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Seismic Hazard in Asia

4 - 8 December 2006

Neodeterministic Hazard Assessment

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NEODETERMINISTIC SEISMIC HAZARD ASSESSMENT

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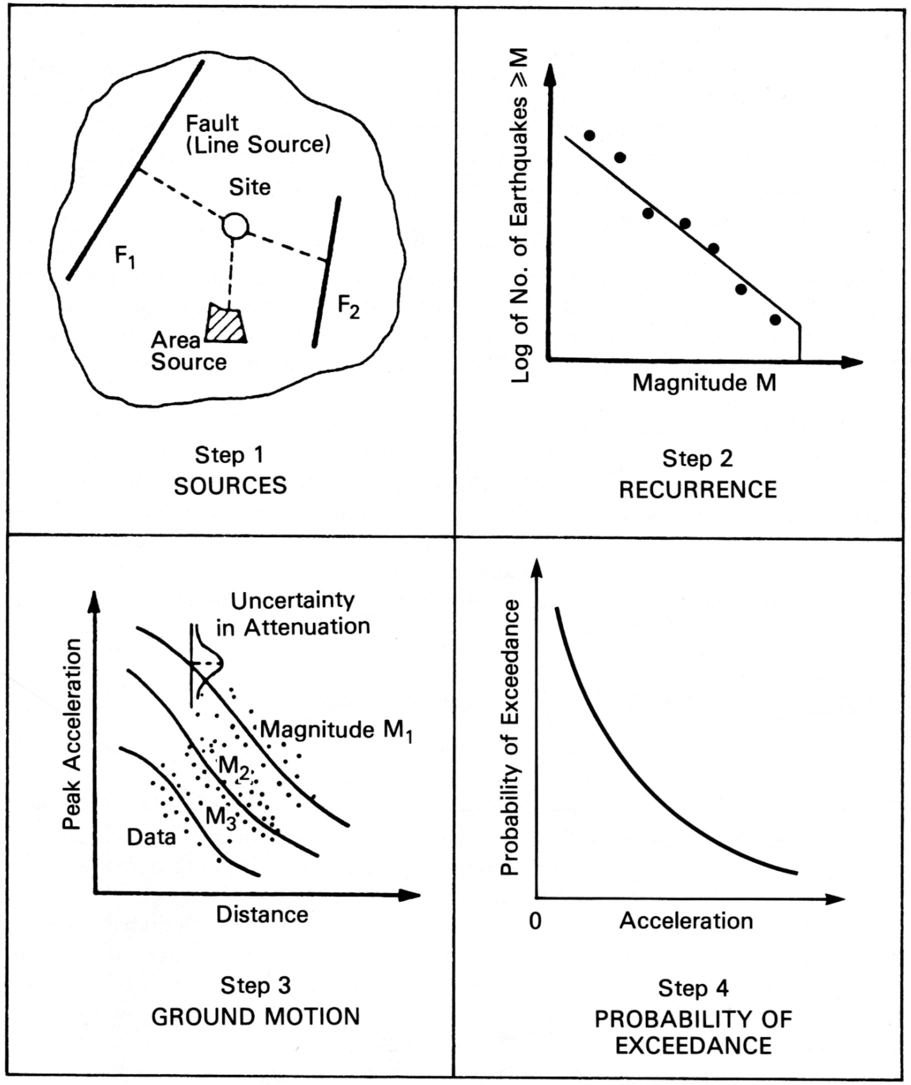

FIGURE 10.2 Basic steps of probabilistic seismic hazard analysis (after TERA Corporation 1978).

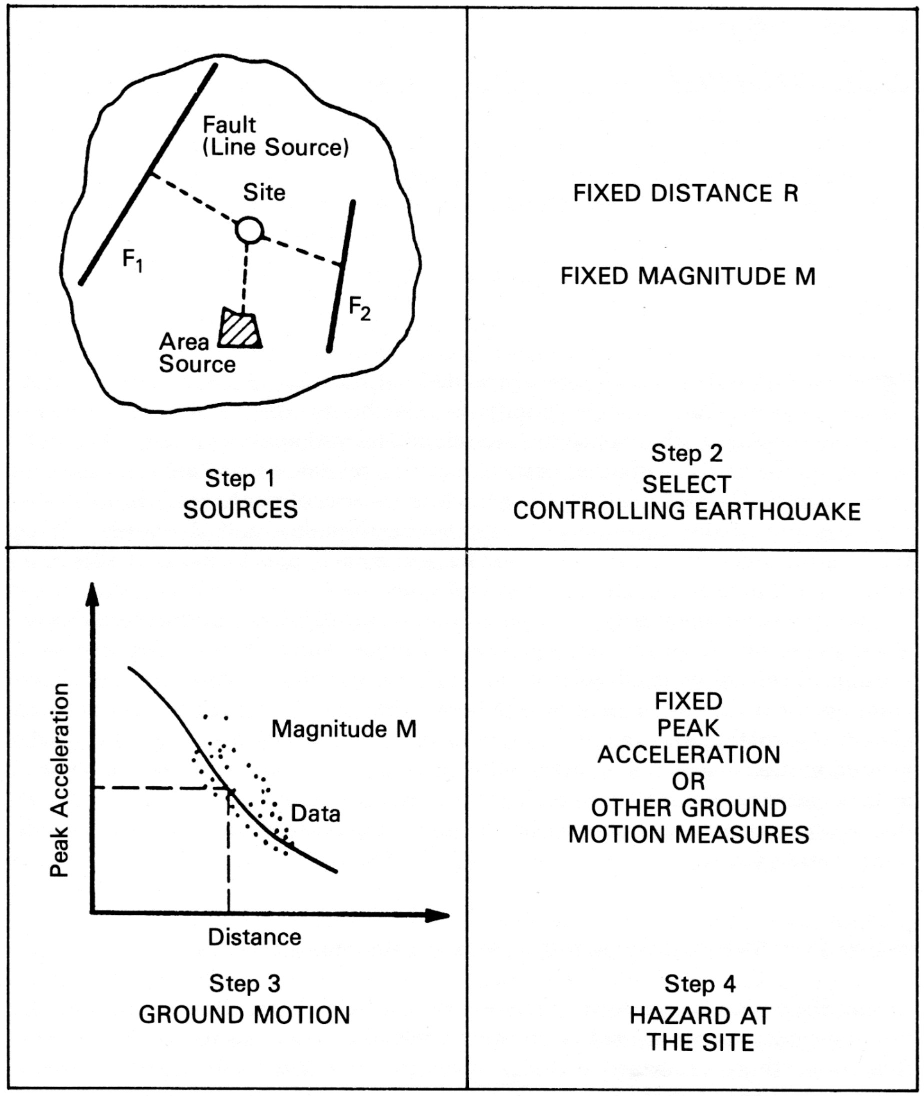

FIGURE 4.1 Basic steps of deterministic seismic hazard analysis (after TERA Corporation 1978).

Probabilistic and Deterministic procedures after Reiter (1990)

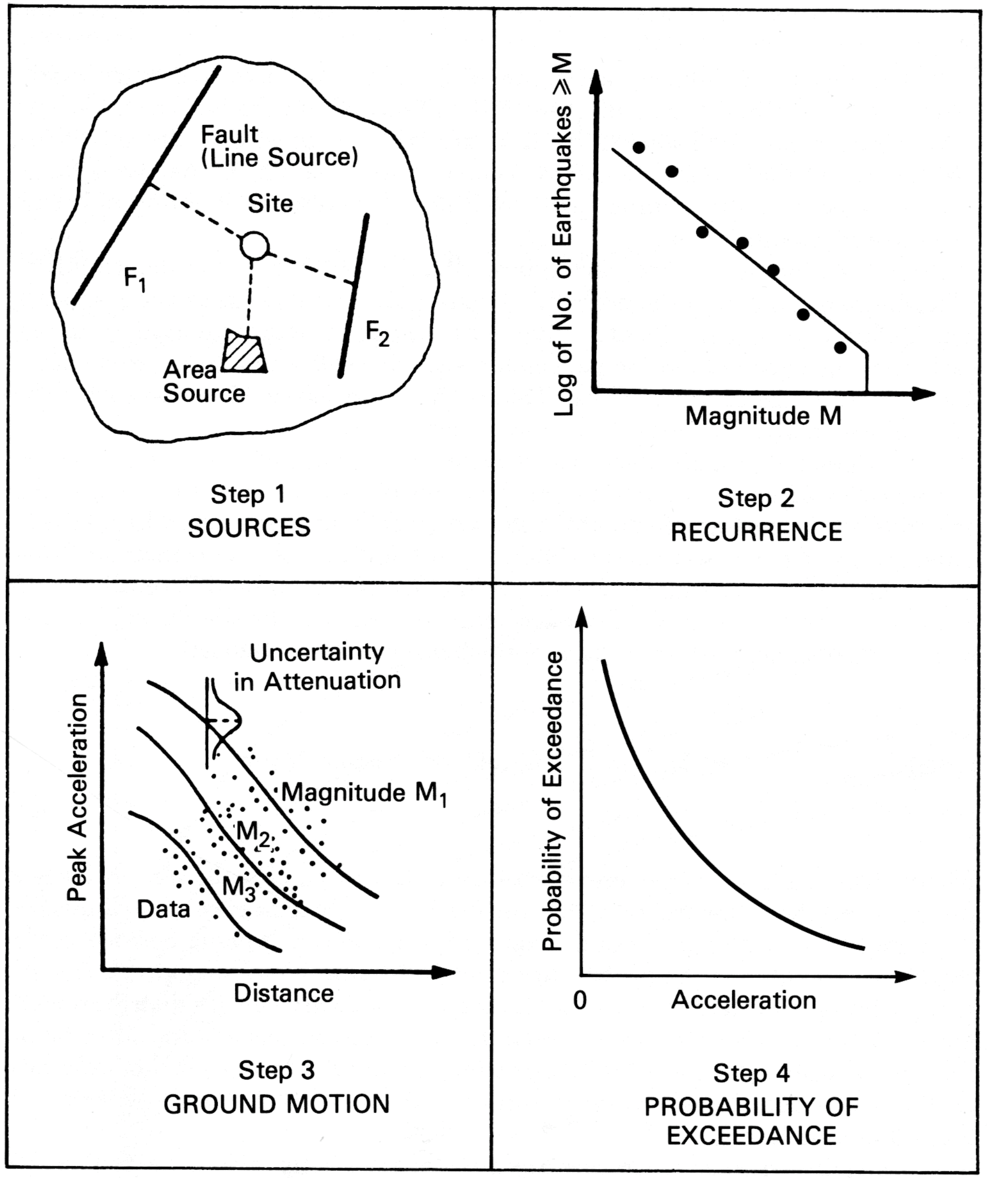

FIGURE 10.2 Basic steps of probabilistic seismic hazard analysis (after TERA Corporation 1978).

Probabilistic

Step 2 - Recurrence can be represented by a linear relation only if the size of the study area is large with respect to linear dimensions of sources.

Step 3 - Attenuation relations are often not translation invariant in the phase space (M, R, S)

↓

Step 4 - ???

M - magnitude; R - source distance; S - local soil conditions

Deterministic

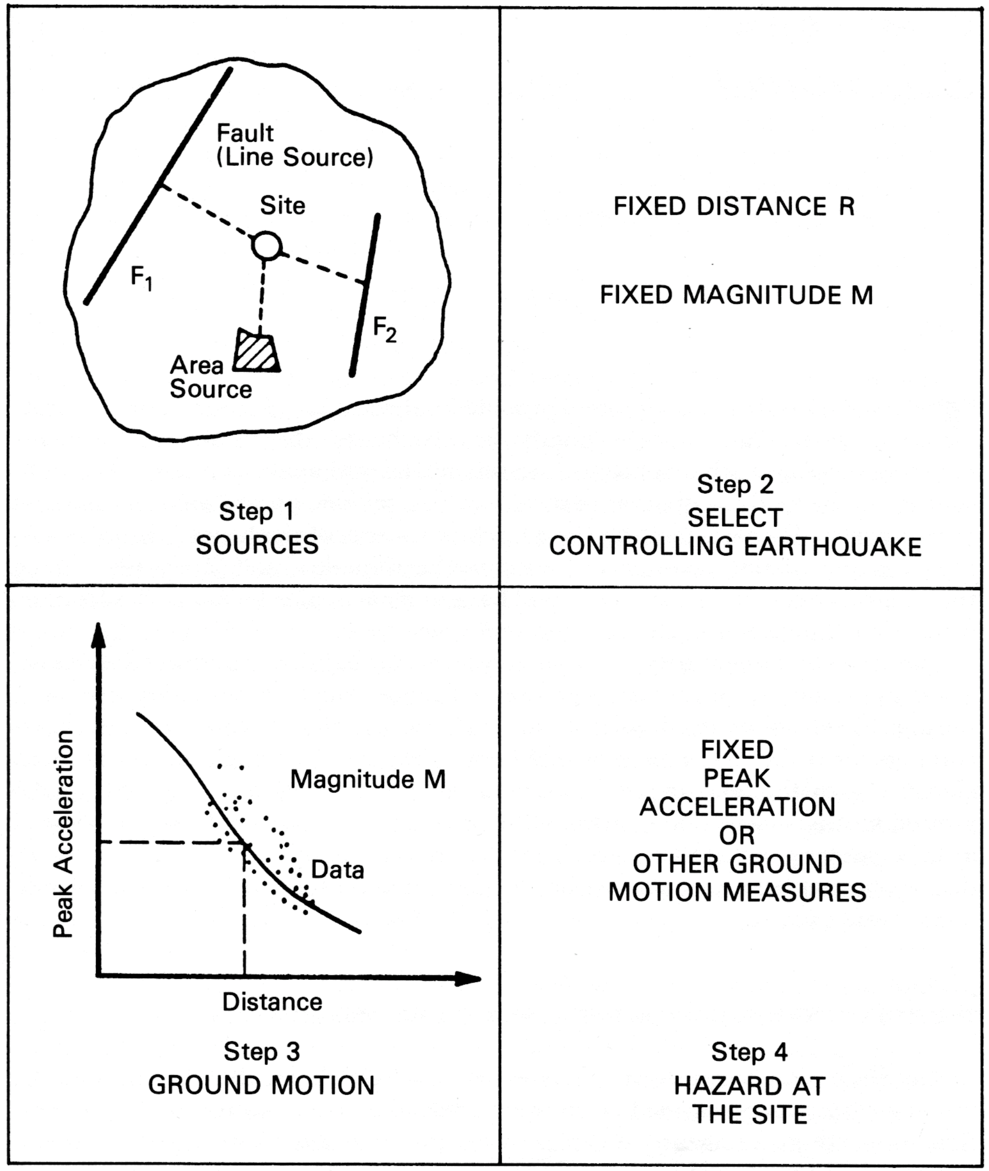

FIGURE 4.1 Basic steps of deterministic seismic hazard analysis (after TERA Corporation 1978).

Step 3 - Attenuation relations are often not translation invariant in the phase space (M, R, S)

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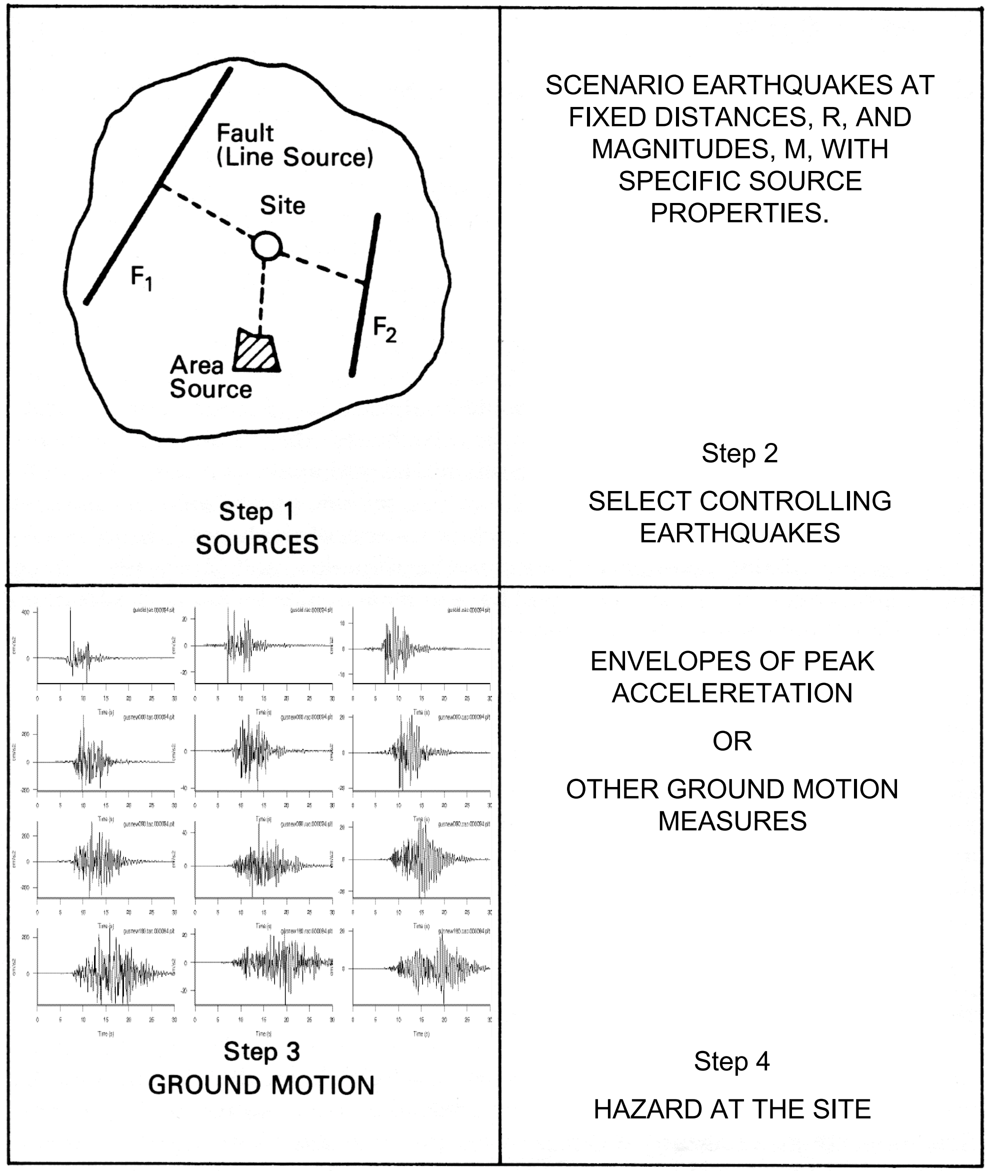


New approach based on synthetic signals computation

No need of empirical attenuation relations

Attenuation Relations

- The attenuation relationships of the ground motion parameters can differ in the assumed functional form, the number and definition of independent variables, the data selection criteria, and the statistical treatment of the data.
- Attenuation relationships assume the same propagation model for all the events, but such a hypothesis is not very realistic.

- The most frequently used attenuation relationships of ground motion parameters, like PGA, PGV, have the form:

$$\log y = a + b\,M + c\log r_f + d\,D_f + e\,S \quad (1)$$

- where y is the ground motion parameter, a, b, c, d, e coefficients empirically determined, r_f and D_f are different measures of the distance from the source and S is a binary variable (0, 1) which depends on the soil type.

D_f is the closest distance from the intersection, with the free surface, of the fault plane or with its extension to the surface, for blind faults (the strike of the fault);

$$r_f^2 = D_f^2 + h_o^2$$

where h_o represents a reference depth. The value of h_o is different when dealing with PGA or PGV, and usually varies between 5 and 10 km for PGA and between 3 and 10 for PGV.

- The coefficients are determined empirically and turn out to be quite sensitive to the data set utilized.
- Usually regional data sets are statistically not significant, while the national or global data sets, even if statistically significant, they can represent very different seismotectonic styles that are not mixable. Quite often the coefficients are obtained in such a way that they turn out to be (almost) independent from magnitude, distance and soil type.

- If we consider the **relative decay** $R_y = y_{r_f}/y_{source}$, where r_f is the distance from the source and the suffix source indicates the values at the closest instrument to the source, typically D_{source} is about 2 km, we have

$$\log R_y = c(\log r_f - \log r_{source}) + d(D_f - D_{source}) \quad (2)$$

- i.e. R_y does not depend upon the magnitude (size of the event) and the kind of soil (local soil conditions).

In the case of Sabetta and Pugliese (1987) relation, c=-1 and d=0, thus

$$\log R_y = \log r_{source} - \log r_f$$

both for PGA and PGV,

Ambraseys et al. (1996) give

$$\log R_y = 0.922(\log r_{source} - \log r_f)$$

Decanini et al. (2001)

$$\log R_y = 0.92(\log r_{source} \log r_f) + 0.0005(D_{source} - D_f)$$

Therefore empirical relations like (1) are not capable to capture relevant aspects of the phenomenon of space attenuation of peak values. This is not surprising since the difference between (2) and (1) indicates that (1) is not translation invariant, i.e. it may not have a general physical meaning.

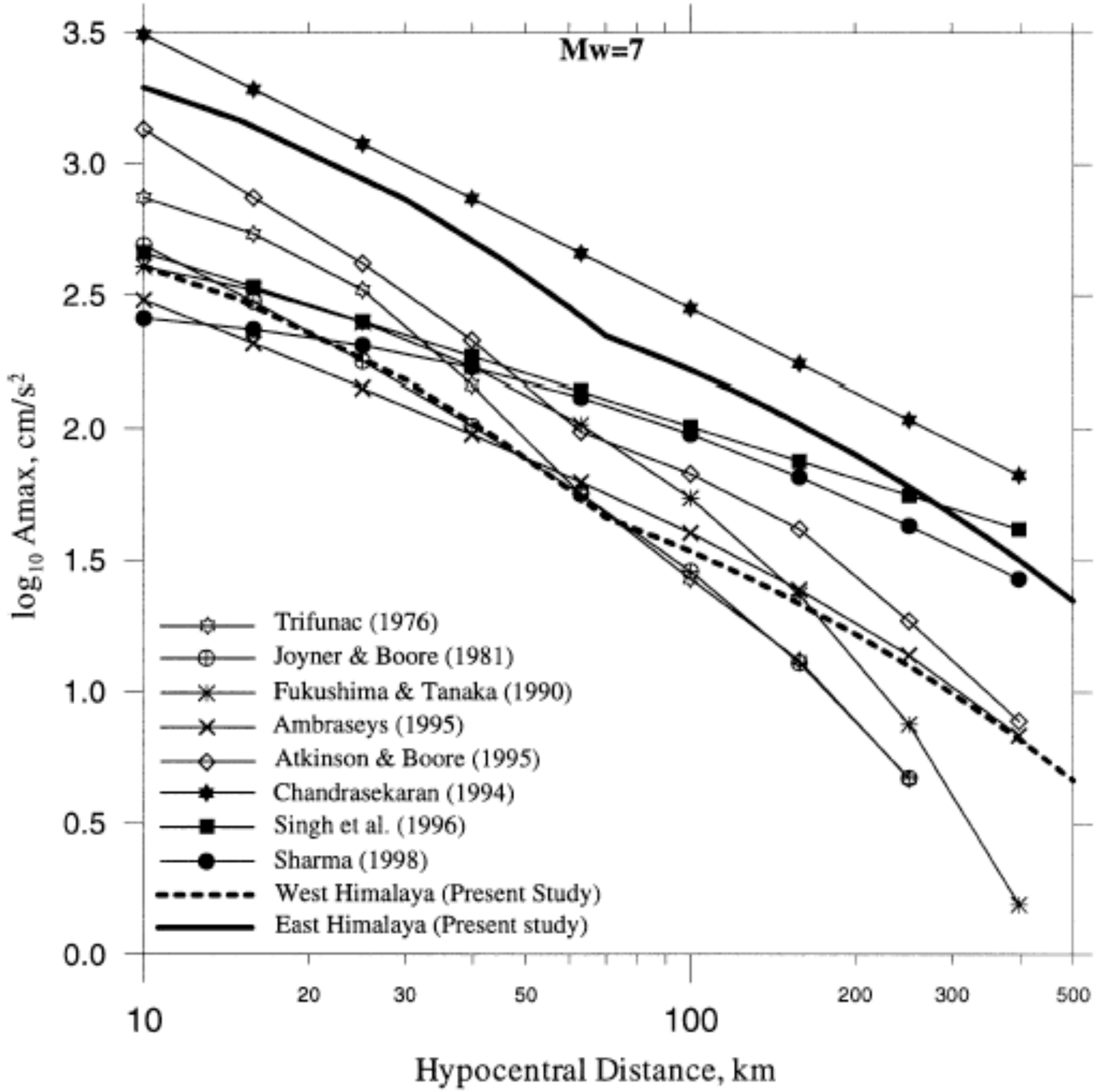
- The analysis of selected events and of a set of strong motion records, classified accordingly to magnitude intervals and soil conditions, indicates that the trend of the relative decay of the areas of the energy spectra in the period range [0.05-4.0] s, AEI (0-4), is not constant: it depends on magnitude and soil type.

- The energetic parameter, AEI (0-4), is a good and relatively stable indicator of the damaging potential of ground motion, therefore it is natural to assume that **PGA and PGV should follow the different laws of relative attenuation, depending on magnitude and soil type**.

- It can be shown (e.g. Panza et al., 2003) that predictions of the relative attenuation of PGA and PGV are in disagreement with the observed values and sometimes between themselves. This aspects evidences the great uncertainties deriving from the existing attenuation functional forms relative to the adopted hazard parameter.

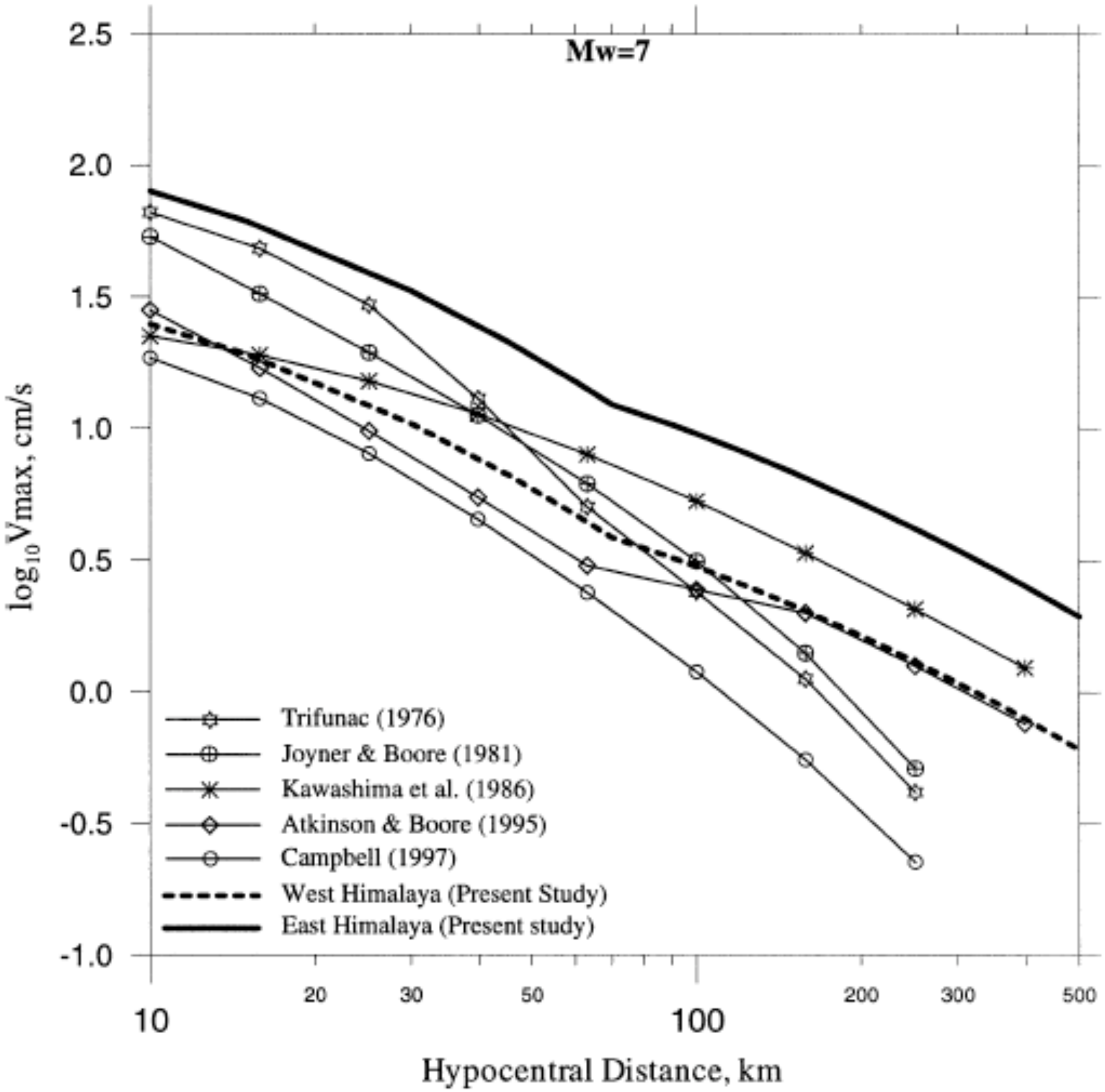
- Recent examples of the strong dependence of the attenuation laws on the considered region and on the grouping in the data processing are given by Mitchell et al. (1997) for Eurasia and Parvez et al. (2001) for the Himalayas, respectively.

Attenuation realtionships for Himalayan earthquakes (acceleration)



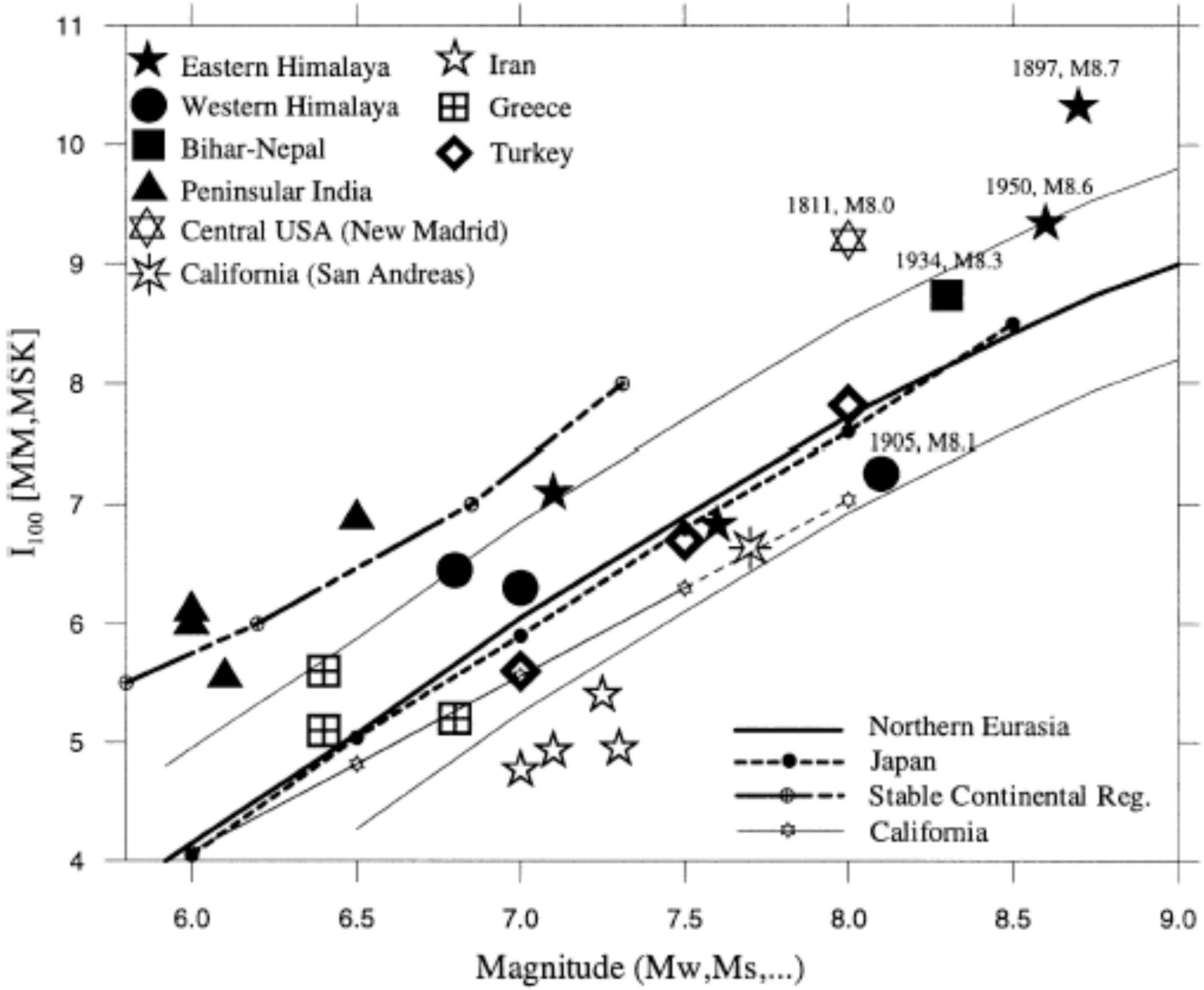
Himalayan earthquakes, compared with other regions of the World

Attenuation relationships for Himalayan earthquakes (velocity)



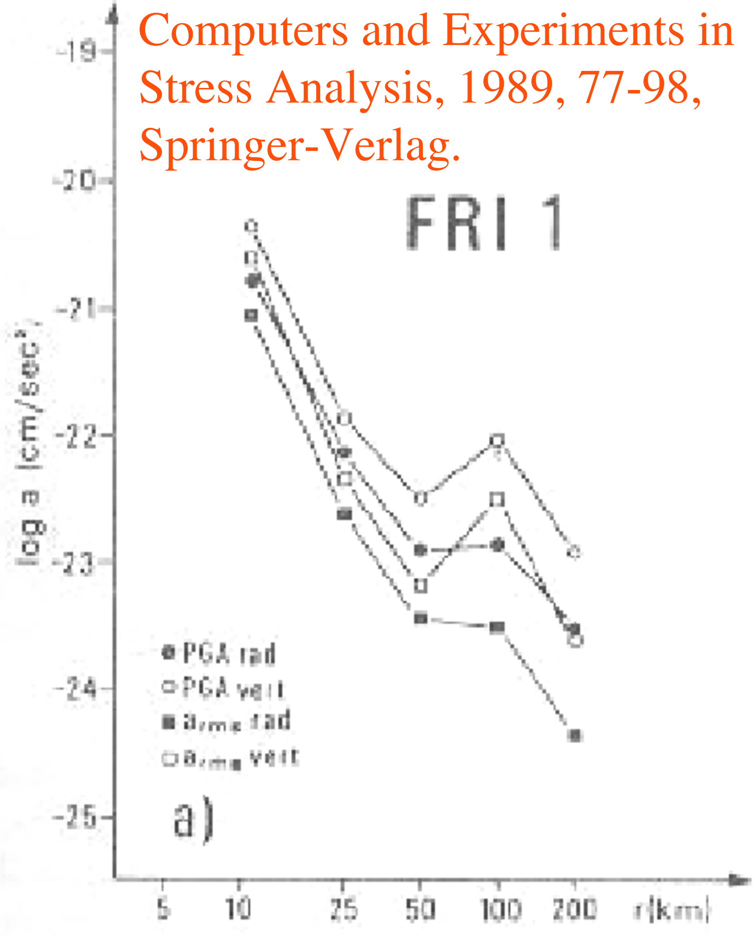
Himalayan earthquakes, compared with other regions of the World

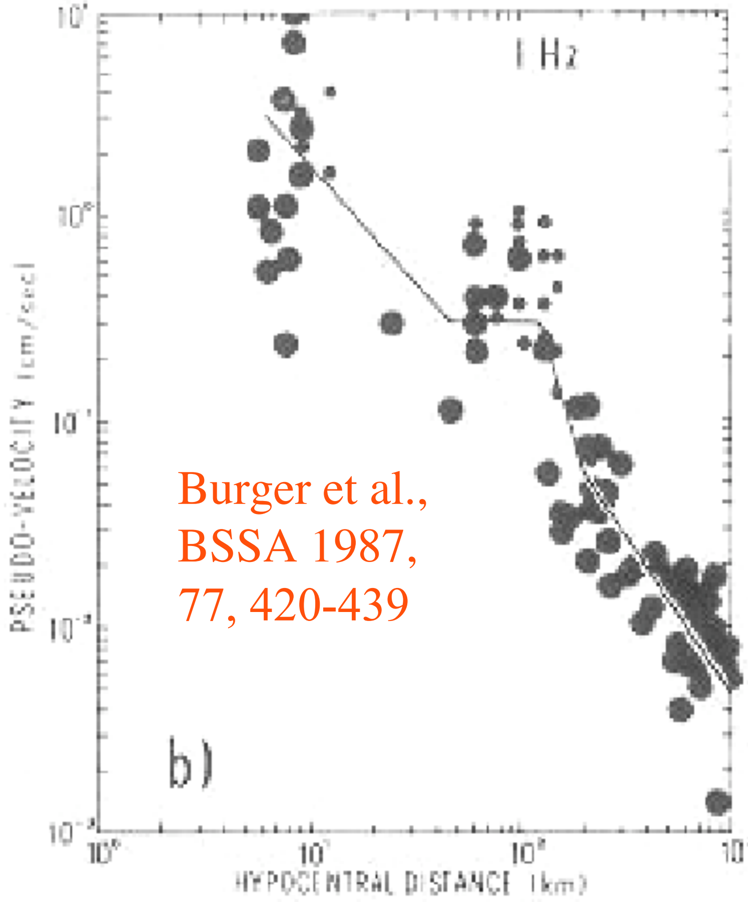
Attenuation relationships for Himalayan earthquakes



Intensity values at 100 km epicentral distance, for different parts of the World

Panza & Suhadolc, In: Computers and Experiments in Stress Analysis, 1989, 77-98, Springer-Verlag.





Burger et al., BSSA 1987, 77, 420-439

Epicentral distance (km)

Recently proposed attenuation relations:

$$\log y = a + bM - \log(r_f + g10^{hM}) + dD_f$$

Thus the relative decay $R_y = y_{r_f} / y_{source}$ remains magnitude (M) dependent:

$$\log y_{r_f} - \log y_{source} = \log R_y =$$
$$\log[h_{source} + g10^{hM} / (r_f + g10^{hM}] + dD_f ;$$

if: $h_{source} \sim 0$ or $D_f >> h_{source}$

$$\log R_y = \log[1 + D_f\, 10^{-hM}/g]^{-1} + dD_f$$

The attenuation relation in the form:

$$\ln\left(S_a(m,r)\right)=g(m,r)+\varepsilon\sigma \qquad (1)$$

even when translation invariant (most of the existing relations are not translation invariant, thus with no physical meaning) is not a conditional probability density function, it represents the functional dependency of the random spectral acceleration on the random variates: magnitude, distance and measurement error (Klügel, 2006).

The laws of multivariate theory of probability are applied, as a rule, to calculate the conditional probability of exceedance of a certain hazard level z for a given set of parameters *m* and *r* by developing the joint probability density distribution for the spectral acceleration and relating it to the marginals of *m* and *r* (assuming independence between *m* and *r*).

The PSHA model is simplified by assuming that g(m,r) is constant and all the randomness of the problem is concentrated in the error term $\varepsilon\sigma$ (univariate approximation).

As a result of the simplification for the probabilistic model we get:

$$\ln (S_a(m,r))=E(g(m,r))+\varepsilon\sigma \qquad (2)$$

By multiplying the simplified equation (2) with the probability density function of ε, performing integration and converting the resulting expression to the complementary probability distribution function one can separate the randomness from the “quasi-deterministic” calculation of ground motion calculation.

Unfortunately this simplifying replacement is completely incorrect from the point of view of mathematics because a random parameter is replaced by a number, by its expected value, and this introduces a systematic error. We can show this by replacing the distribution *g(m,r)* by a series (assuming that the development into a series is possible, which is the case here) around its expected value *E(g(m,r))*.

This yields:

$$g(m,r) = E(g(m,r)) + \Delta(m,r) \qquad (3)$$

Here $\Delta(m,r)$ is a nontrivial (not equal to 0) random variable describing the deviations of $g(m,r)$ around its expected value. Replacing $g(m,r)$ in (1) by equation (3) we obtain:

$$\ln (S_a(m,r))=E(g(m,r)) + \Delta + \varepsilon\sigma \qquad (4)$$

Replacing ln $(S_a(m,r))$ in equation (2) by equation (4) we obtain as a result:

$$\Delta = 0 \qquad (5)$$

This is obviously wrong by the way *Δ(m,r)* was defined. So we obtained a statement of the same logical value as "x equals 0 for any x" as the result of the simplifications made in the traditional PSHA model.

What drives the uncertainty ?

The PSHA – methodology !!!

ε

$$\lambda(a)=\sum_{i=1}^{S}\nu\int_R\int_M \Phi'\left(\frac{\ln a - g(m,r)}{\sigma}\right) f_R(r|m)\, f_M(m)\,dr\,dm$$

$$\lambda(a)=\sum_{i=1}^{S} N_i(M_{\min})\int_M\int_R\int_{\varepsilon} f_{mi}(M)\, f_{Ri}(r|M)\, f_{\varepsilon}\, P(\ln(a)>a|M,R,\varepsilon)\,d\varepsilon\, dR\, dM$$

How to define the bounds ?

„Conditional" Probability of exceedance of acceleration level *a*

Both expressions do not represent a „ conditional" probability of exceedance but an unconditional univariate „approximation" - mathematically incorrect; the more independent random model parameters we include into our logic tree model, the larger will be the mean hazard (until convergence to a theoretical upper limit)

Violation of the total probability theorem

Ambiguous results

Illustration of consequences;
Introduction of a systematic error

Attenuation equation

$$\ln\left(a(m,r)\right) = g(m,r) + \varepsilon\sigma \quad (1)$$

$g(m,r)$ is the regression mean for the determination of ground motion acceleration from a large serie of measurements

Probabilistic model, m, r treated as random variates

$$g(m,r) \rightarrow \tilde{g}(m,r) \rightarrow \Gamma$$

Γ is a random function

Ideal case

$$g(m,r) \simeq E(\Gamma)$$

But mathematically

$$E(\Gamma) \neq \Gamma$$

Developing Γ into a series around its expected value

$$\Gamma = E(\Gamma) + \Delta(m,r)$$

and replacing g(m,r) in (1)

Systematic error

$$\Delta(m,r) = 0$$

Replacing g(m,r) by E(Γ) in (1)

Impact of the mathematical error on the results of a PSHA

$$\Pr\left(\left|\Gamma - E(\Gamma)\right| \geq \varepsilon\sigma\right) \leq \frac{1}{\varepsilon^2}$$

Impact can be assessed approximately by Chebyshev's inequality

Upper limit of validity of the univariate approximation

$$\varepsilon \approx 1$$

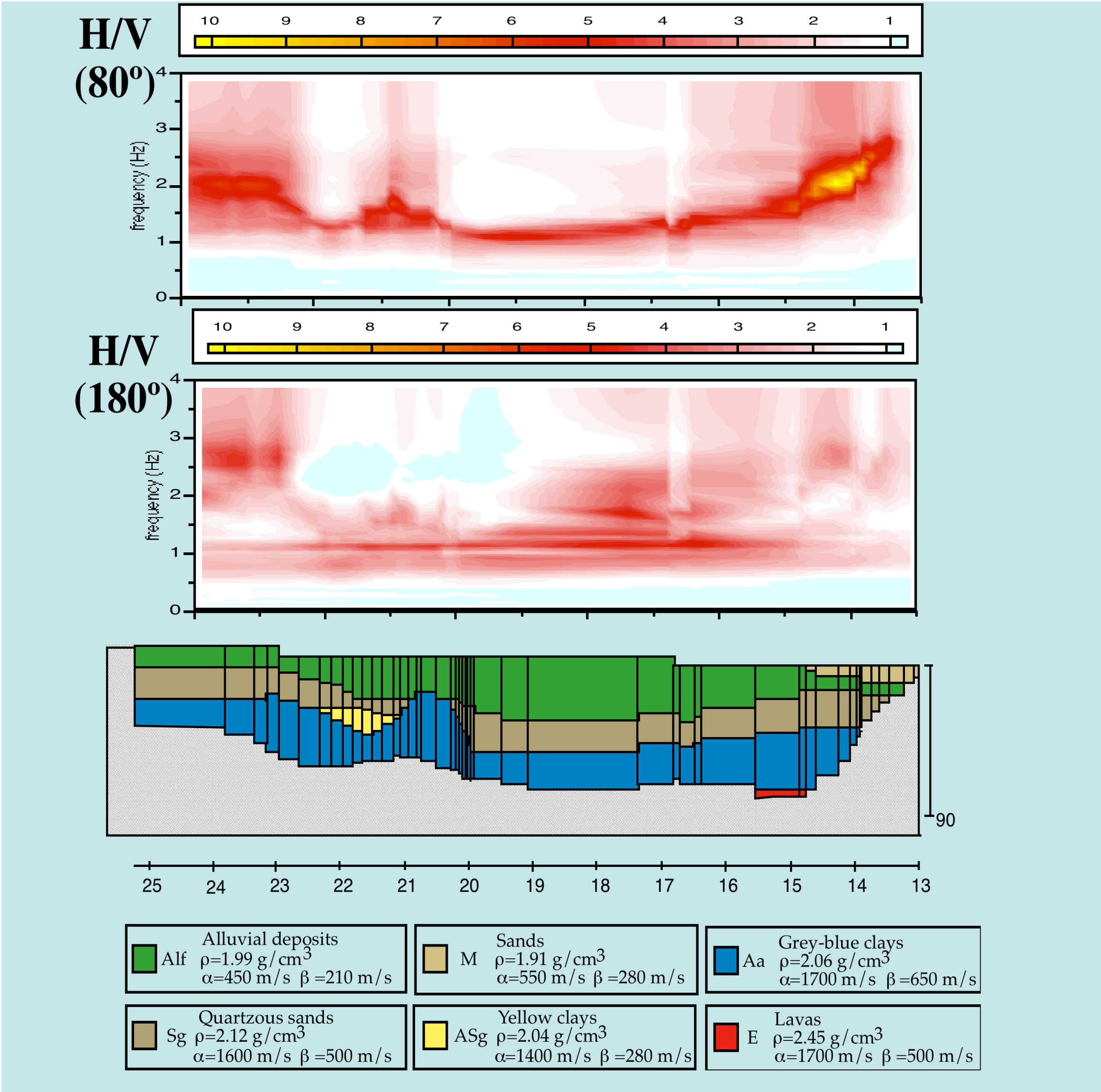
Error can be reduced by returning to intensities !!!

Another problem is that σ has to be adjusted, too (conditional uncertainty depending on the model).

The use of synthetic seismograms is imposed by the necessity to bypass the problem arising, not only from the problems connected with attenuation relations, but also from the fact that the so called site effects, are rather a wishful thinking than a physical reality and the local response is strongly influenced by the source, as shown in what follows.

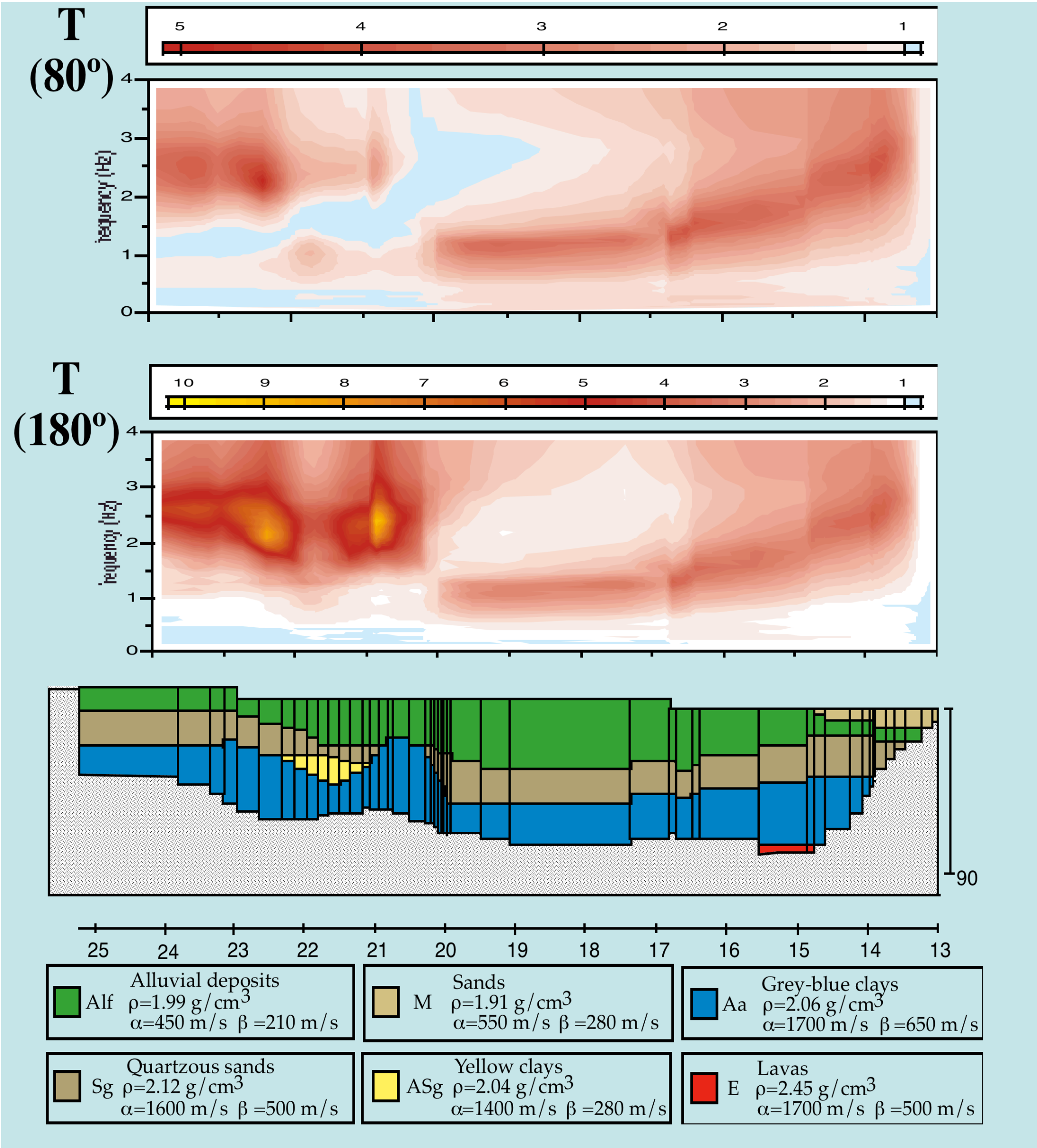
- **H/V** is the spectral ratio between horizontal and vertical components of motion.
- **RSR** is the ratio between the response spectra amplitudes (5% damping) obtained with the local and the bedrock structures

Seismic input modeling
(azimuthal effect on H/V)

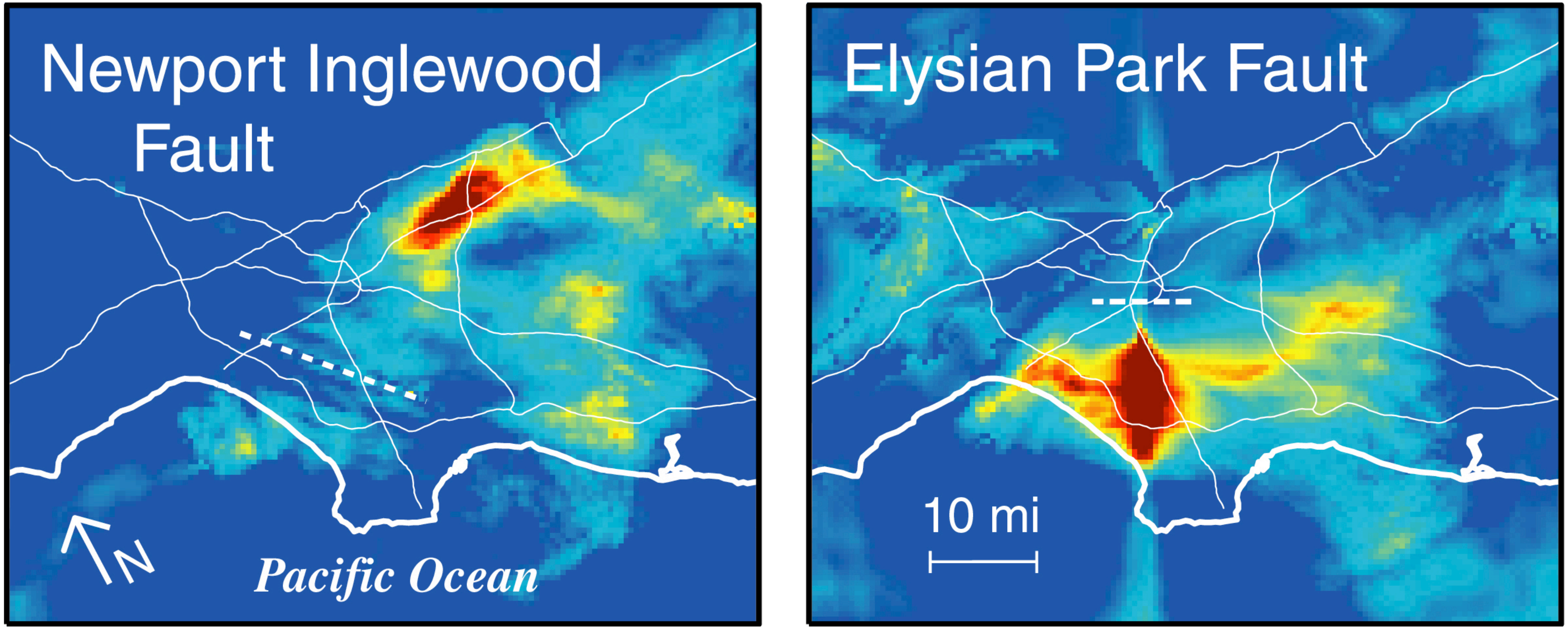


Seismic input modeling

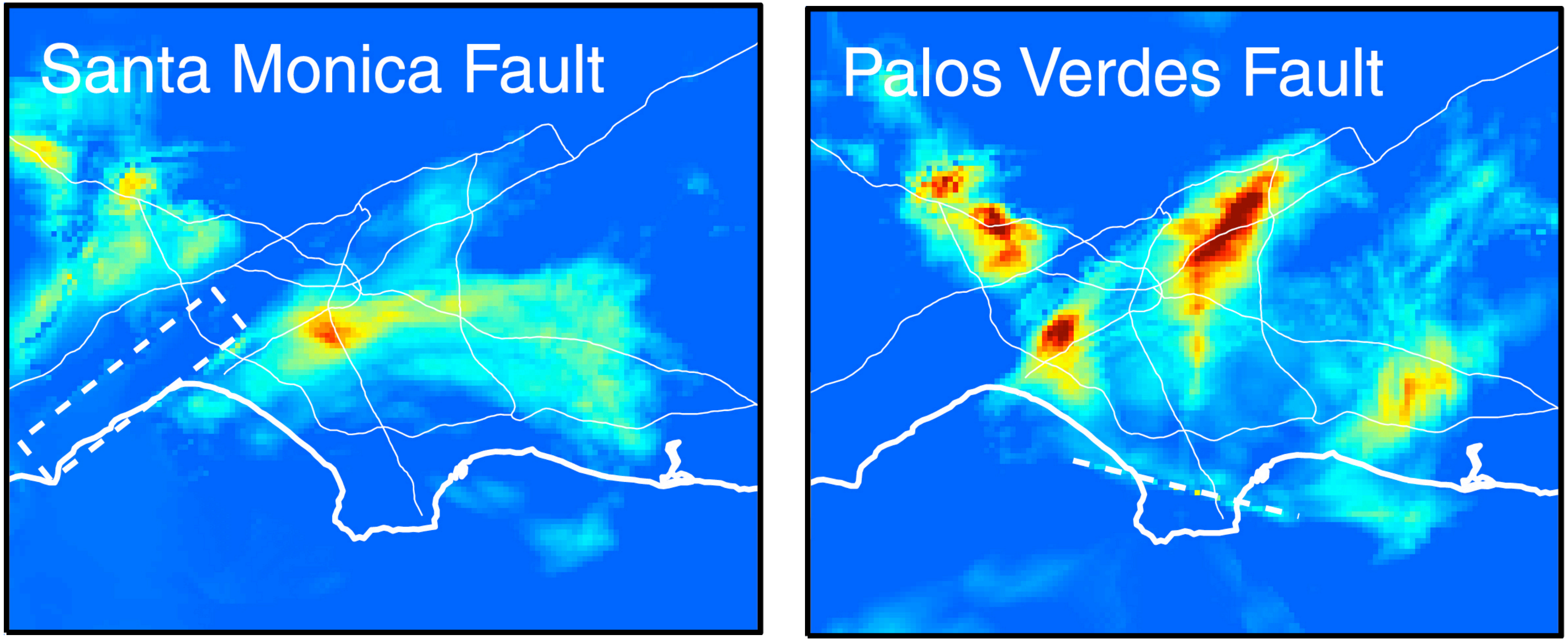
(azimuthal effect on RSR)



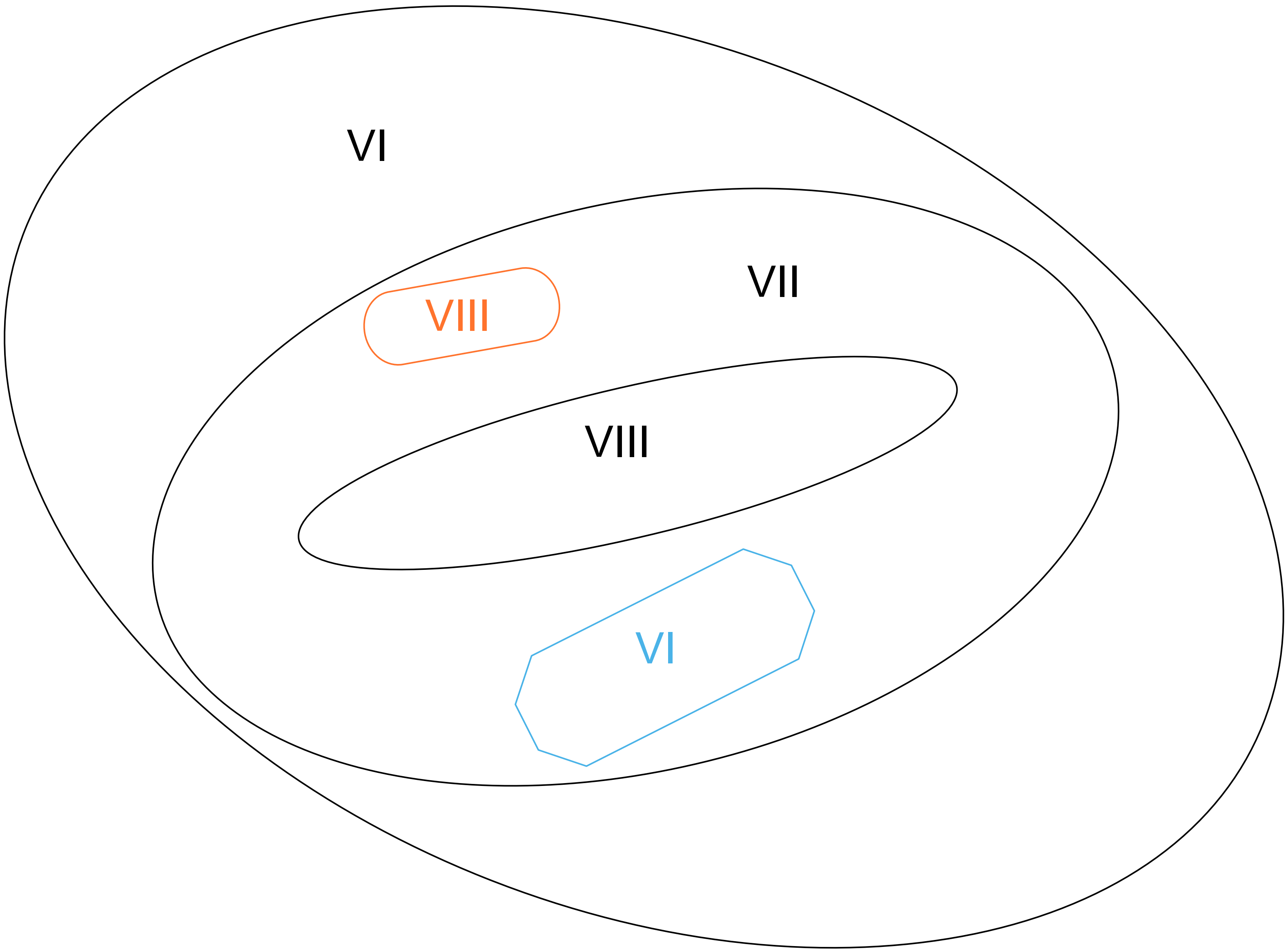
RSR for SH component of motion



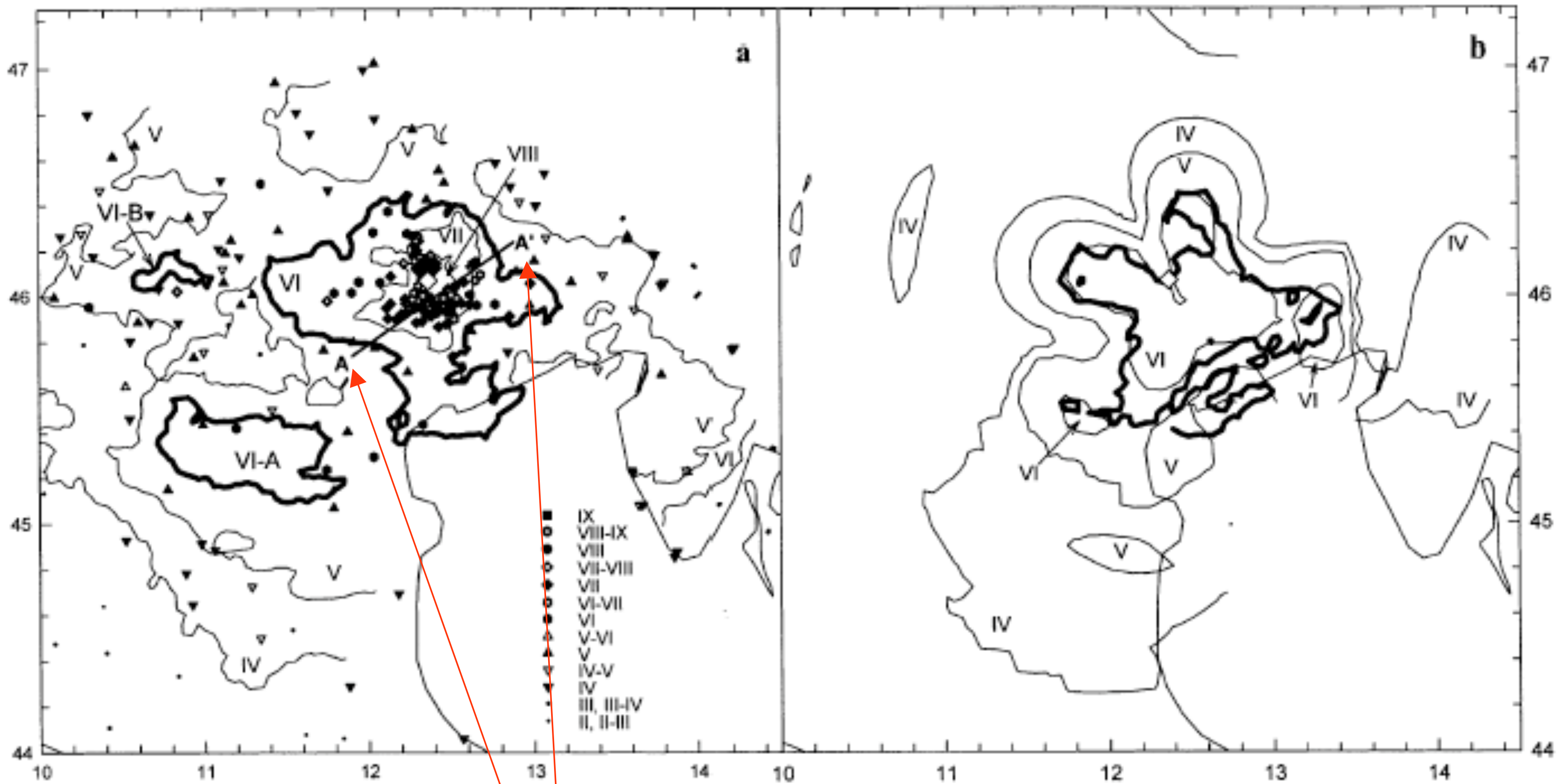
These images of the Los Angeles Basin show "hotspots" predicted from computer simulations of an earthquake on the Elysian Park Fault and an earthquake on the Newport-Inglewood Fault (represented by the white dashed lines). What is shown is **not** how much shaking was experienced at a particular site but rather how much more or less shaking (highest levels are shown in red) a site receives **relative to what is expected** from only the magnitude of the earthquake and the site's distance from the fault. These images consider only part of the total shaking (long-period motions) and were calculated by using a simplified geologic structure. (Data for images courtesy of Kim Olsen, University of California, Santa Barbara, SCEC Phase III report)



"hotspots" predicted from computer simulations of an earthquake on the Santa Monica Fault and an earthquake on the Palos Verdes Fault (represented by the white dashed lines). SCEC Phase III report, Field, 2000, BSSA, see also http://www.scec.org/phase3/

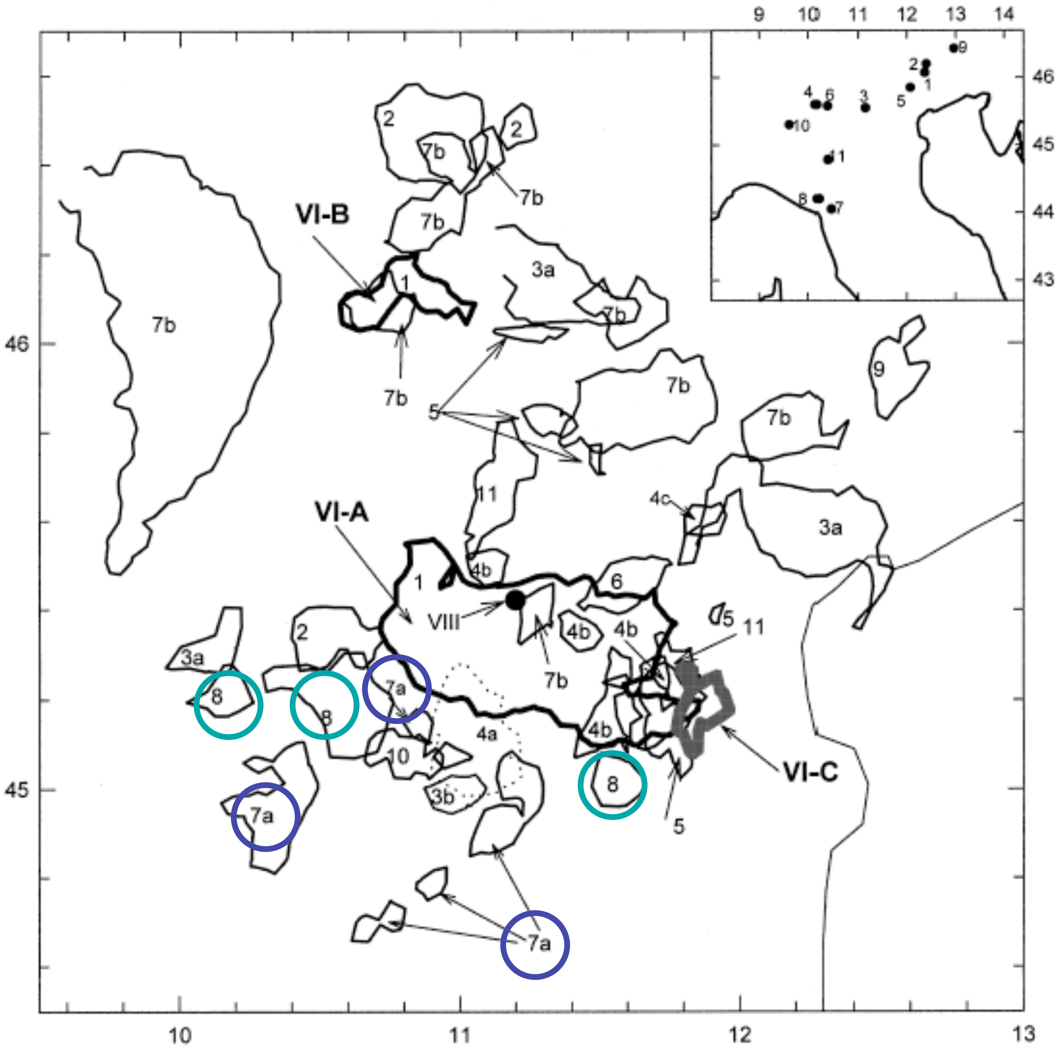


Schematic representation of multi-connected isoseismals



Alpago earthquake (18.10.1936, M_L=5.8): MCS Intensity data (*point-like symbols*) and isolines defined with polinomial filtering; segment (A, A') separates the zone with $I \geq$VI on mountain from that on plain. Areas VI-A e VI-B are local effects?

(b) isolines of the synthetic a_p-field (*thin line*) and reconstruction of the theoretical I_a=VI isoline (*bold line*) using the original observation points and the polynomial filtering technique (Molchan et al., 2002, PAGEOPH, 159).



1) 18.10.1936, Alpago, V+1 (*think line*; VI-A, VI-B), area VI-C is an alternative to the area VI-A due to instability of the the polynomial.

2) 29.06.1873, Bellunese, V+1 (2).

3) 7.06.1891, Veronese, IV+1 (3a), V+1 (3b).

4) 27.11.1894, Franciacorta, IV-1 (4a, *dotted line*), III+1 (4b), II+1 (4c).

5) 4.03.1900, Valdobbiadene, IV+1 (5).

6) 30.10.1901, Salo, IV+1 (6).

7) 27.10.1914, Garfagnana, V+1 (7a), IV+1 (7b).

8) 7.09.1920, Garfagnana, IV+1 (8).

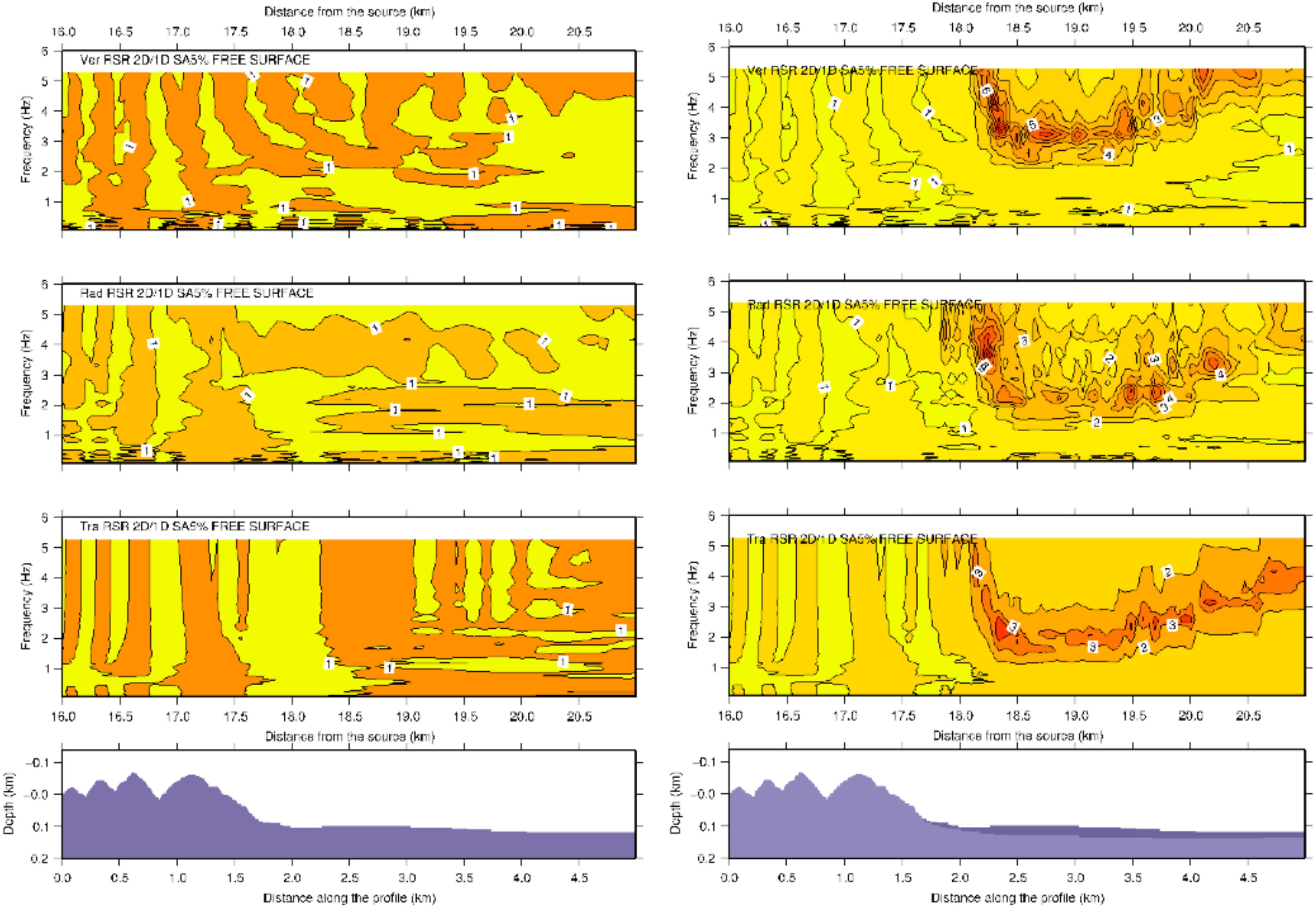
9) 12.12.1924, Carnia, IV+1 (9).

10) 15.05.1951, Lodigiano, V+1 (10).

11) 15.07.1971, Parmense, IV+1 (11).

Secondary parts (*thin line*) of the multi-connected isoseismals for the 11 earthquakes in the zone of Alpago earthquake.

Earthquake 1.10.1995, Dinar, Turkey



Distance from the source (km)
Ver RSR 2D/1D SA5% FREE SURFACE
Rad RSR 2D/1D SA5% FREE SURFACE
Tra RSR 2D/1D SA5% FREE SURFACE
Frequency (Hz)
Depth (km)
Distance along the profile (km)

CONCLUSIONS

Case studies of seismic hazard assessment techniques indicate the limits of the currently used methodologies, deeply rooted in engineering practice, based prevalently on a probabilistic approach, and show that the related analyses are not sufficiently reliable to characterize seismic hazard. The probabilistic analysis of the seismic hazard is basically conditioned by the definition of the seismogenic zones.

CONCLUSIONS

Particularly important are the parameters used to characterize the damage potential of earthquake ground motion and the attenuation relationships for the estimation, for a given earthquake, of the ground motion at a site.

CONCLUSIONS

The quantification of the critical ground motion expected at a particular site requires the identification of the parameters that characterize the severity and the damage potential. Such critical ground motion can be identified in terms of energy and displacement demands – the latter particularly relevant for seismic isolation – which should be evaluated by considering the seismological, geological, and topographic factors affecting them.

CONCLUSIONS

In view of the limited seismological data – especially scarce are displacement time histories – it seems more appropriate to resort to a scenario-based deterministic approach, as it allows us the realistic definition of hazard in scenario-like format to be accompanied by the determination of advanced hazard indicators as, for instance, damaging potential in terms of energy.

CONCLUSIONS

Such a determination, due to the limitation of the number of strong motion records, requires to resort to broad band synthetic seismograms, that allow us to perform realistic waveform modelling for different seismotectonic environments, taking into account source properties (e.g. dimensions, directivity, duration, etc.), lateral heterogeneities, and path effects.

CONCLUSIONS

At present, only from a careful performance of modelling experiments, it is possible to realistically account for effects such as long duration pulses, shaking duration, temporal distribution of pulses, non-linear structural response in terms of strength, energy and displacement. In fact the estimation of such effects requires the use of complete signals and cannot be made considering partial signals or single phases.

CONCLUSIONS

Each synthetic strong ground motion history, characterized as a function of its damage potential, constitutes a useful addition to the records database that increases our choices in selecting acceleration histories for various analyses. The growing database for near-field and soft soil strong motion signals (recorded and modelled), gives the opportunity to enhance the state of knowledge in damage potential evaluation.

THE END

THANK YOU FOR YOUR ATTENTION