GP1M2: Median Amplification Factors Soil Profile 1, Material 2

Supporting Computions (cont.)

- **Effect of Input Level (RVT runs)**



LP1M1: Median Amplification Factors Soil Profile 1, Material 1

LP2M1: Median Amplification Factors Soil Profile 2, Material 1

LP1M2: Median Amplification Factors Soil Profile 1, Material 2

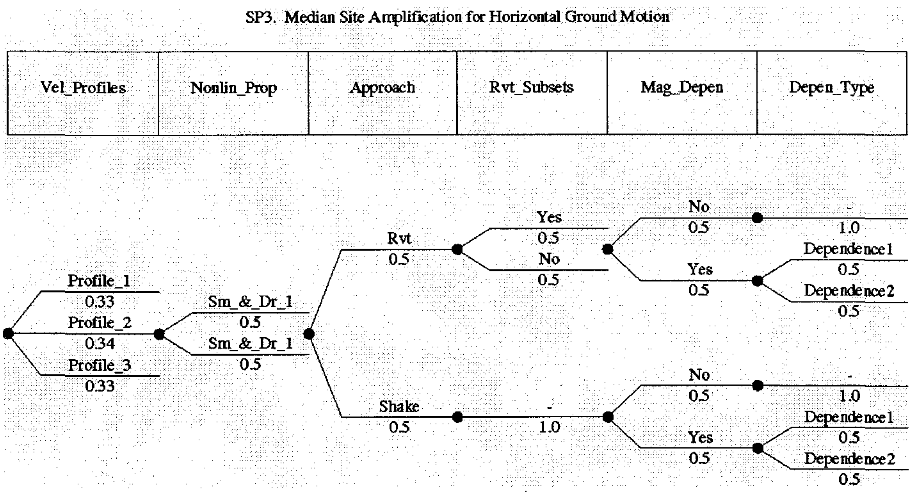
LP2M2: Median Amplification Factors Soil Profile 2, Material 2

Expert Models

- Logic Trees for
  - Median Amplification of Horizontal Ground Motion
  - Median Amplification of Vertical Ground Motion
  - Aleatory Variability of Horizontal Ground Motion
  - Aleatory Variability of Vertical Ground Motion
- Estimation of Maximum Ground Motions

Expert Models (cont.)

- **Example for Median Amplification of Horizontal Ground Motion**



Expert Models (cont.)

Weights for Alternate Velocity Profiles

Profile	Expert 1	Expert 2	Expert 3	Expert 4
Site 1, Profile 1	0.5	0.4	0.45	0.5
Site 1, Profile 2	0.2	0.2	0.35	0.3
Site 1 Profile 3	0.3	0.4	0.20	0.2
Site 3, Profile1	0.8	0.7	0.7	0.7
Site 3, Profile 2	0.2	0.3	0.3	0.3

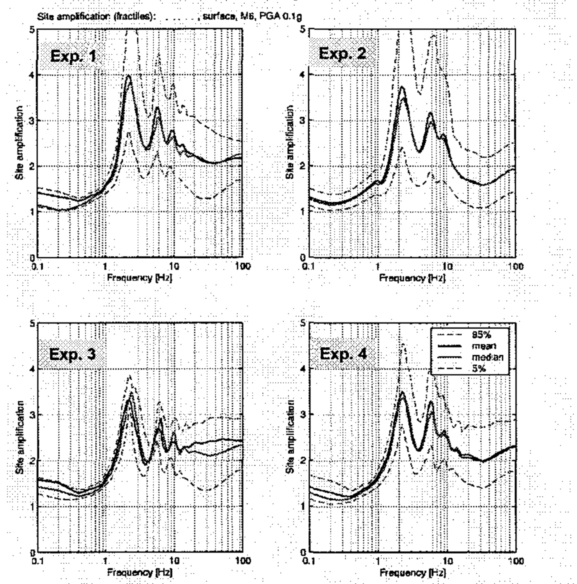
Weights for non-linear material properties

Model	Expert 1	Expert 2	Expert 3	Expert 4
Ishibashi&Zhang	0.65	0.5	0.30	0.3
Hardin&Drenevich	0.35	0.5	0.70	0.70

Experts' Models (cont.)

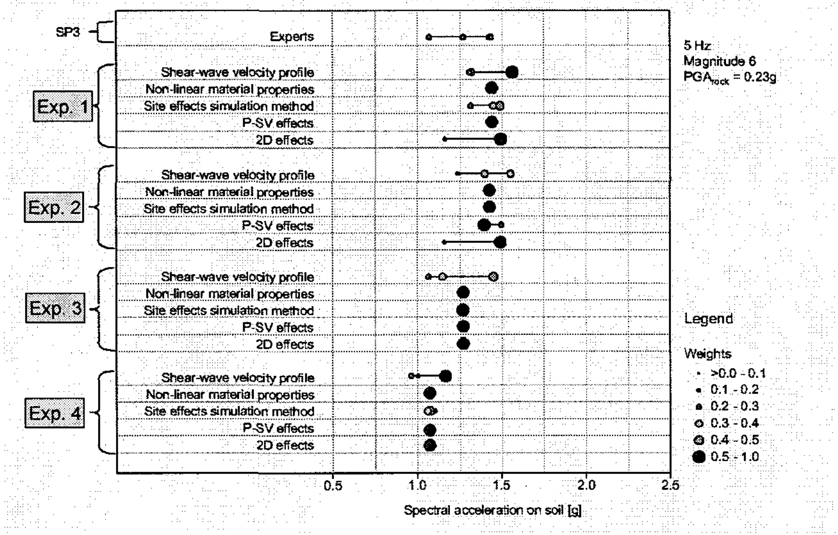
- Epistemic uncertainties of site amplification function

- Surface
- Magnitude 6
- PGA 0.10g on rock



Experts' Models (cont.)

Contribution of the SP3 logic tree branches to the median amplification at 5 Hz for Magnitude 6 und PGA $_{rock}$ = 0.23g at one site



Lessons Learned and Conclusions

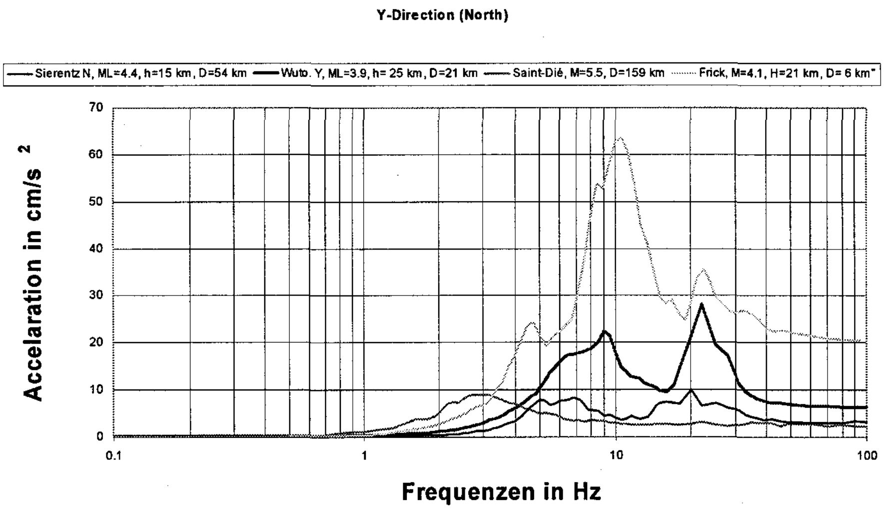
- The uncertainties on the soil shear wave velocity profiles and dynamic soil properties are major contributors to the uncertainty in the soil hazard.
- These uncertainties can be generally reduced by additional geological and geotechnical site investigations. The cost/benefit of such investigations should be examined carefully for existing plant sites.
- The uncertainty caused by non-linear material properties increases for high ground motion levels.
- This uncertainty in the non-linear material properties can be reduced by additional geotechnical investigations to determine non-linear soil properties.
- To analyse the site specific seismological data (real earthquake records) may be a simple and an effective approach to specify more reliable shear wave velocity profiles and to reduce the uncertainties.
- To increase the reliability of the site specific data will lead to estimate the maximum ground motion precisely.
- The aleatory variability is considered in the expert models of mean ground motion as separate branches for P-SV and 2-D effects, these effects are included also in the logic trees for the aleatory variability. The attenuation models for rock motion contains these effects too. This means aleatory effects are included three times in the entire process of soil hazard evaluation. In the end this leads to unrealistic high soil hazard results.

Comparison of Site Area Investigations

IAEA Safety Standard Series No. NS-G-3.3 Evaluation of Seismic Hazards for NPP's	PEGASOS
3.17 Site area studies should include the entire area covered by the plant, which is typically one square kilometer	Fulfilled, geological and geotech. Data is compiled for an area of 4. km^2
3.18 The database should be developed from detailed geological, geophysical and geotechnical studies complemented by in situ and laboratory testing	fulfilled
3.19 The following investigations of the site area performed: Geological and geotechnical Hydrogeological investigations Investigations of site effects	The existing data fulfill the requirements. Hydrogeological data exists Ambient vibration measurements Existing real earthquake records at some sites were presented at WS1. However the experts did not consider these data to validate Vs profiles
3.20 All the data required for assessing the dynamic soil-structure interaction should be acquired in the course of these investigations	fulfilled
3.21 The data are typically presented on maps at a scale of 1:500 and with appropriate cross-sections :	PEAGASOS Data are on the GIS, might be presented on maps at the required scale of 1:500

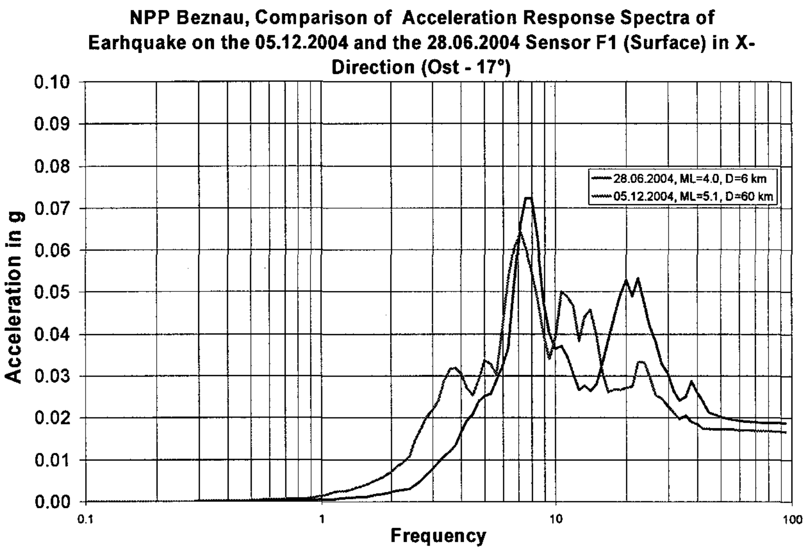
Site-Specific Seismological Data

Comparison of the acceleration response spectra on the rock (weathered)

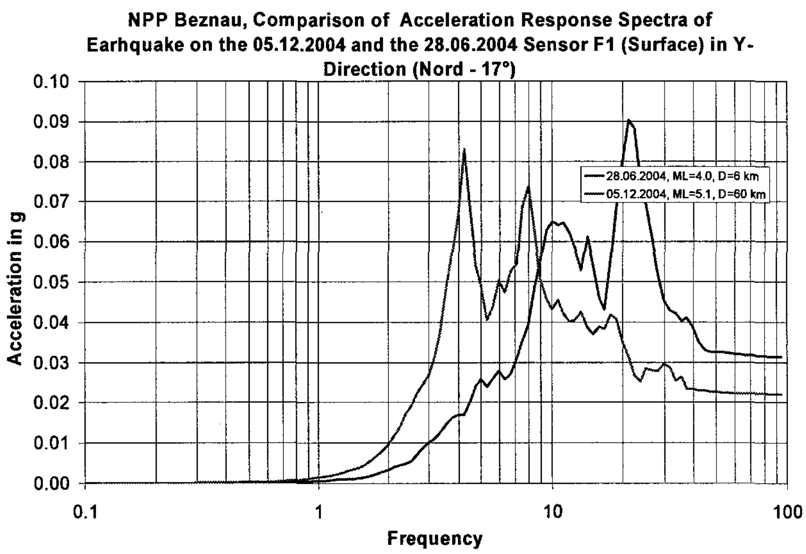


5% Damping

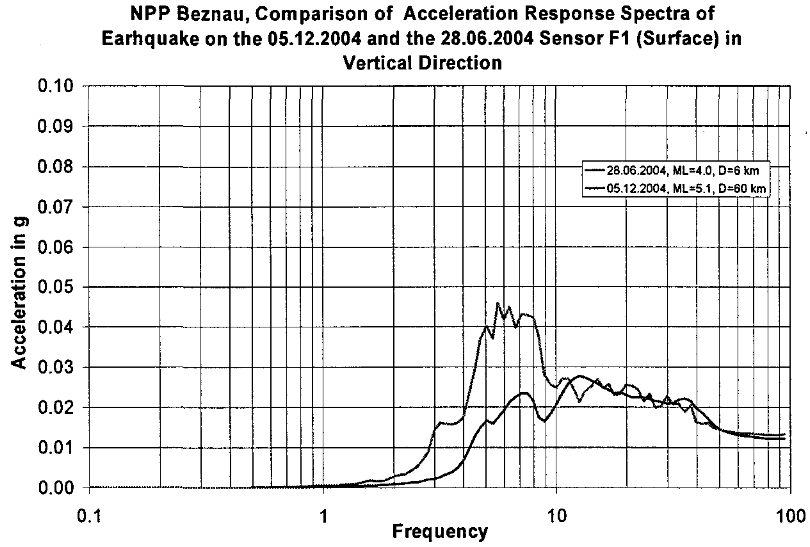
Site Specific Seismological Data



Site Specific Seismological Data



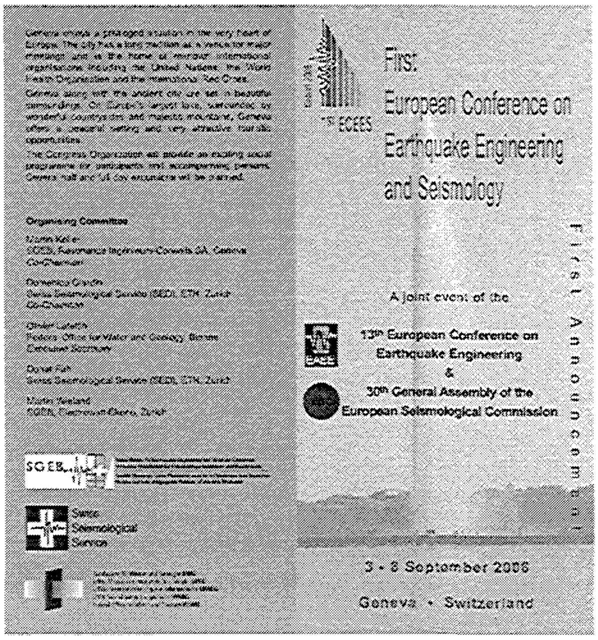
Site-Specific Seismological Data



Summary

- SSHAC-Level 4 Methodology is fully implemented in Site-Response Characterisation.
- PEGASOS geological and geotechnical site investigations fulfill the related IAEA Safety Standard No NS-G-3.3 with except for site specific seismological data.
- Geological and geotechnical database contain all available technical information and serve a basis for further investigations.
- The results of some additional site investigations are ambiguous. They do not help to reduce the uncertainties, on the contrary they increase uncertainties.
- The experts considered the uncertainty on the geological and geotechnical data using different shear-wave velocity profiles and multiple set of non-linear material properties.
- Each expert used different weights for each Vs-profile and non-linear material property set in his logic tree model.
- The RVT-Method with Soil Profile Randomization is an effective method for large amount of site response simulations. The chosen constraints for Soil Profile Randomization avoided physically unrealistic soil profiles.
- The large amount of epistemic uncertainty in soil hazard is caused by the uncertainty in the site specific geological and geotechnical data. This uncertainty can be reduced by appropriate site specific investigations.
- The treatment of aleatory variability is an unresolved issue in the probabilistic soil hazard evaluation.
- The solution for a realistic and physically more reliable site specific soil hazard evaluation will be a challenge for the involved technical community in the near future. The interaction between geoscientists, seismologists and engineers will lead a big contribution to solve this complex issue.

Join to the



References and Glossary

- NUREG/CR-6372, Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, Senior Seismic Hazard Committee, Main Report, April 1997
- PEGASOS- A Comprehensive Probabilistic Seismic Hazard Asessment for Nuclear Power Plants in Switzerland, Abrahamson N. et al, 12th European Conference on Earthquake Engineering
- IAEA, Safety Standard Series No. NS-G-3.3, 2002, Evaluation of Seismic Hazard for Nuclear Power Plants
- Fäh, D., Kind F., and D. Giardini, 2001, A theoretical investigation of average H/V ratios, Geophysical Journal Int., 145 535-549
- Silva, 1976, W.J. Body Waves in a Layered Anelastic Solid. Bull. Seismic Ass. Am. 66 (5) 1539 – 1554
- Jongmans D. , Demanet D.,1993, The importance of surface waves in vibration study and the use of Rayleigh waves for estimating the dynamic charesteristics of soils, Engineering Geology 105 -113
- Pecker Alain, 2004, An estimate of maximum ground surface motion for non.zero velocity, C.R: Mecanique 332 725- 730, www.sciendirect.com
- Pecker Alain, accept. for publ. 2004, Maximum Ground Surface Motion in Probablistic Seismic Hazard Analyses, Journal of Earthquake Engineering

References and Glossary (cont.)

- PEGASOS: **P**robabilistische **E**rdbeben-**G**efährdungs-**A**nalyse für KKW-**S**tand**O**rte in der **S**chweiz
- SSHAC: Senior Seismic Hazard Committee
- SED: **Sc**hweizerischer **E**rdbeben-**D**ienst (Swiss Seismological Service)
- SASW: Seismic Analysis fo Surface Waves
- RVT: Random Vibration Theory (Silva, 1972)
- SHAKE: A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits , Schnabel, Lysmer&Seed, 1972