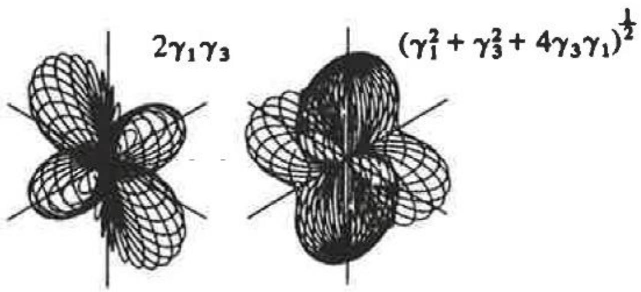


Modelling as a tool to augment ground motion data in regions of diffuse seismicity (AddGROUND)

Abstract: Ludovic Fülöp[1], Björn Lund[4]

Project group: Vilho Jussila[1], Jouni Saari[2], Peter Voss[3], Billy Fälth[4], Jari Puttonen[5], Pekka Heikkinen[6]

[1] VTT Technical Research Centre of Finland, [2] ÅF-Consult, [3] Geological Survey of Denmark and Greenland (GEUS), [4] Uppsala University, [5] Aalto University, [6] Helsinki University

12-13.01.2016 – Nordic perspectives of Fukushima: Where are we now and where do we go? Joint NKS-R and NKS-B Seminar, Stockholm

Outline

- Seismic studies with nuclear safety relevance
  - Probabilistic seismic hazard assessment (PSHA);
  - Structural vibration;
  - System and component (SSC's) qualification;
- Starting points for AddGROUND.
- Safety relevance of the research targets to NPP's
- Activity and results in AddGROUND
  - Seismic observations;
  - Modeling parameters and preliminary output;
- Conclusions / Discussion / How Fukushima is relevant

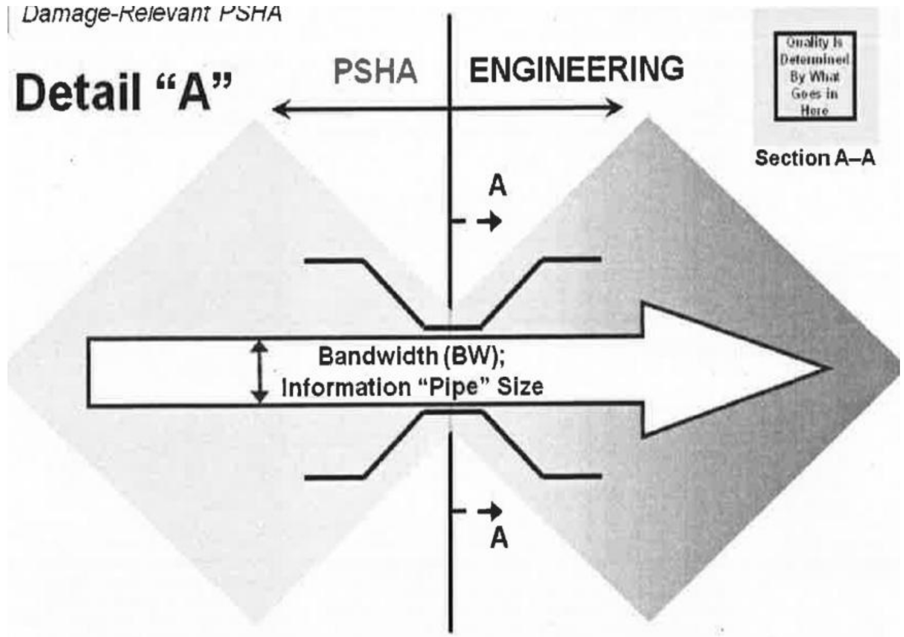
Seismic studies with nuclear safety relevance

Background & Safety relevance

- NPP's are in operational/planning/design phases & the repositories add another dimensions to the seismic safety challenge;

- R&D needs to create background for the seismic design of new-builds & maybe contribute to safety upgrade of existing plants;

- Multidisciplinary approach involving all aspects of seismic assessment:
  - evaluation of the hazard (PSHA),
  - safety of structures
  - qualification systems and components.



* Damage relevant PSHA: Communication bandwidth and quality at the ground motion to engineering interface, R. T. Sewell, OECD-NEA Workshop, Lyon, 8 April. 2008

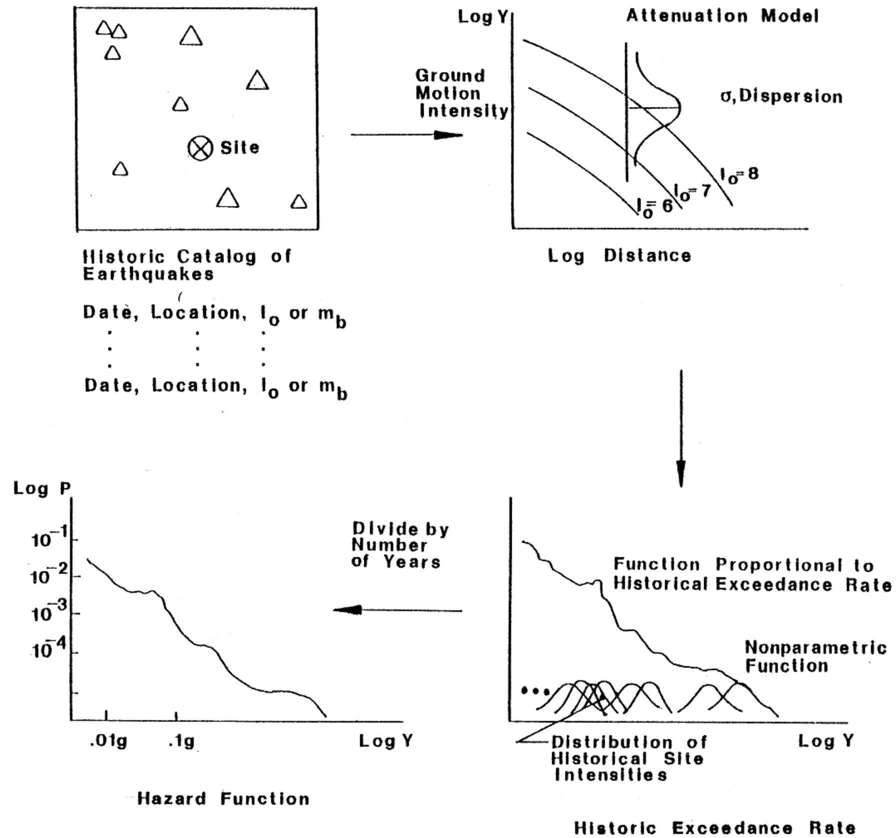
Probabilistic seismic hazard assessment (PSHA)

- **Methodology**

PSHA is a methodology of establishing the probability of an occurrence, by accounting the effects of continuous independent random variables affecting the event.

- **Benefit**

It is a rational way to estimate hazard. For surface infrastructure, the aim is to calculate the probability of exceedance of a ground motion level P[A]. The “occurrence” is the exceedance of a ground acceleration or spectral acceleration level, while the independent variables are earthquake size (I_o, m_b, M_w) and a distance measures.



$$P[A] = \iint P[A \mid s \text{ and } r]\, f_S(s)\, f_R(r)\, ds\, dr$$

* D. Veneziano, C. A. Cornell, and T. O’Hara, “Historical Method of Seismic Hazard. Analysis,” Electric Power Research Institute Report EPRI NP. 3438, 1984.

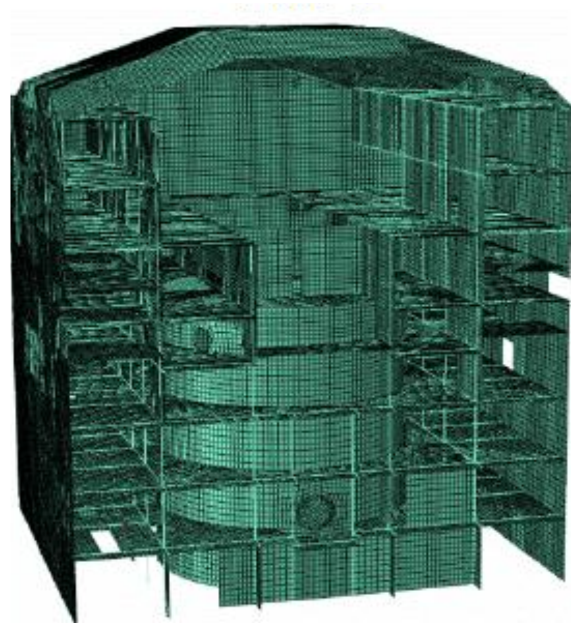
Structural vibration

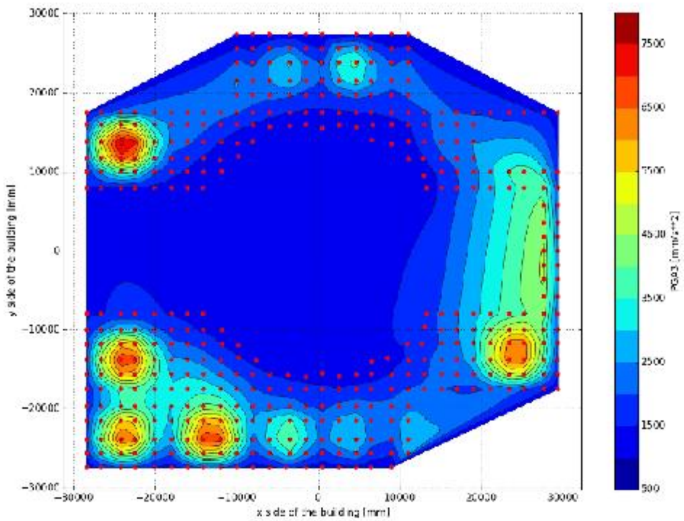
- **Methodology**

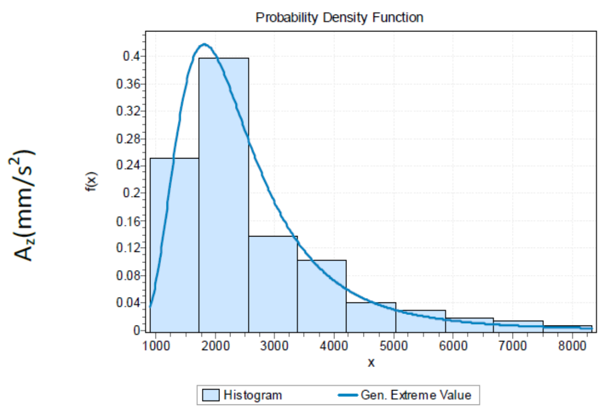
Dynamic modeling of complex structures. Automated extraction and synthesis of vibration data.

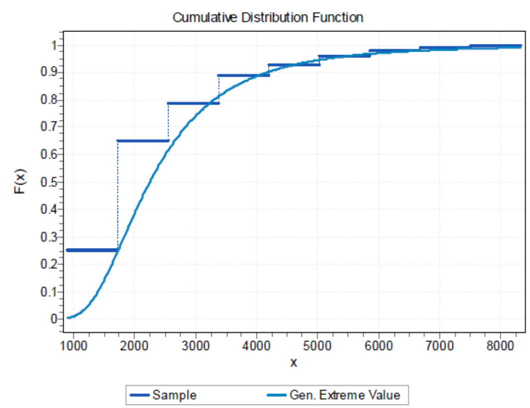
- **Benefit**

Rational way to qualify uncertainties essential for a PRA. Possibility to optimize equipment requirements by reducing qualification requirements. Savings potential because of reduced conservativeness on equipment side.









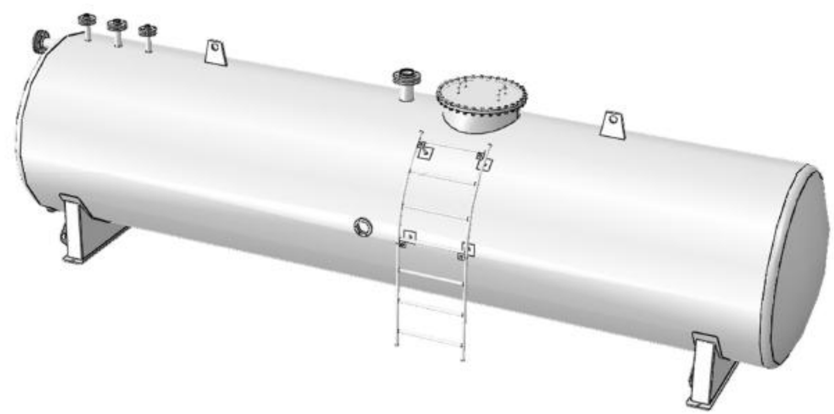
System and component (SSC's) qualification

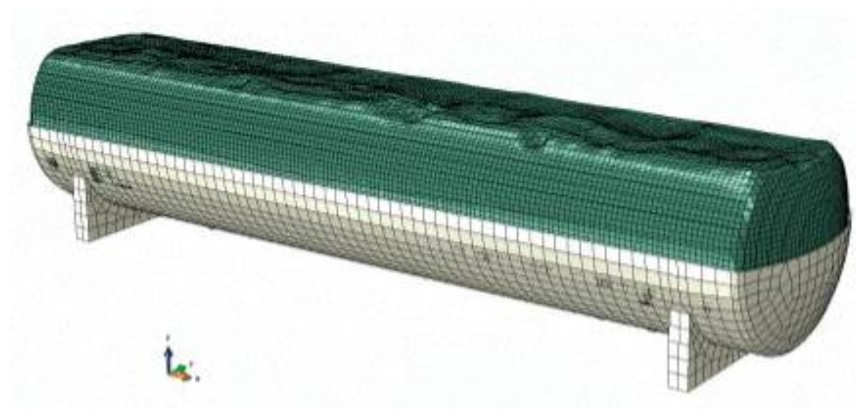
- **Methodology**

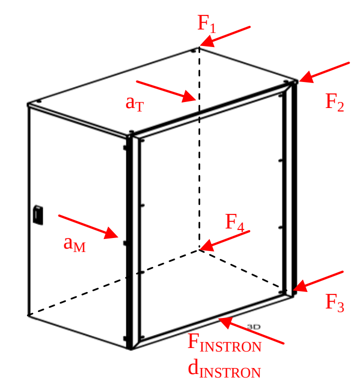
Qualification of equipment using international standards, covering aging effects and auxiliary loads. Qualification by analysis, testing, analysis & testing.

- **Benefit**

Full spectrum of qualification planning, sophisticated modeling, testing, reporting. Focus for export industry.



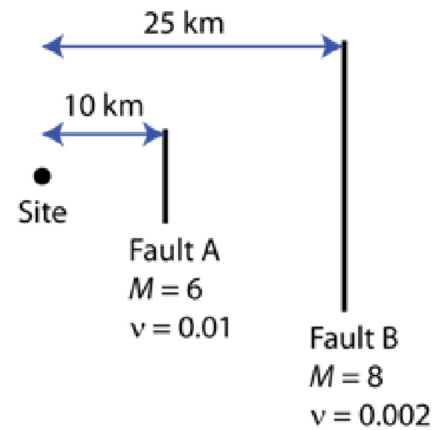




Starting points for AddGROUND

Principle of de-aggregation

- For multiple hazard sources, the resulting hazard estimate can be back-attributed to one or another source.
- In the example a nearby fault produces *M*=6 events (A) with higher annual occurrence rate (v=0.01), while the farther source M=8 events (B) with lower rate (v=0.002).



- Annual rate of exceedance of *Sa(1s)* is given with individual hazards for A and B. Small but frequent A causes exceedance of small *Sa's*; large and rarer B exceedance of large *Sa's.*

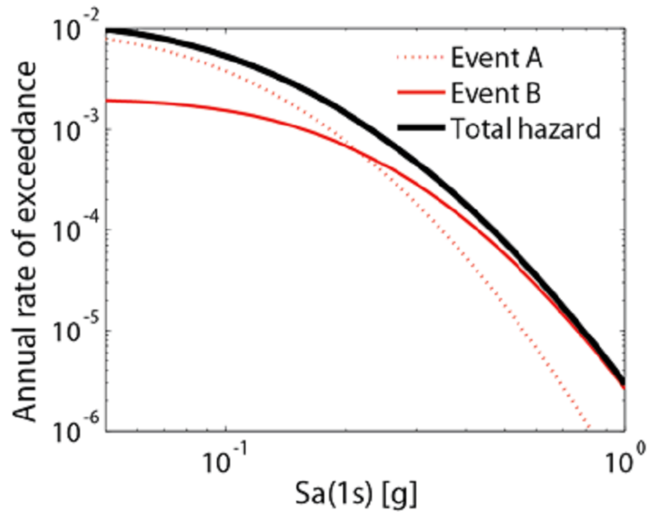
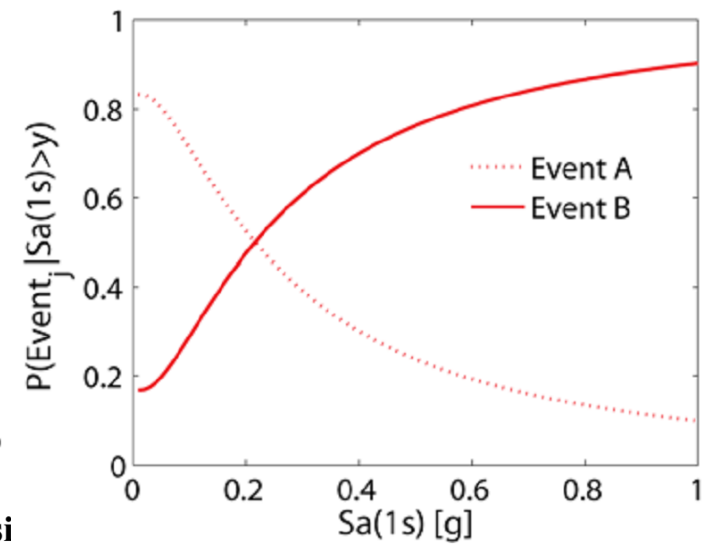


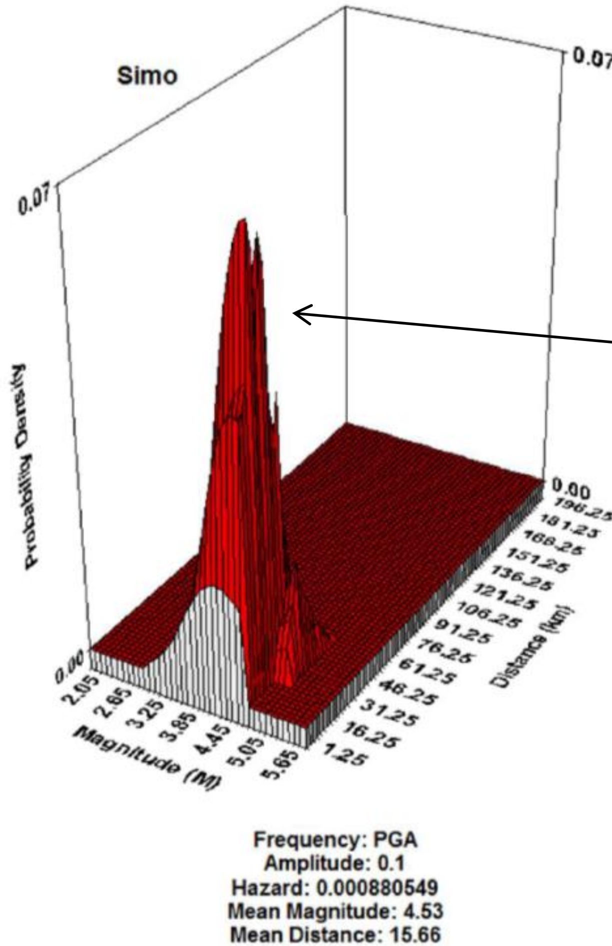
Figure 3. Hazard curves for the example si

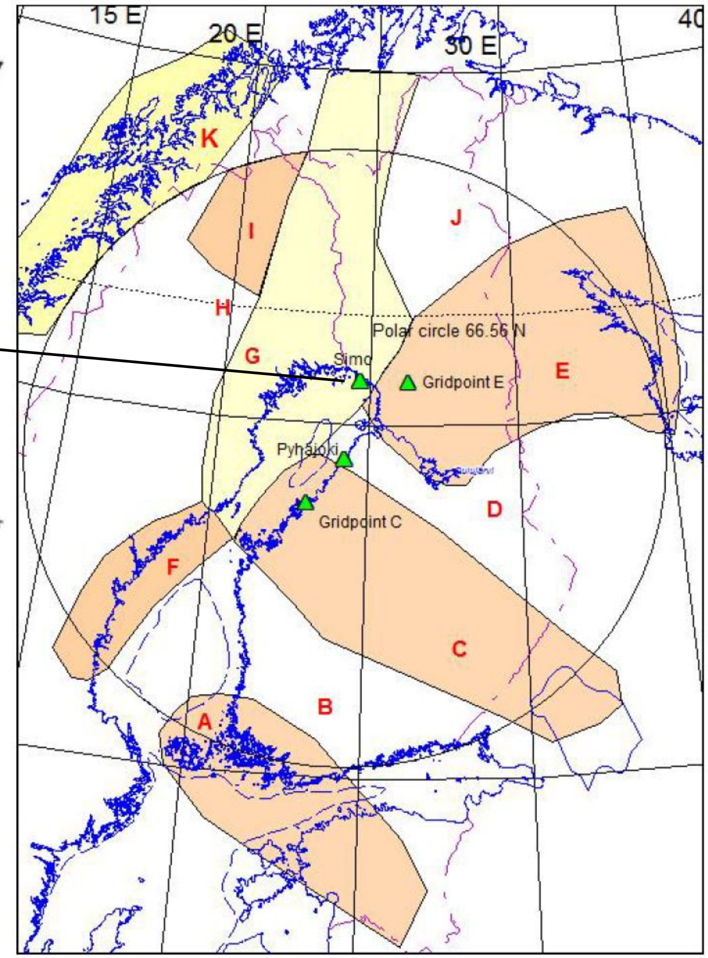


* T. Lin and J. Baker, "Probabilistic seismic hazard deaggregation of ground motion prediction models," in 5th International Conference on Earthquake Geotechnical Engineering, Santiago, Chile, 2011.

Dominating source of hazard from PSHA

- De-aggregation shows that vibrations of engineering/safety significance (0.05*g-0.1*g) are from earthquakes in the range of M=3-5.
- Hazard is most significant from earthquakes with the epicenter distance below D=40km.
- M_{max} was M_{max_obs}+0.5 for each source zone.



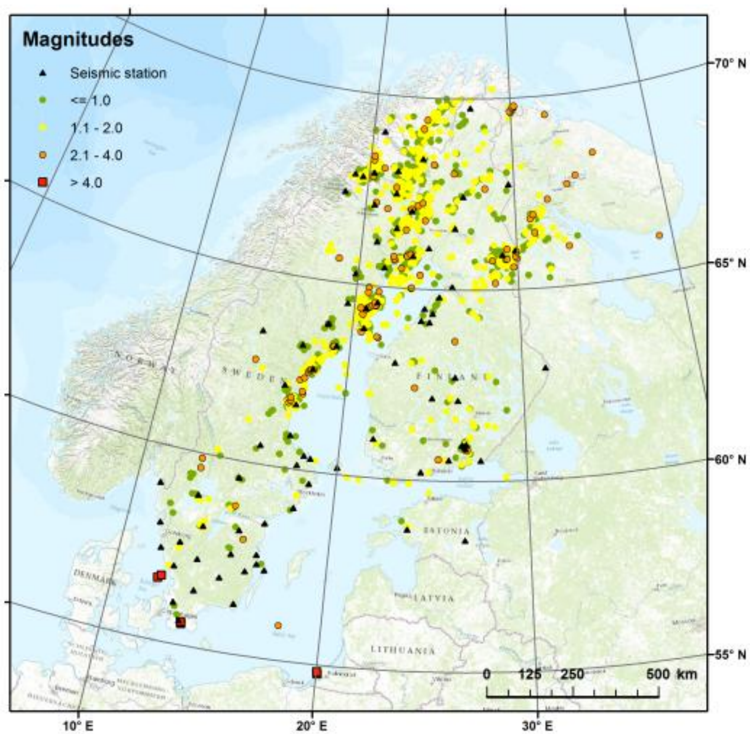


…ure 1-2 Belts of higher seismic activity (colored areas). Capital letters A … K refer to 11 …smic zones delineated (see Table 2-1). Calculated sites are marked with green triangles. …e source areas used in 2013 calculations were inside the 500 km circle around Pyhäjoki.

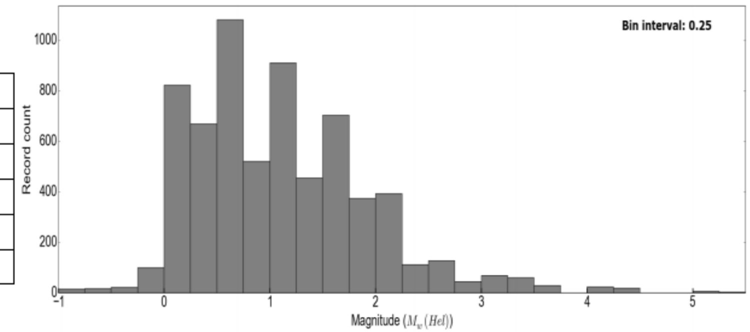
* M. Malm and J. Saari, "SESA, Subproject 1 - Earthquake Hazard Assessment, Progress Report 2014," ÅF-Consult Ltd, Research Report DSAF14R, Dec. 2014.

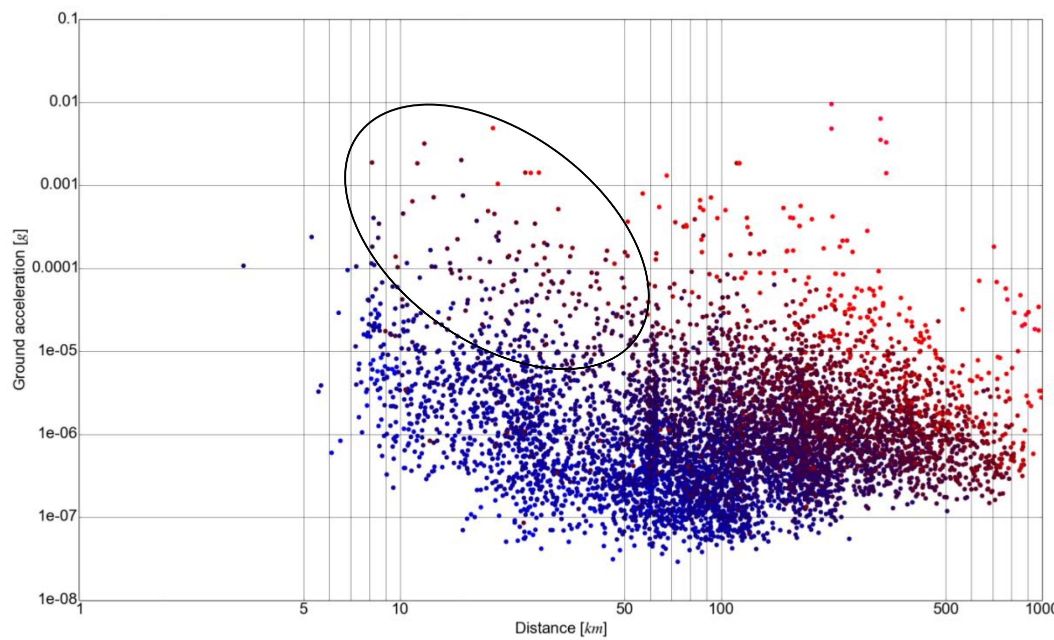
Few data points in the relevant M-D range

- Data underlying the recent GMPE for Fennoscandia* is better, but the available points for <30km is still limited for larger M's.



Recording stations	84
Events	1701
Recordings	6465
Magnitude range	$-1.0 \leq M_w(Hel) \leq 5.3$
Distance range	$0.0 \leq R \leq 991.7$ km
Depth range	$0.0 \leq d \leq 49.3$ km





The full ground motion database. The coloring describes the magnitude of the event that generated the recording with a gradient from blue for low magnitude to red for high magnitude.

* Tommi Vuorinen, *New Fennoscandian Ground Motion Characterization Models,* MSc thesis, University of Helsinki, Helsinki, Finland, 2015. This is an update compared to data in *Evaluating seismic hazard for the Hanhikivi nuclear power plant site. Seismological characteristics of the seismic source areas, attenuation of seismic signal, and probabilistic analysis of seismic hazard* (Saari et al., 2015)

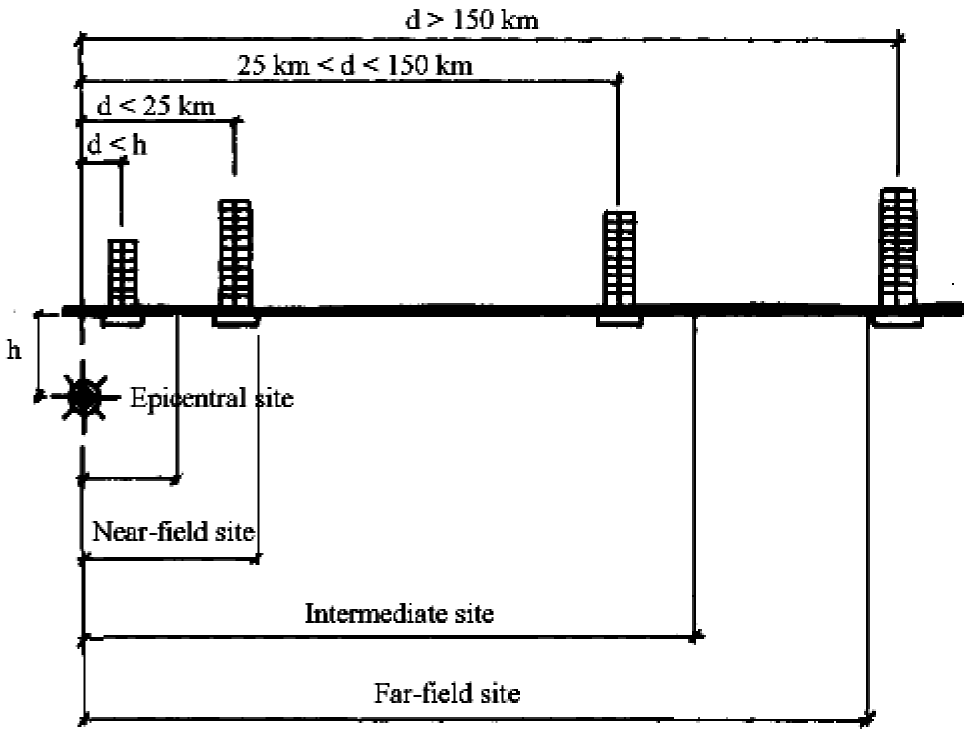
The purpose of ADDGROUND is to…

- Maintain a workgroup at the seismology/engineering interface. This role in Finland was maintained by the SAFIT2014/SESA project between 2010-2014.
- Create a Nordic Cooperation group on seismic safety. Because of the seismo-tectonic similarities this cooperation is natural and essential.
- Because of the data scarcity underpinning the significant contributor region to the hazard on NPP plants (the near-source region), attempt to create synthetic data for this region based on modeling of the fault and propagation path.
- Fault modeling has been developed in the repository framework (SKB/POSIVA) using rock-mechanics principles, which knowledge exploit in AddGROUND.

Safety relevance to structure design

The engineering near-field have particular features

- Classification of sites from earthquake engineering point of view:

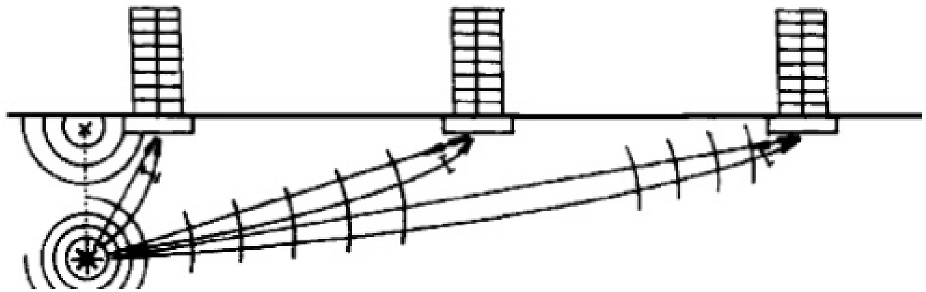


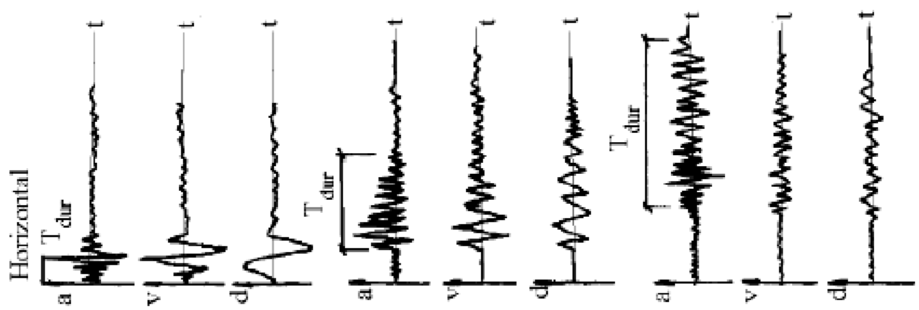
- Significant duration is reduced;
- Higher-frequency shaking is present;
- Vertical shaking components may be more significant than horizontal components;
- Loading is not in repeated shaking cycles, but high velocity pulses;

* V. Gioncu, F. Mazzolani, Earthquake Engineering for Structural Design, 2010

Effect on duration

- Propagation-path increases duration. Records in near-source sites are shorter. Duration estimates for M>4 after Trifunac and Brandy (1975).
- Strong motion duration is the key factor affecting damage potential of earthquakes, especially for ductile systems.

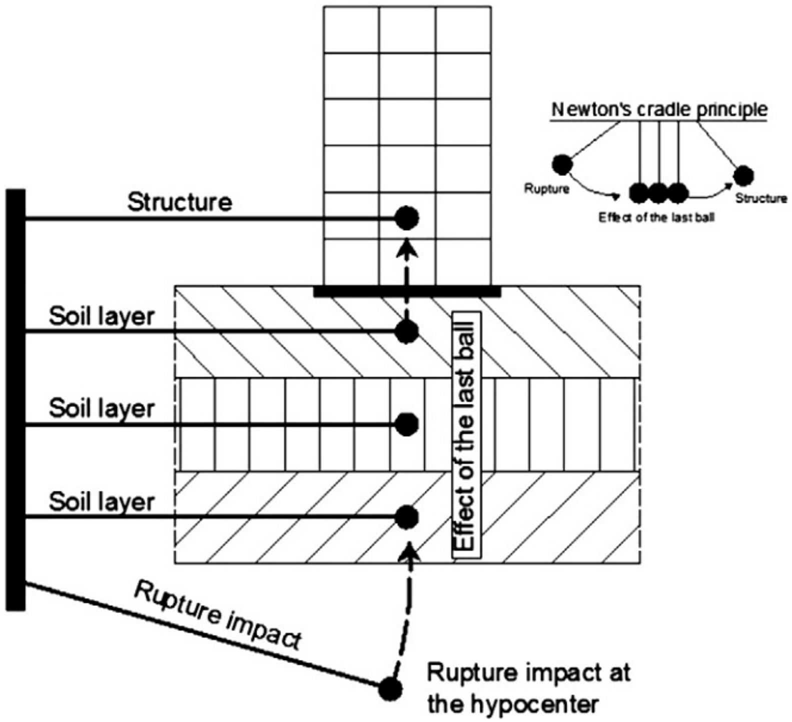




* V. Gioncu, F. Mazzolani, Earthquake Engineering for Structural Design, 2010

Ratio of vertical to horizontal accelerations

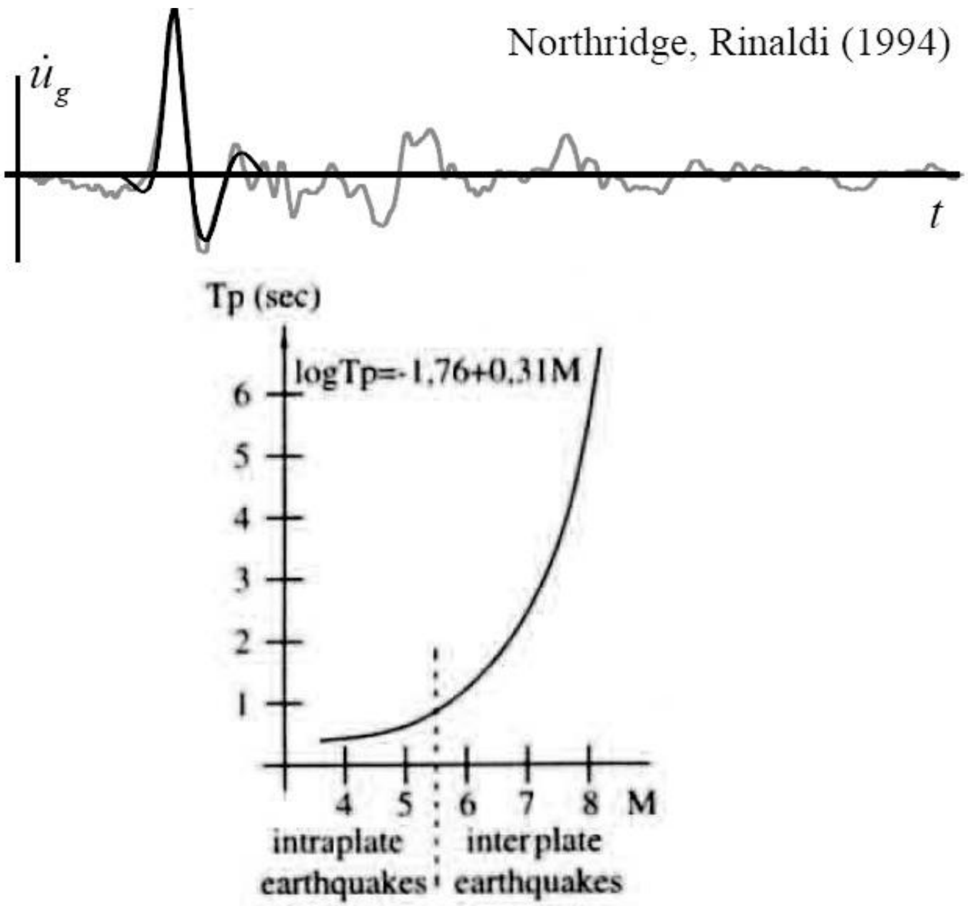
- <u>Vertical accelerations</u> may be larger than horizontal accelerations due to effect of last ball and direct propagation of P-waves.



Ashiyahama apartment building (Kobe). Brittle fracture of steel box-section columns in a modern 51 buildings, situated on the fracture line.

* V. Gioncu, M. Mosoarca, and A. Anastasiadis, "Local ductility of steel elements under near-field earthquake loading," *Journal of Constructional Steel Research*, vol. 101, pp. 33–52, Oct. 2014.

Velocity peak amplitude and duration

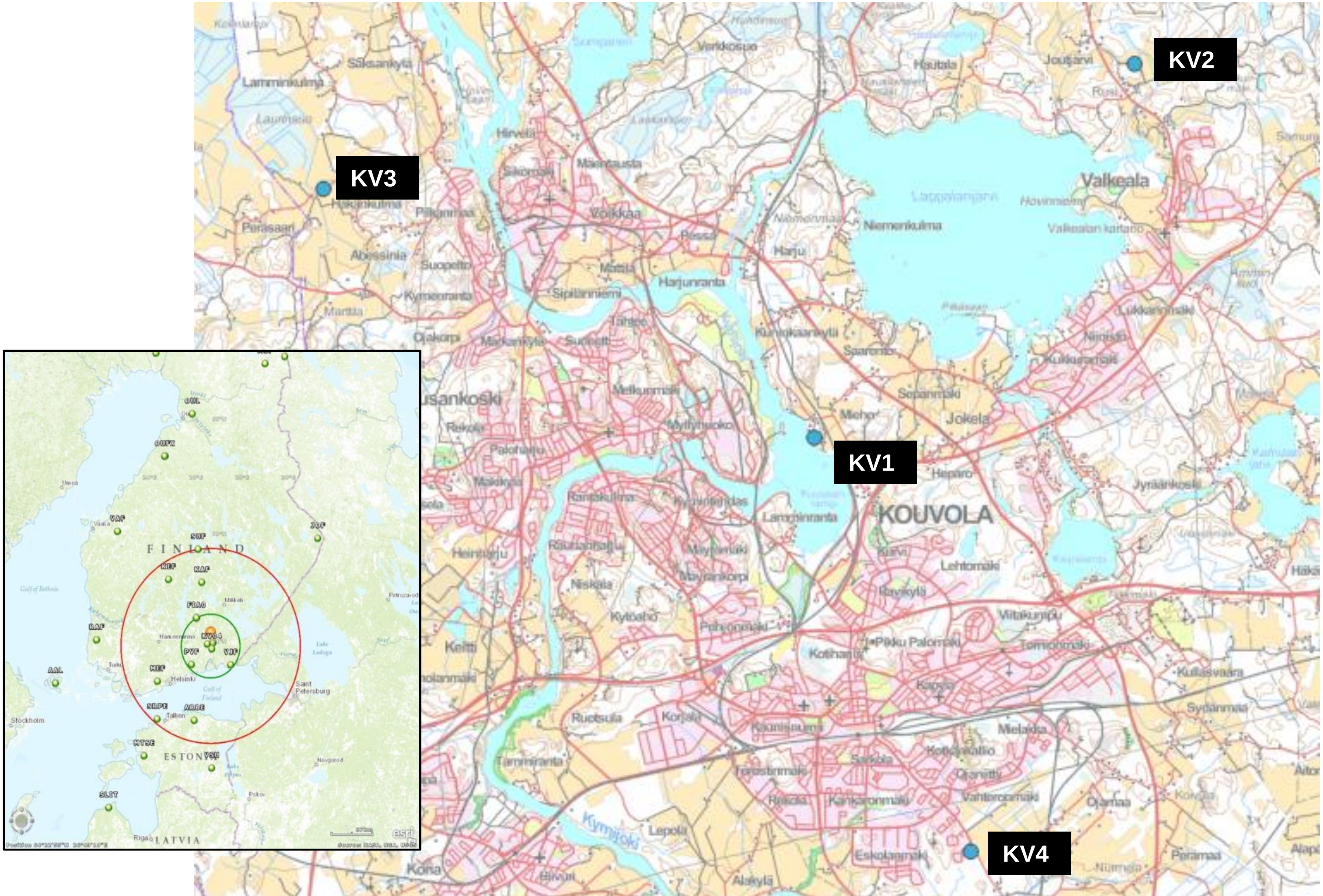


* Pulse periods vs. magnitudes proposal by (Gyorgyi et al, 2006)

- In near-source areas one main feature of GM is the long-pulse pattern of velocity records. Generally, these pulses are around 1-2 sec for larger events.
- Definition of significant pulses, number of significant pulses and analytical models for velocity pulses Alavi and Krawinkler (2000), Mateescu and Gioncu (2000) etc. are developed.

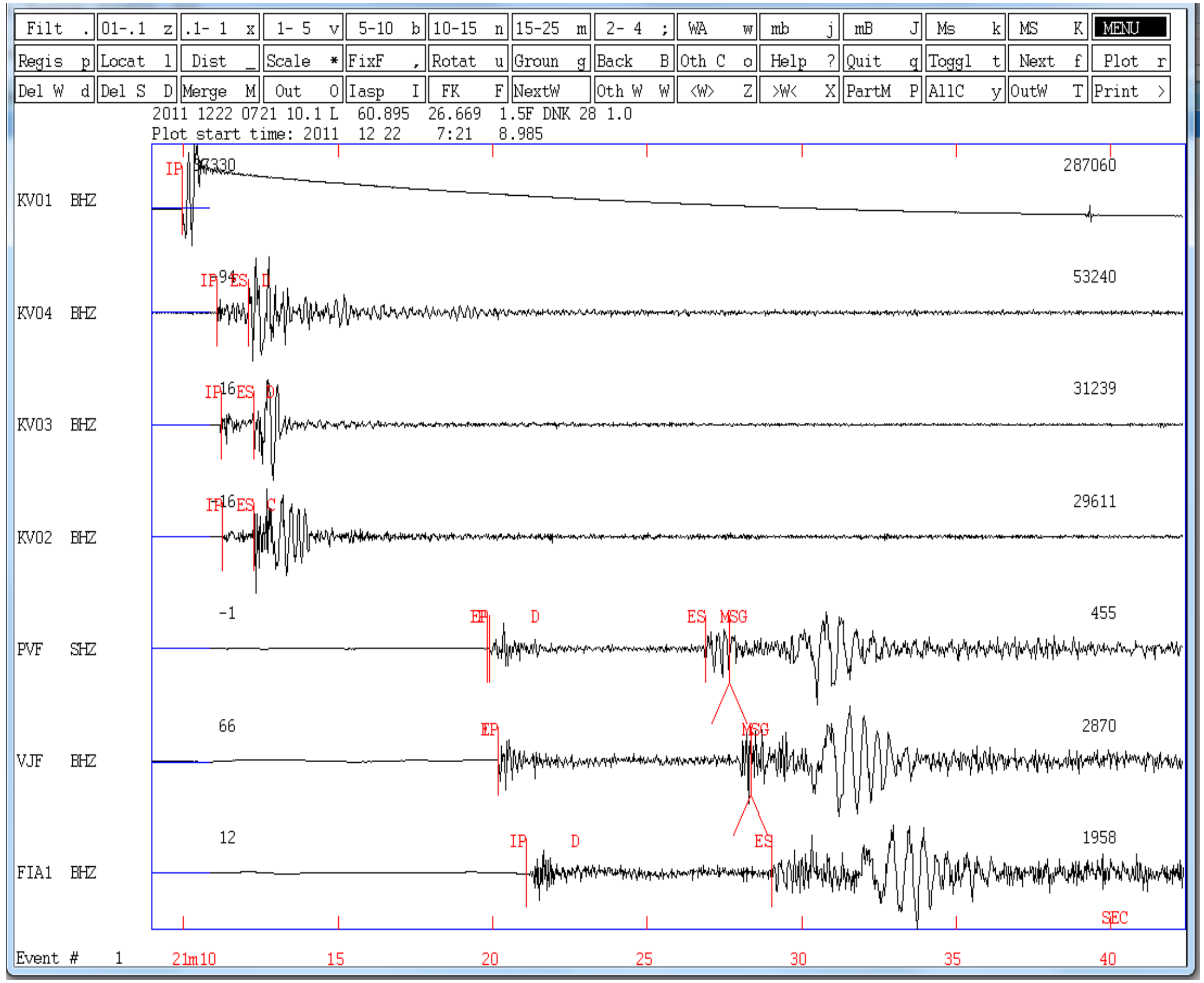
Progress in AddGROUND: Seismic observations.

Data on swarm 2012 (highest magnitude M_L 2.6)

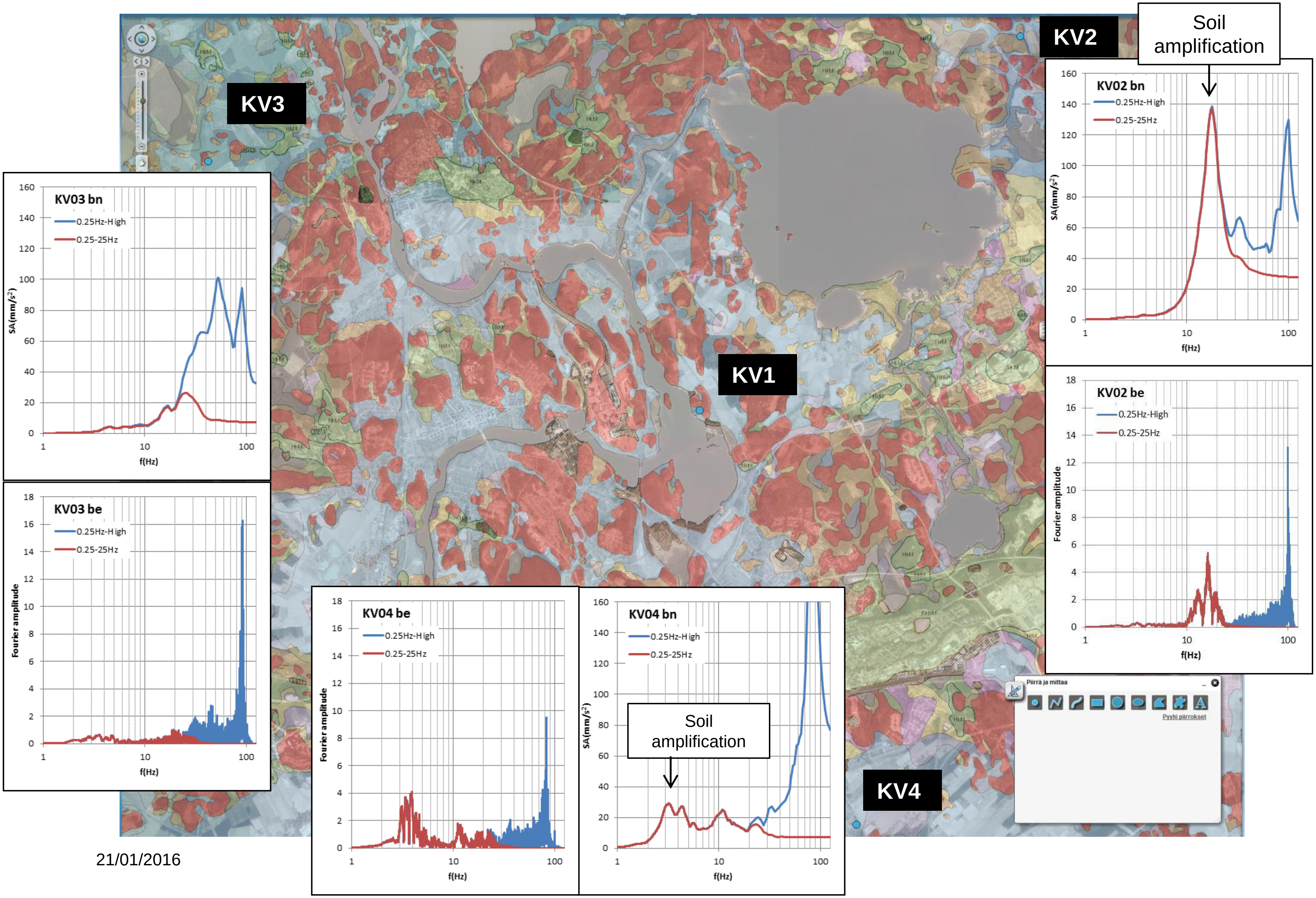


Data analysis in SEISAN

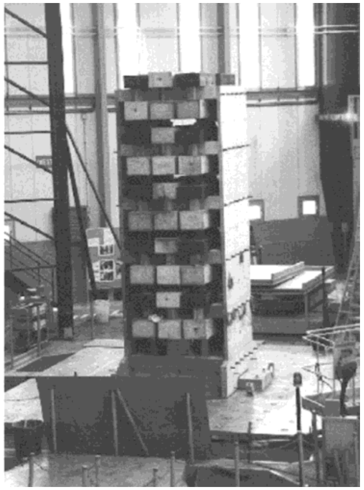
- All stations are used for:
  - for location, FPS;
  - but not correct D/V/A, magnitudes;
- KV stations re-imported from SEED files. They have correct D/V/A.
- Example Z components from nearby temporary KV stations, and stations of the general network (PVF, VJF, FIA1).
- KV01 hard to interpret. P and S waves overlapping.

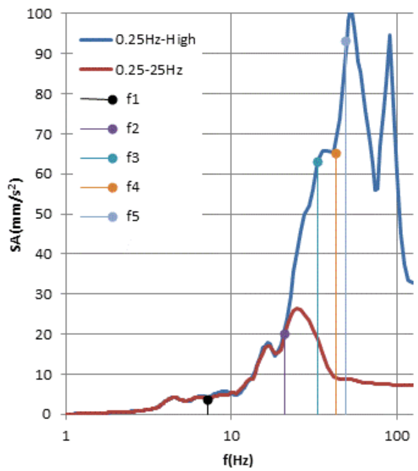


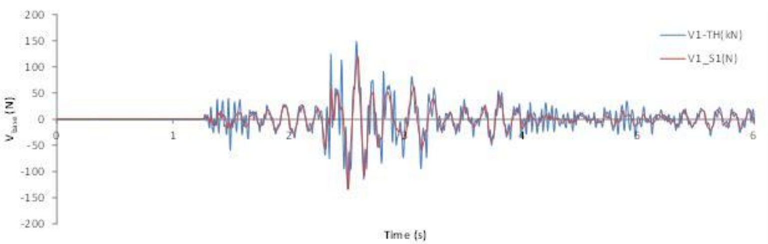
PSA response spectra (M_L2.6)



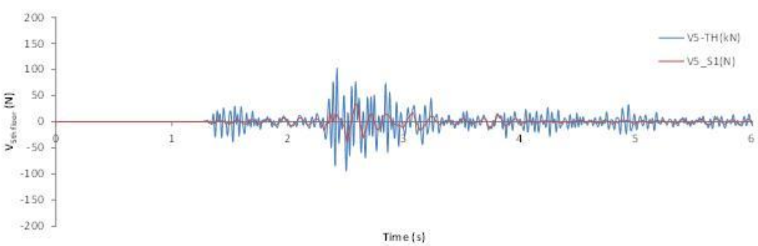
Safety significance for NPP’s







Base force from time-history analysis (blue) and 1st mode contribution (red)

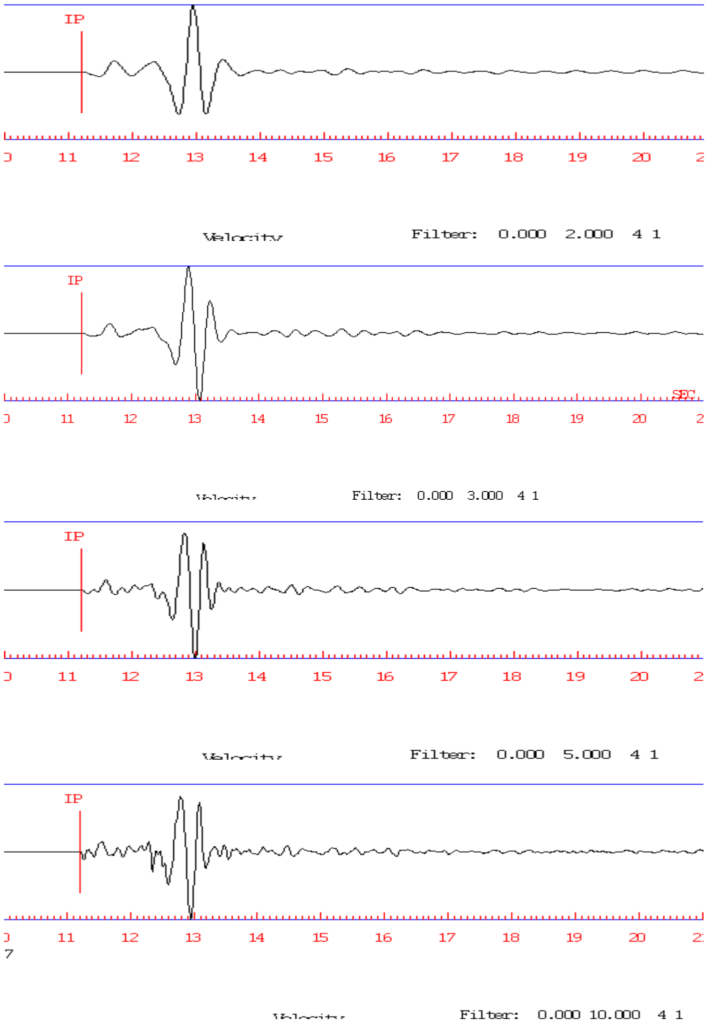


5th floor shear force from time-history analysis (blue) and 1st mode contribution (red)

- Same 5 floor shear building as studied in IAEA/JRC, but with emphasized on contribution from high frequencies.
- Conclusions agree. Base shear, top displacement are not increased by NF, only local responses.
- Labbe (2011) argues for review of design to deal with high frequency inputs – “*The conventional NPP approach was established in order to deal with low frequency input motions on stiff buildings, i.e. situations before the recording of high frequency ground input motions.”*

* P. Labbé and A. Altinyollar, “Conclusions of an IAEA–JRC research project on the safety significance of near-field seismic motions,” Nuclear Engineering and Design, vol. 241, no. 5, pp. 1842–1856, May 2011.

KV station velocity-pulse characteristics



- At the KV03 stations, on rock the velocity-pulse characteristics of the signal can be observed.
- The velocity signal is characterized by few pulses. The main features of the signal are contained in up to 3-5Hz.
- High velocity loading is responsible for some building damage observed in near-field earthquakes (Gioncu *et al.* 2014) .

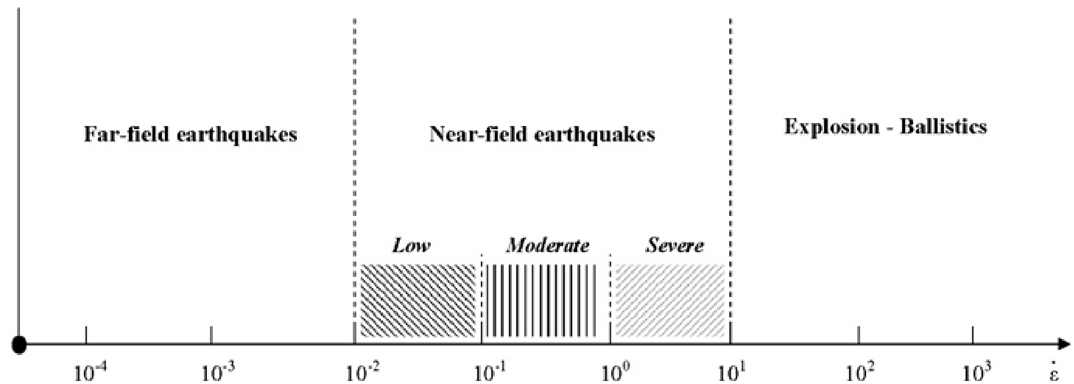


Fig. 7. Strain rate effects and dynamic actions.

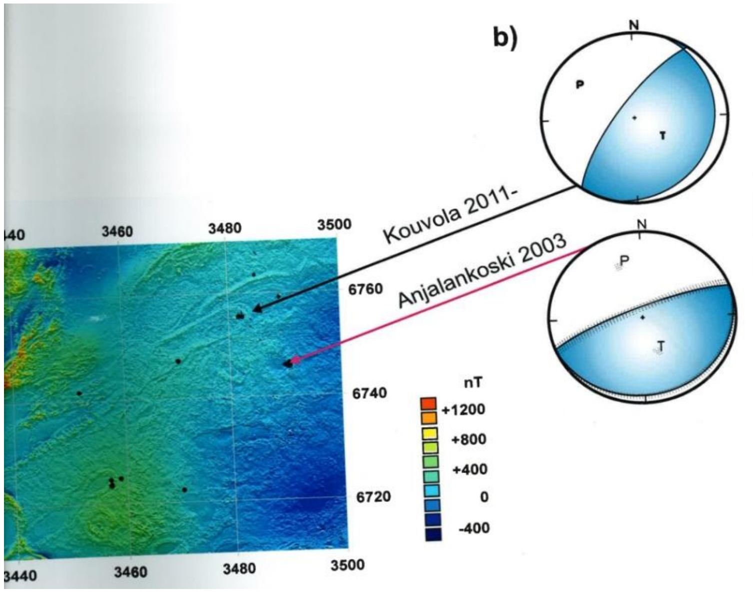
* V. Gioncu, M. Mosoarca, and A. Anastasiadis, “Local ductility of steel elements under near-field earthquake loading,” Journal of Constructional Steel Research, vol. 101, pp. 33–52, Oct. 2014.

Progress in AddGROUND: Modeling parameters and preliminary output.

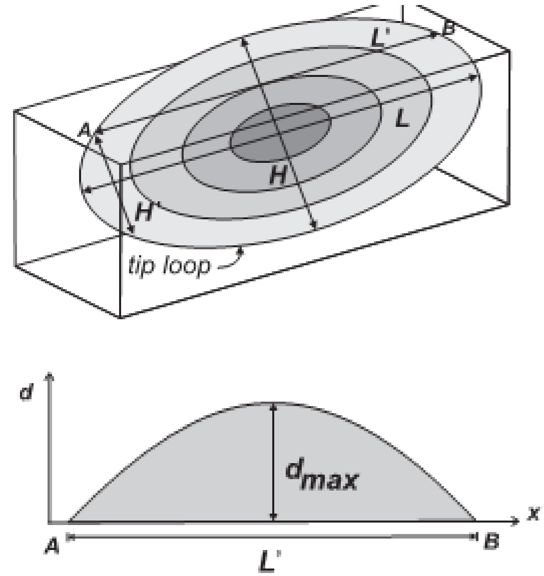
Summary of modeling inputs – in COMPSYN

- Fault area 60x60m…200x200m. Experiment with larger area smaller displacement, smaller area larger displacements – keeping constant M_w (M_w estimate is M_w=2.32);
- Fault plane solution STR=216º, DIP=75º, RAK=95º;
- Slip rate 0.005-0.04s;
- Earth model slight adaptation of the one received from the Institute of Seismology.

Fault plane solution (FPS) and fault size/slip and



Composite from strongest events:
STR=216º, DIP=75º , RAK=95º



L=H~50…200m, d_{max}~0.003…0.05m

A. Korja and E. Kosonen, "Seisotronic Framework and Seismic Source Area in Fenniscandia, Northern Europe," Institute of Seismology, University of Helsinki, Helsinki, Finland, REPORT S - 63, 2015.

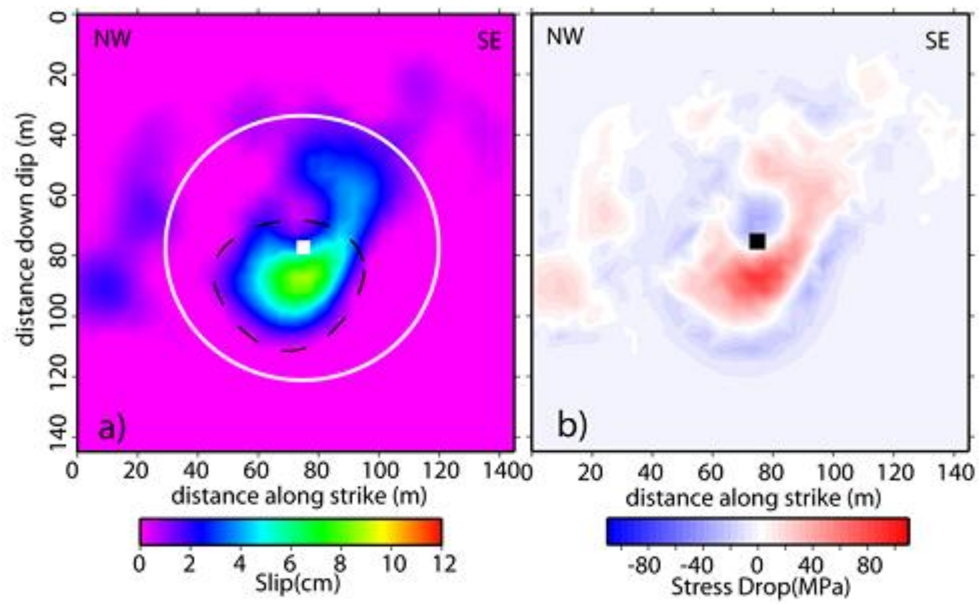
Y.-S. Kim and D. J. Sanderson, "The relationship between displacement and length of faults: a review," *Earth-Science Reviews*, vol. 68, no. 3–4, pp. 317–334, Jan. 2005.

Fault slip is more complex

- Situation more complicated concerning fault slip. Strong asperities concentrate the stress drop and slip is on smaller area.
- This is relevant for repository modeling and also to emphasize directivity effects, but fault is modelled simply in AddGROUND.

Table 1. Repeating Event Hypocenter Information[a]

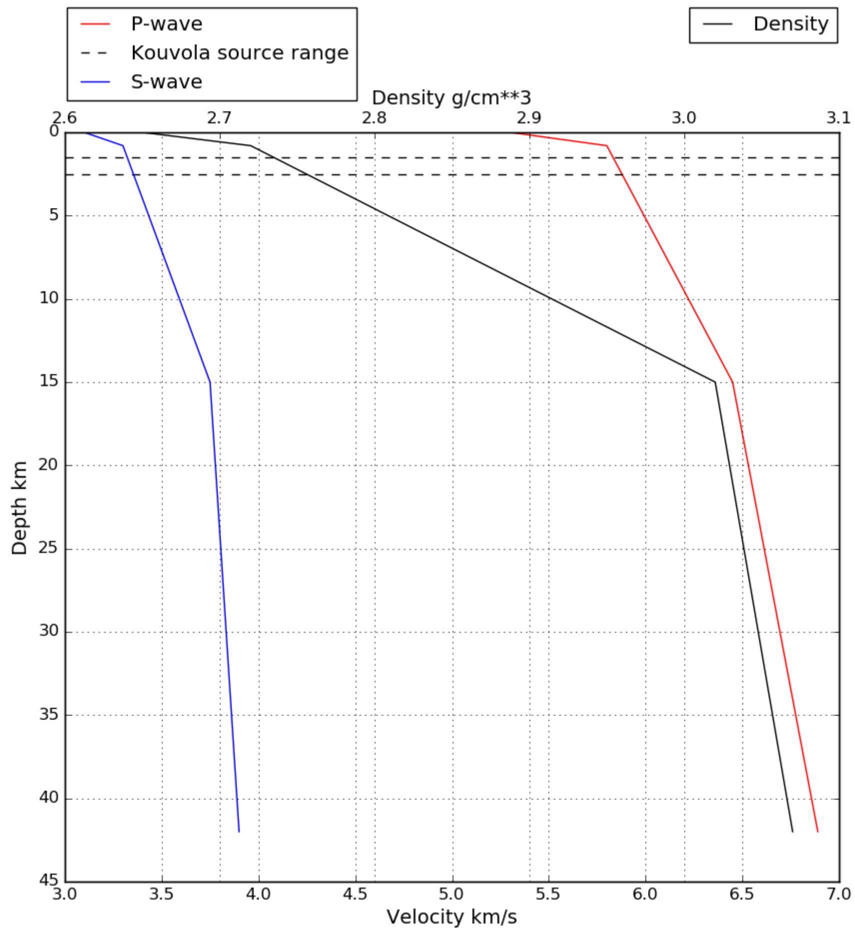
Event Id	Yr.dyr.hr:mn:s	Latitude	Longitude	Depth, km	Mw
EVT1	2003.293.11:25:43.11	35.981002	120.546769	2.073	2.10
EVT2	2004.274.04:36:42.05	35.980977	120.546777	2.071	2.04
EVT3	2004.343.07:16:45.99	35.980977	120.546777	2.072	2.08
EVT4	2005.197.03:33:09.54	35.980994	120.546769	2.072	2.06
EVT5	2006.306.01:40:23.04	35.980990	120.546769	2.072	2.10
EGF	2005.162.05:53:54.96	35.980908	120.546729	2.076	0.68



D. Dreger, R. M. Nadeau, and A. Chung, “Repeating earthquake finite source models: Strong asperities revealed on the San Andreas Fault,” Geophys. Res. Lett., vol. 34, no. 23, p. L23302, Dec. 2007.

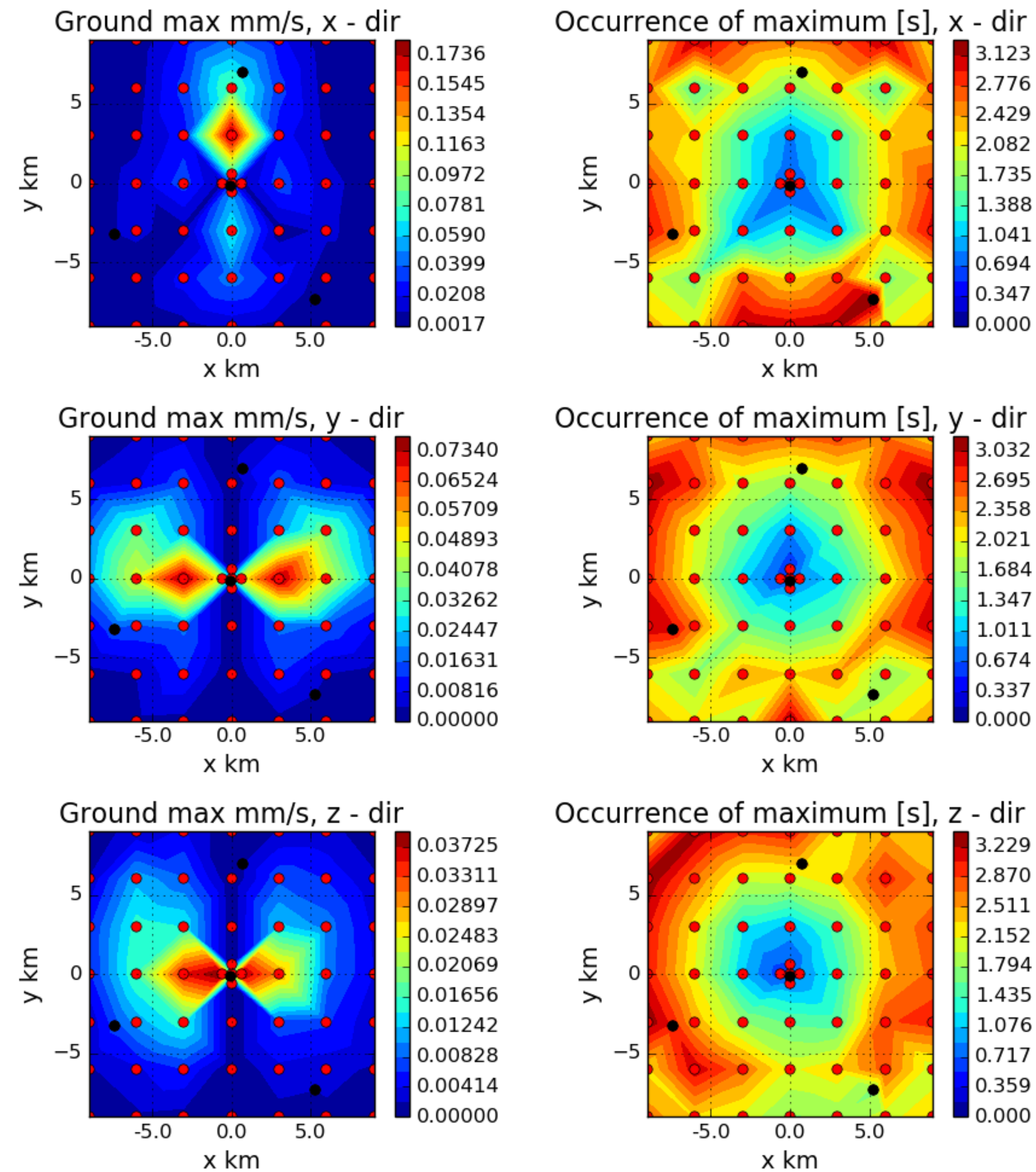
Kouvola 1D earth model

- Density, P and S wave values suggested at depth 0.0 and 0.8 km by Kai Front;
- P and S wave velocities at depth 15 and 42 km by Institute pf Seismology, Finland;
- Density at 15 km was assumed to be 0.3 g/cm**3 larger than at 0.8 km;



Maximum velocities test model 9

- Dip 59 degree from vertical;
- 61 observers
- Fault at 1.4-1.6 km in depth;
- Strike plane width 0.2 km
- Velocities are absolute maximums;
- Including Kouvola stations;
- Modified example source model;



Conclusions

- The measurement data from the engineering near-field in Fennoscandia is limited, and will remain so due to low activity of the region and scarce network. Modeling is the only option to increase understanding of this region.

- Shaking characteristics are available from small magnitude measurements. These observations conform to known effects:
  - High and very high frequency input is present;
  - Significant duration of the motion is reduced;
  - Pulse-like loading is observed;
  - … but careful separation of the soil effects is necessary (not an issue with NPP plants as they are founded on the base-rock);

- These shaking characteristics activate higher modes of vibration, send high frequency shaking in the SSC's and load structures with high velocity pulses. Reduce the efficiency of damping, since the consist of few pulses.

Conclusions

- Global response is not activated by high-frequency content, and global damaging potential of the NF earthquakes is low. They may affect equipment qualification.

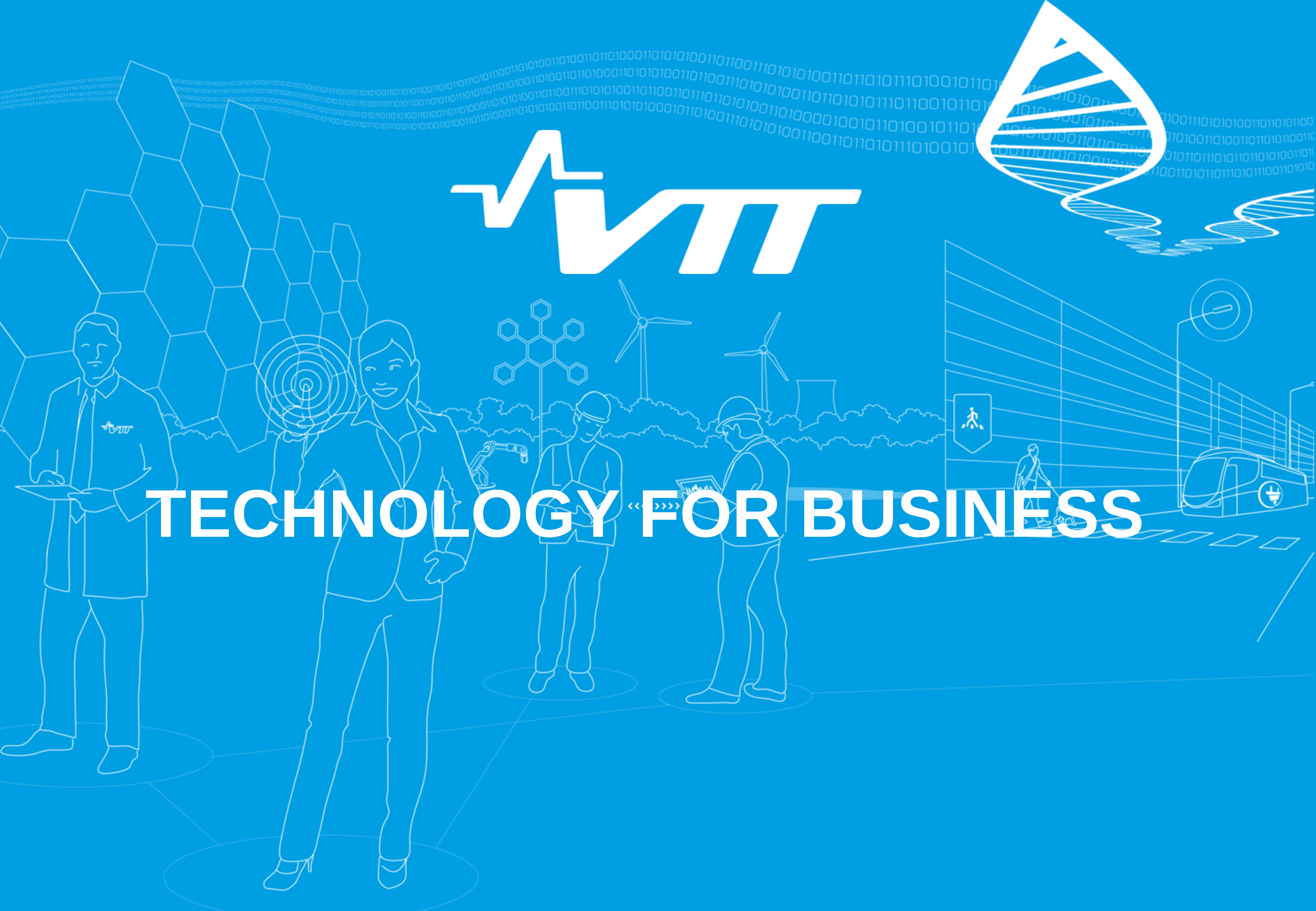
- The consequence of high-velocity loading was studied in the context of ordinary buildings. The main effects are increasing strength, reducing/eliminating ductility and turning failures into fragile fractures. These may not be so significant for NPP’s because SSC’s are designed for strength. But the topic is worth looking at.

- Modeling some of the features of the shaking of the engineering near-field is possible – i.e. the main velocity pulses. But there are serious challenges for high-frequencies.

How Fukushima is relevant

- While closely following the Fukushima accident, it is clear that few if any technical lessons may be applicable in Fennoscandia, one of the most stable, low seismicity continental regions.
- However, it is correct decision to dedicate resources to high-impact low-probability events like earthquakes, even in Fennoscandia. Especially since the low likelihood of occurrence leaves societies under-prepared, while even minimal mitigating actions would result in important improvements.
- Also, it is imperative to maintain integration at the interfaces between disciplines, because "*what seismologists provide may differ from what engineers really need for seismic design**". It is needed to maintain an understanding of the methods in the connected disciplines in order to ensure that the information transferred is retaining safety relevant features. We organized two Workshops for this purpose in 2015.

* Z. Wang, "Understanding Seismic Hazard and Risk: a gap between engineers and seismologists," in *Proceedings of the Fourteenth World Conference on Earthquake Engineering, China, 2008*, Beijing, China, 2008.


TECHNOLOGY FOR BUSINESS