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Atoms for Peace and Development

IAEA-Asian Nuclear Safety Network (ANSN) Regional Workshop on Site Evaluation for Small Modular Reactors (SMRs)

Seismic Hazards For Nuclear Installations

Haikou-Hainin-China

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General Hazard Framework for Nuclear Installations

IAEA Safety Standards
for protecting people and the environment

Site Evaluation for Nuclear Installations

Specific Safety Requirements
No. SSR-1

IAEA Safety Standards
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Seismic Hazards in Site Evaluation for Nuclear Installations

Specific Safety Guide
No. SSG-9 (Rev. 1)

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Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants

Safety Guide
No. NS-G-3.6

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2. SAFETY PRINCIPLES AND CONCEPTS

2.1. As stated in SF-1 [1]: "**The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.**" Paragraph 2.1 of SF-1 [1] states:

"This fundamental safety objective of protecting people — individually and collectively — and the environment has to be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks. To ensure that facilities are operated and activities conducted so as to achieve the highest standards of safety that can reasonably be achieved, measures have to be taken:

(a) To control the radiation exposure of people and the release of radioactive material to the environment;
(b) To restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation;
(c) To mitigate the consequences of such events if they were to occur."

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2. SAFETY PRINCIPLES AND CONCEPTS

2.2. Paragraph 2.2 of SF-1 [1] states:

“The fundamental safety objective applies for all facilities and activities, and for all stages over the lifetime of a facility or radiation source, including planning, siting, design, manufacturing, construction, commissioning and operation, as well as decommissioning and closure. This includes the associated transport of radioactive material and management of radioactive waste.”

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2. SAFETY PRINCIPLES AND CONCEPTS

2.3. This Safety Requirements publication establishes requirements for application of the principles of SF-1 [1], in particular Principles 8 and 9:

-"All practical efforts must be made to prevent and mitigate nuclear or radiation accidents" (Principle 8 of SF-1 [1]).

-"The primary means of preventing and mitigating the consequences of accidents is 'defence in depth'. Defence in depth is implemented primarily through the combination of a number of consecutive and independent levels of protection that would have to fail before harmful effects could be caused to people or to the environment" (para. 3.31 of SF-1 [1]).

-"Defence in depth is provided by an appropriate combination of [inter alia] … [a]dequate site selection and the incorporation of good design and engineering features providing safety margins, diversity and redundancy" (para. 3.32 of SF-1 [1]).

-"Arrangements must be made for **emergency preparedness and response for nuclear or radiation incidents**" (Principle 9 of SF-1 [1]).

2. SAFETY PRINCIPLES AND CONCEPTS

2.4. To address Principle 8 of SF-1 [1], site evaluation for a nuclear installation shall characterize the natural and human induced external hazards that could affect the safety of the nuclear installation (see Requirement 1). The site evaluation shall provide adequate input to the design and safety assessment for demonstration of protection of people and the environment from harmful effects of ionizing radiation.

2.5.To address Principle 9 of SF-1 [1], site evaluation for a nuclear installation shall provide adequate input for demonstration of protection of people and the environment from the consequences of radioactive releases. The site evaluation shall identify the site characteristics that could affect the feasibility of planning effective emergency response actions in the external zone.

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5. EVALUATION OF EXTERNAL HAZARDS

5.1. This section establishes requirements for the evaluation of external hazards. These requirements are to be applied as appropriate for the type of nuclear installation as well as the site under consideration.

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SEISMIC HAZARDS

Requirement 15: Evaluation of fault capability

Geological faults larger than a certain size and within a certain distance of the site and that are significant to safety shall be evaluated to identify whether these faults are to be considered capable faults. For capable faults, potential challenges to the safety of the nuclear installation in terms of ground motion and/or fault displacement hazards shall be evaluated.

5. EVALUATION OF EXTERNAL HAZARDS

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5.2. Capable faults shall be identified and evaluated. The evaluation shall consider the fault characteristics in the site vicinity. The methods used and the investigations made shall be sufficiently detailed to support safety related decisions.

5.3. The potential effect of fault displacement on safety related structures, systems and components shall be evaluated. The evaluation of fault displacement hazards shall include detailed geological mapping of excavations for safety related engineered structures to enable the evaluation of fault capability for the site.

5.4. A proposed new site shall be considered unsuitable when reliable evidence shows the existence of a capable fault that has the potential to affect the safety of the nuclear installation and which cannot be compensated for by means of a combination of measures for site protection and design features of the nuclear installation. If a capable fault is identified in the site vicinity of an existing nuclear installation, the site shall be deemed unsuitable if the nuclear installation safety cannot be demonstrated.

5. EVALUATION OF EXTERNAL HAZARDS

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[5] A fault is considered capable if, on the basis of geological, geophysical, geodetic or seismological data (including palaeoseismological and geomorphological data), one or more of the following conditions applies:

(a) The fault shows evidence of past movement or movements (significant surface deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to infer that further movements at or near the surface could occur. In highly active areas, where both earthquake data and geological data consistently and/or exclusively reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods will be required.

(b) A structural relationship with a known capable fault has been demonstrated such that movement of one could cause movement of the other at or near the surface.

(c)The maximum potential earthquake associated with a seismogenic structure is sufficiently large and at such a depth that it is reasonable to infer that, in the geodynamic setting of the site, movement at or near the surface could occur.

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5. EVALUATION OF EXTERNAL HAZARDS

Requirement 16: Evaluation of ground motion hazards

An evaluation of ground motion hazards shall be conducted to provide the input needed for the seismic design or safety upgrading of the structures, systems and components of the nuclear installation, as well as the input for performing the deterministic and/or probabilistic safety analyses necessary during the lifetime of the nuclear installation.

5.5. Hazards due to earthquake induced ground motion shall be assessed by means of appropriate methods. The effect of the vibratory ground motion in combination with other seismically induced events, if any, shall be considered. The potential for seismicity due to human activities shall also be considered. Such as construction of dams, mining, and operation of oil wells and gas wells.

Review: Earthquakes and Earthquake Engineering

Seismology : is the scientific study of eartquakes and the propagation of elastic waves through the earth or through other planet-like bodies. The field also includes studies of earthquake effects, such as tsunamis as well as diverse seismic sources such as volcanic, tectonic, oceanic, atmospheric, and artificial processes (such as explosions).

A related field that uses geology to infer information regarding past earthquakes is paleoseismology. A recording of earth motion as a function of time is called a seismogram. A seismologist is a scientist who does research in seismology.

Multidisciplinary science, links physics with other geosciences (geology, gephysics, geography)

International science

Large span of amplitudes (~ 10^{-9} – 10^{1} m)

Very large span of wave periods (~ 10^{-3} – 10^{4} s)

Very young science (second half of the 19^{th} century)

Review: Earthquakes and Earthquake Engineering

Seismology deals with all aspects of earthquakes:

A) Observational seismology

- Recording earthquakes (microseismology)
- Database of earthquakes
- Observing earthquake effects (macroseismology)

B) Engineering Seismology

- Estimation of seismic hazard
- Estimation of risk

C) Physical Seismology

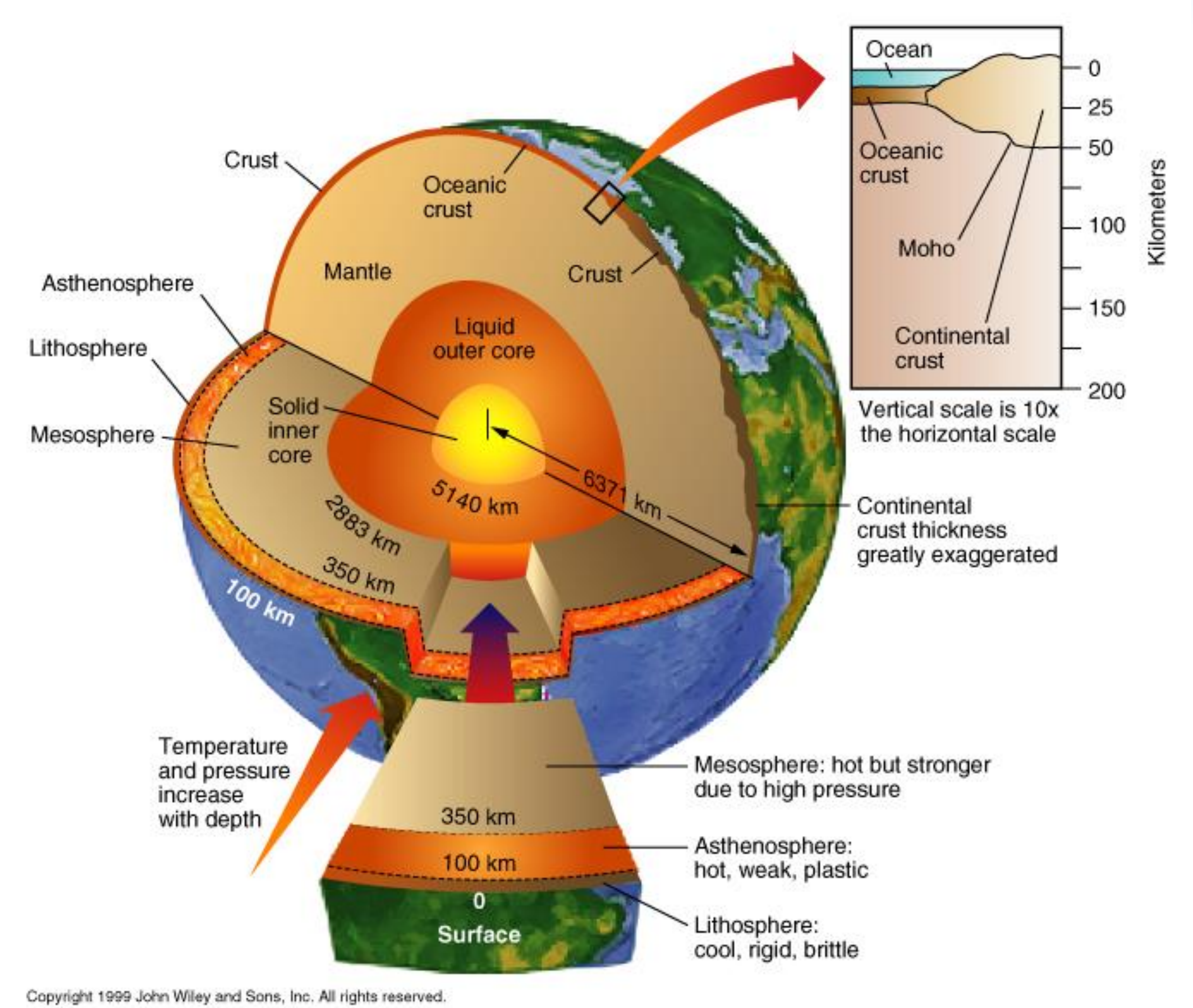
- Study of the properties of the Earth's interior
- Study of physical characteristics of seismic sources

Review: Earthquakes and Earthquake Engineering

Earthquakes: Sudden release of strain energy through movement along a fault.

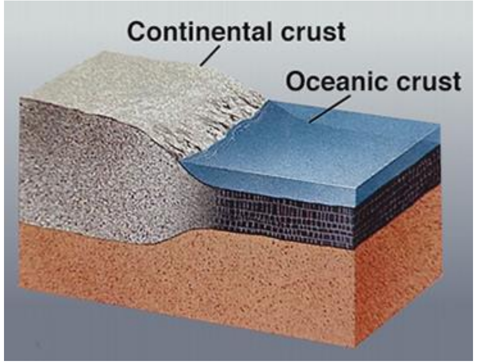
Myths about earthquakes:

Review: Earthquakes and Earthquake Engineering



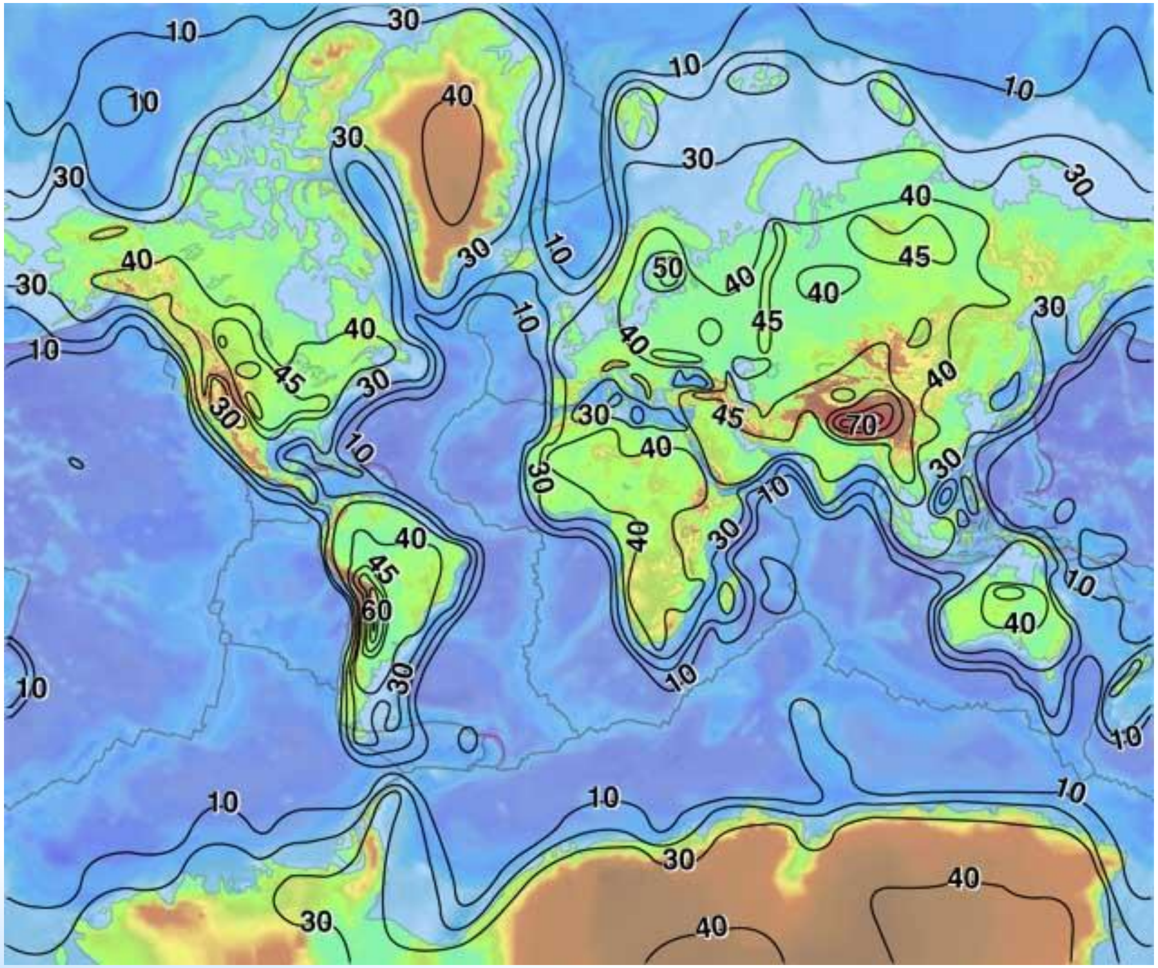
Review: Earthquakes and Earthquake Engineering

- Crust the shallowest layer.
- The most heterogeneous layer in the Earth.
- ~ 33 km thick for continents and ~10 km thick beneath oceans; however it varies from just a few km to over 70 km globally.



- The boundary between the crust and the mantle is mostly *chemical*. The crust and mantle have different compositions.
- This boundary is referred to as the Mohorovičić discontinuity or “Moho”.
- It was discovered in 1910 by the Croatian seismologist Andrija Mohorovičić.

Crustal Thicknesses



http://quake.wr.usgs.gov/research/structure/CrustalStructure/index.html

Heat Convection

Convective heat transfer, often referred to simply as **convection**, is the transfer of heat from one place to another by the movement of fluids.

Convection in the astenosphere enables tectonic processes – **PLATE TECTONICS**

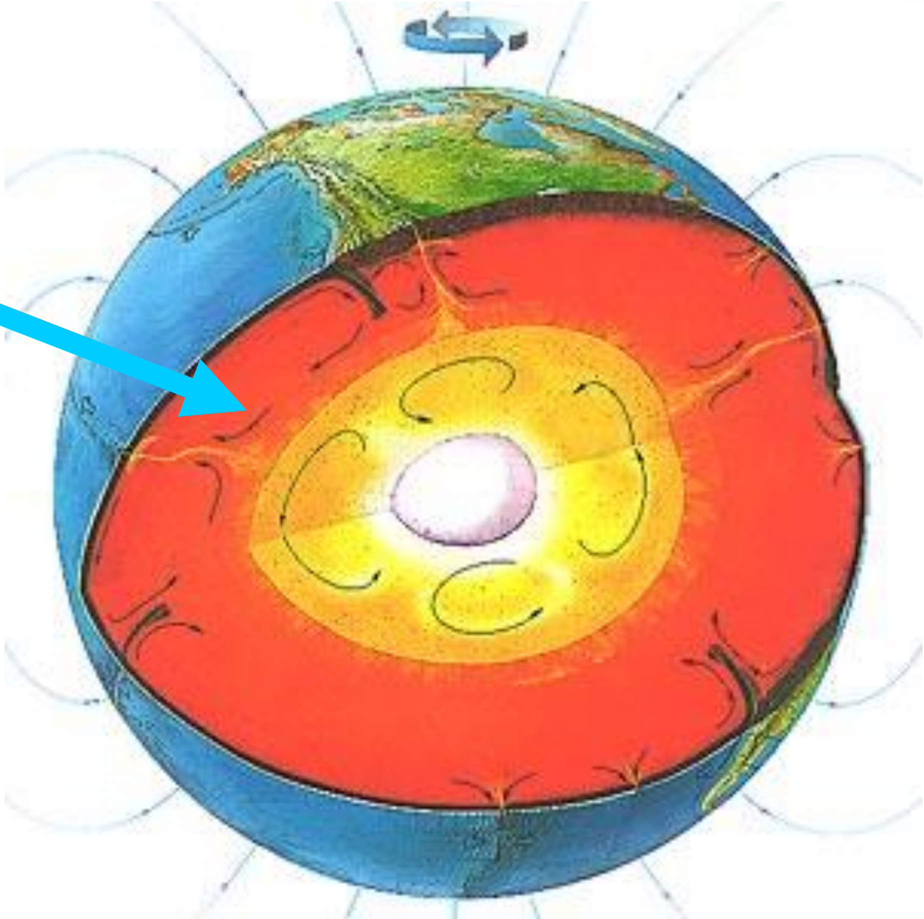


PLATE TECTONICS theory is very young (1960-ies)

Basic İdea: A shell of ridig plates (continents are “rafting” on a viscous interior (mantle)

It provides answers to the most fundamental questions in seismology:

- Why earthquakes occur?
- Why are earthquake epicenters not uniformly distributed around the globe?
- At what depths are their foci?

Evidence for Plate Movements

- Geology
- Topological
- Paleontology and Paleoclimates
- Hot spots
- Seismology
- GPS
- Earthquakes
- Volcanoes
- Mountains

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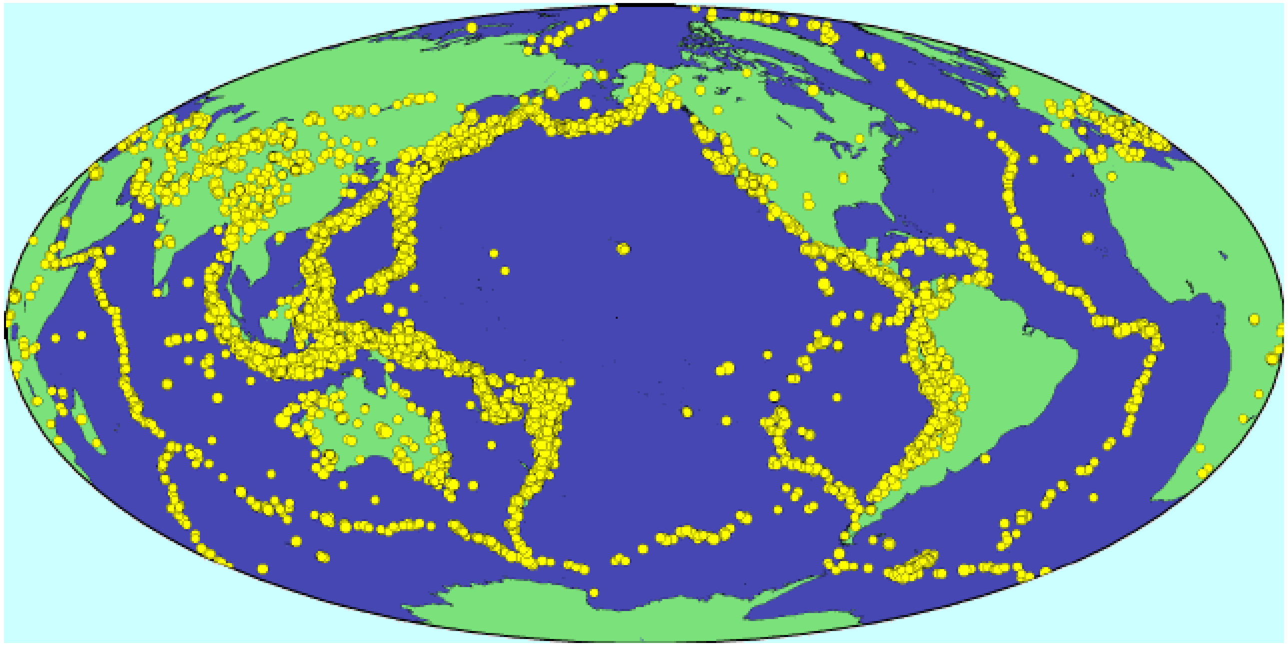
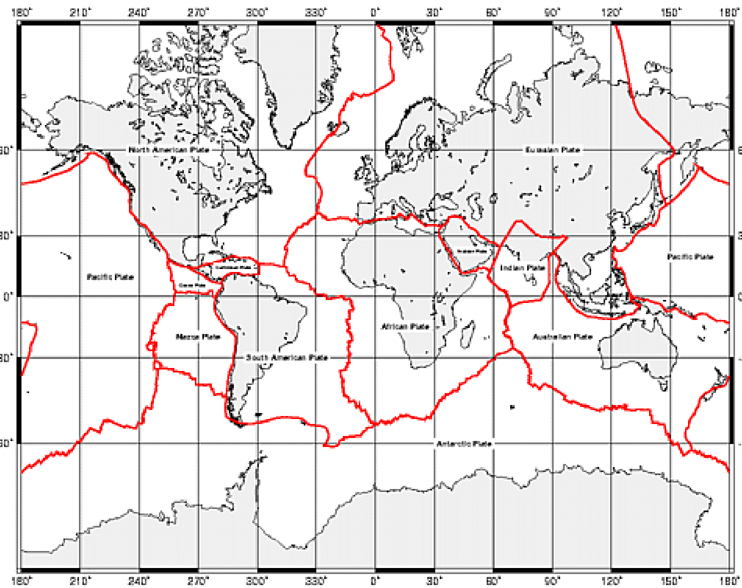
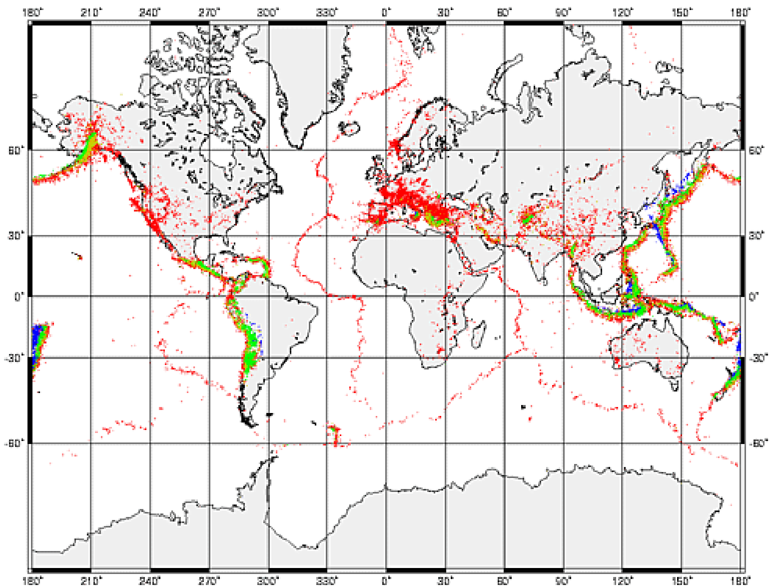
Seismicity in the World

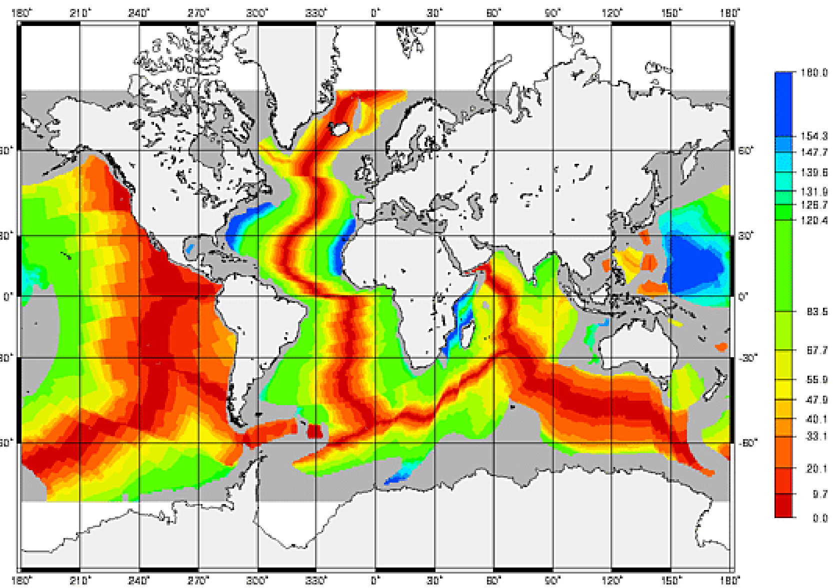


MAJOR TECTONIC PLATES

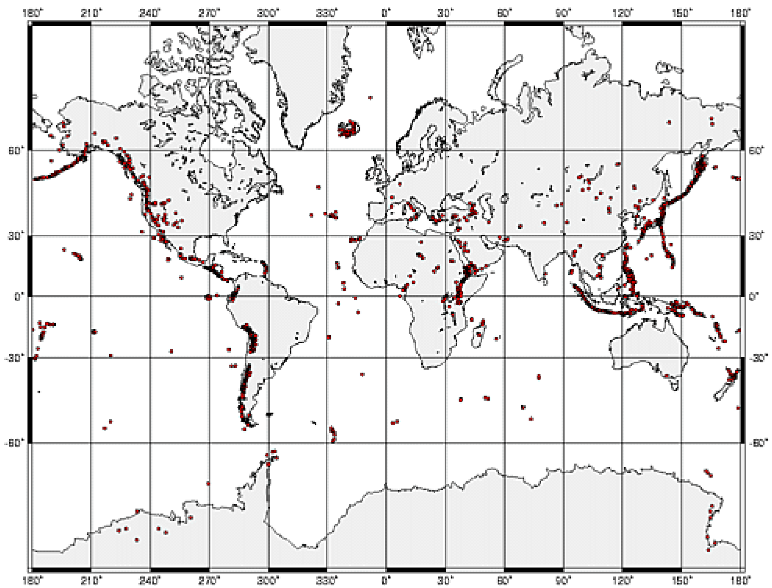


EARTHQUAKE EPICENTRES



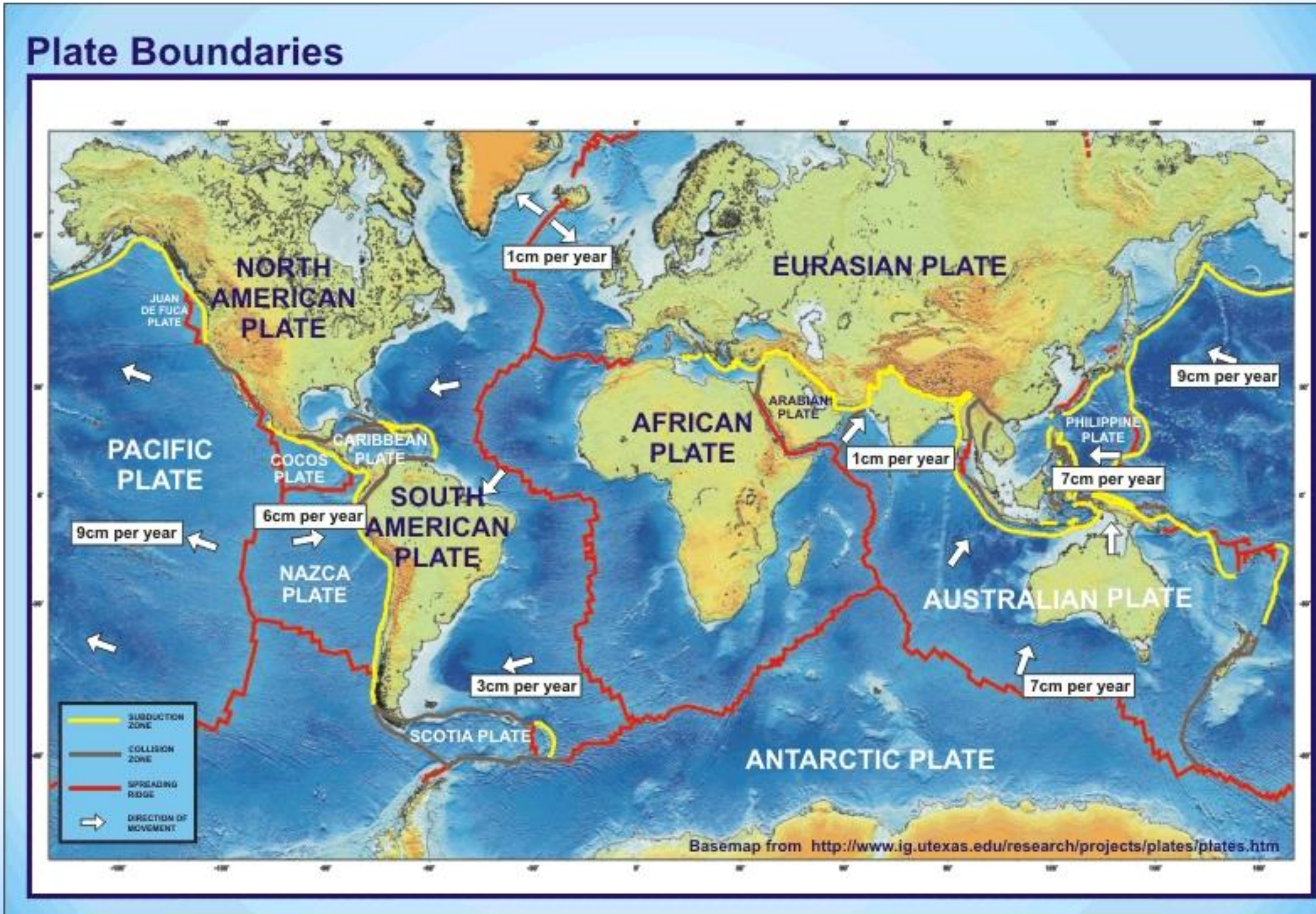


OCEAN-BOTTOM AGE

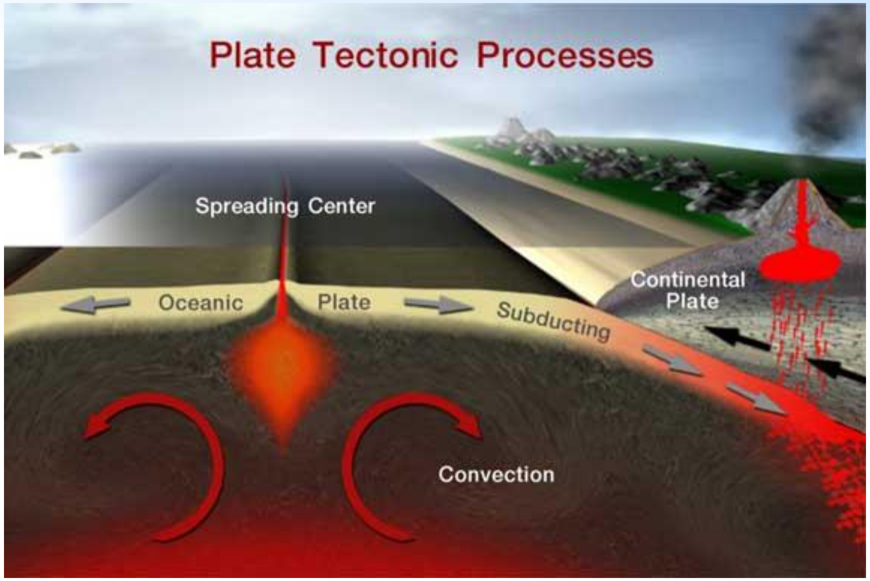


VOLCANOES

Plate Movements



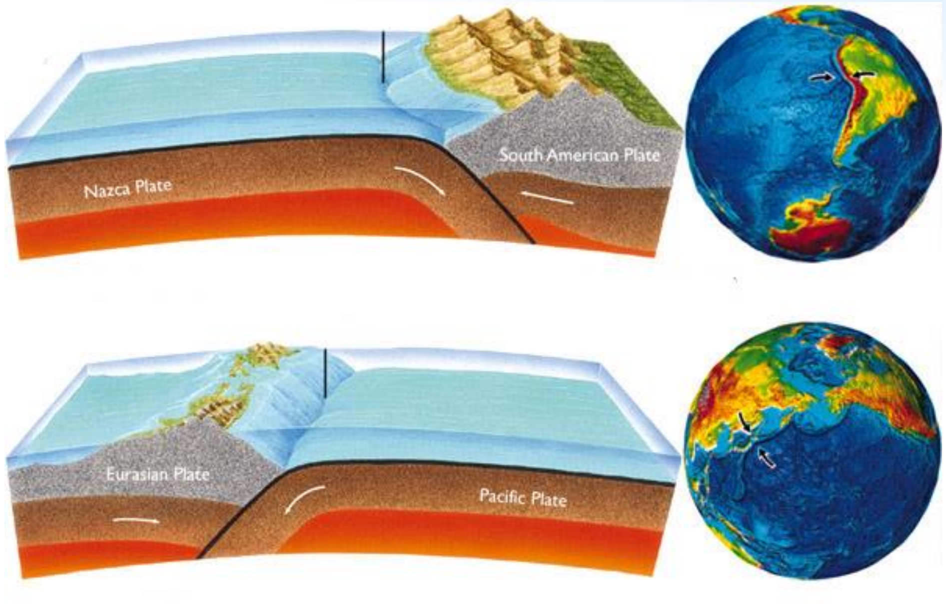
- Tectonic **plates** are large parts of litosphere **'floating'** on the astenosphere



- Convective currents move them around with velocities of several cm/year.
- The plates interact with one another in three basic ways:
  a)collide
  b)move away from each other
  c) slide one past another

Review: Earthquakes and Earthquake Engineering

- Collision leads to **SUBDUCTION** of one plate under another. Mountain ranges may also be formed (Himalayas, Alps...).
- It produces strong and sometimes very deep earthquakes (up to 700 km).
- Volcanoes also occur there.



EXAMPLES: Nazca – South America

Eurasia – Pacific

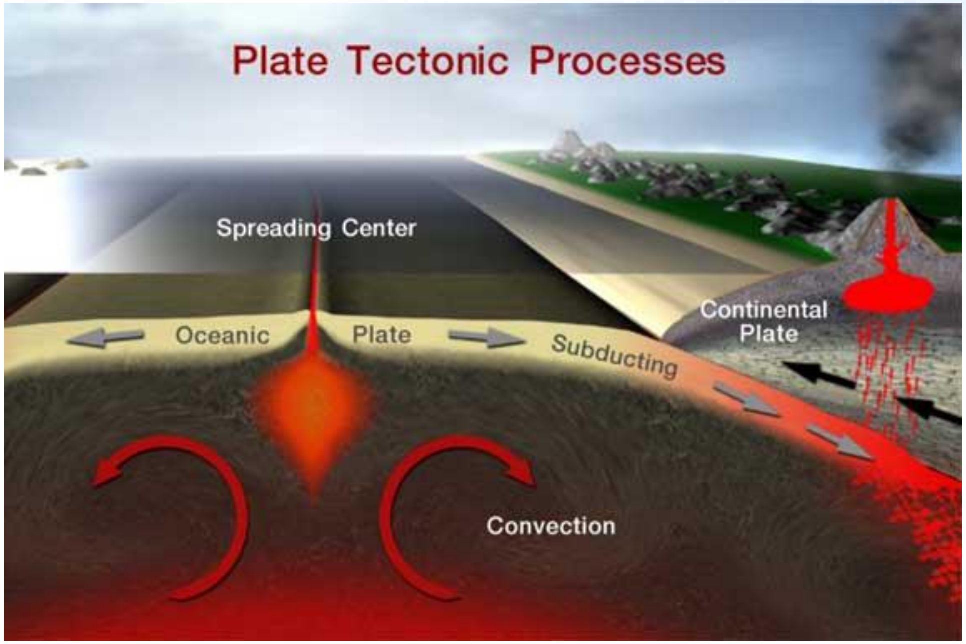
1960 Chilean EQ, M=9.5

1964 Alaskan EQ M=9.2

1994 Bolivian EQ M=8.3

Review: Earthquakes and Earthquake Engineering

- Plates moving away from each other produce **RIDGES** between them (spreading centres).
- The earthquakes are generally weaker than in the case of subduction.



EXAMPLES: Mid-Atlantic ridge (African – South American plates, Euroasian –North American plates)

Red Sea 1995 Nuweiba EQ

Nazca Ridge

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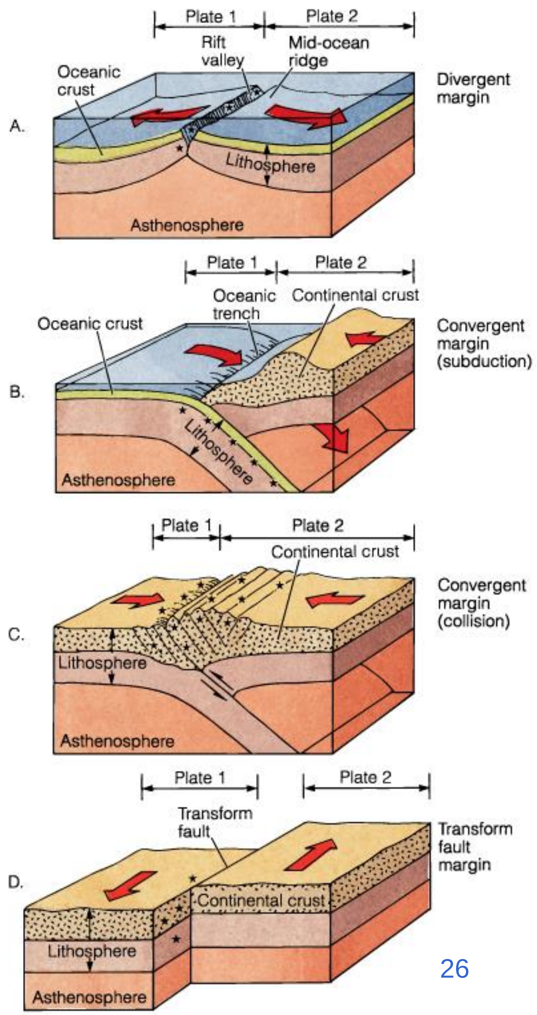
- Plates moving past each other do so along the **TRANSFORM FAULTS.**
- The earthquakes may be very strong.



EXAMPLES: San Andreas Fault (Pacific – North American plate)

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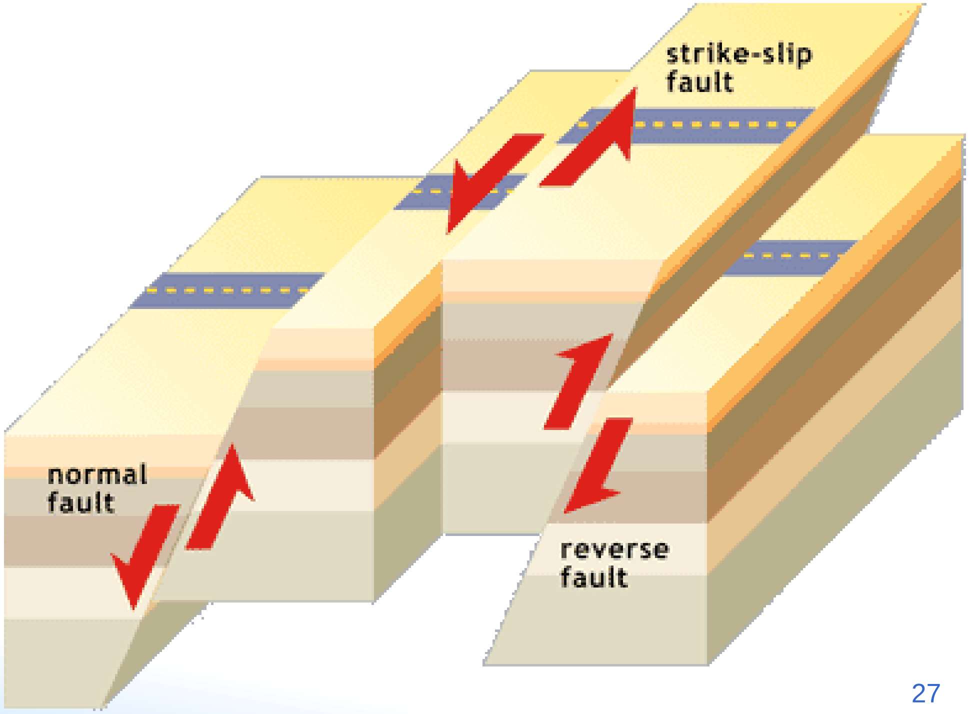
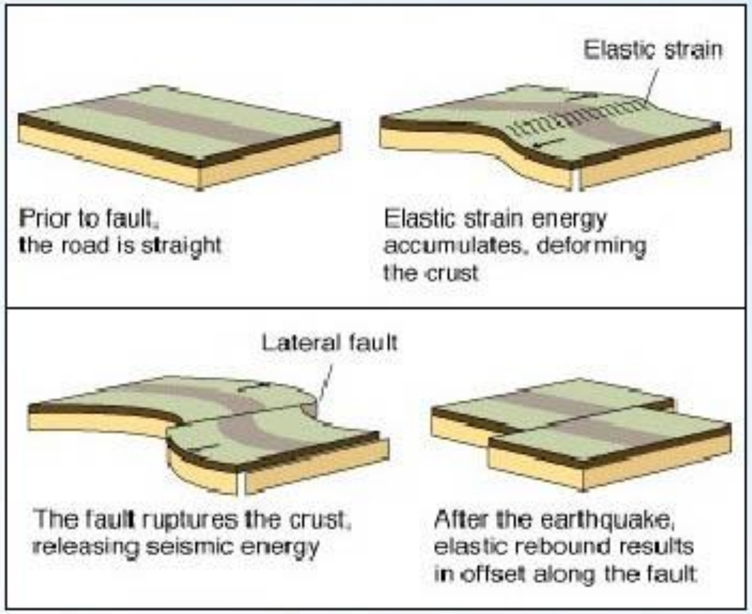
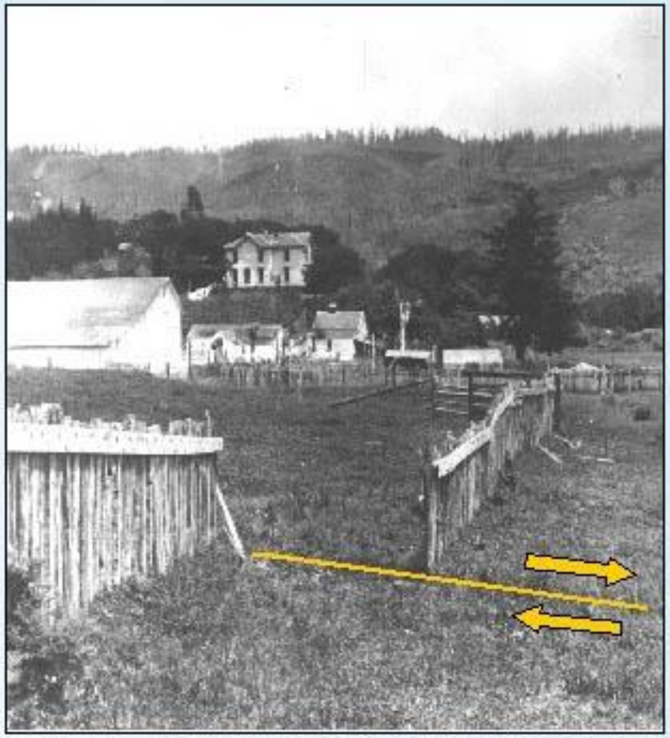
- Earthquakes occur at **FAULTS.**
- Fault is a weak zone separating two geological blocks.
- Tectonic forces cause the blocks to move relative one to another.



Elastic Rebound Theory Relates Faulting and Earthquakes

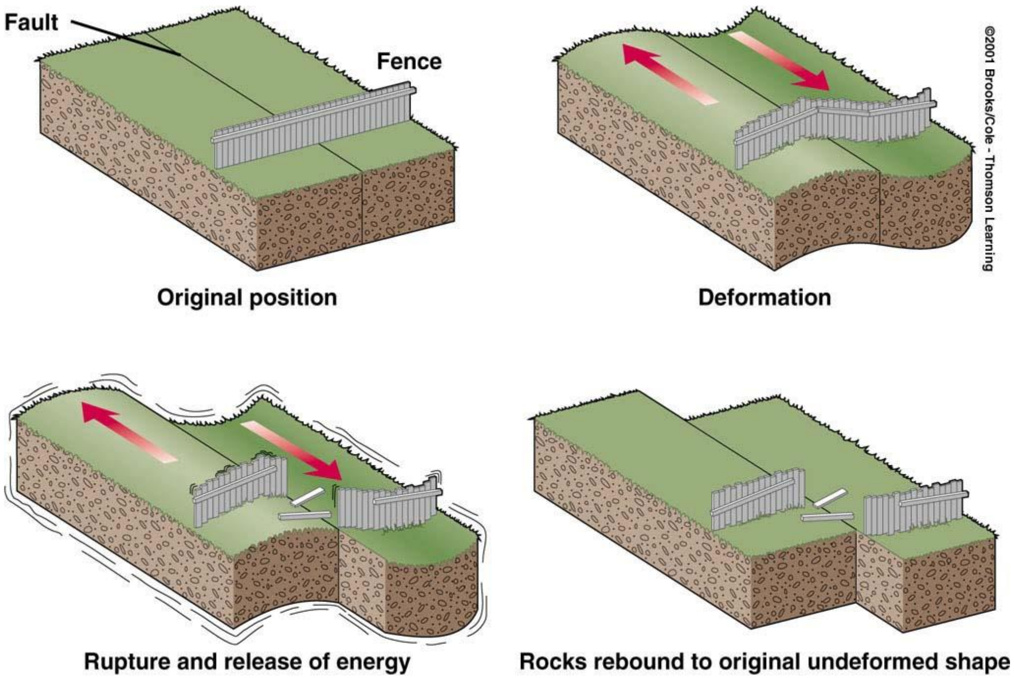


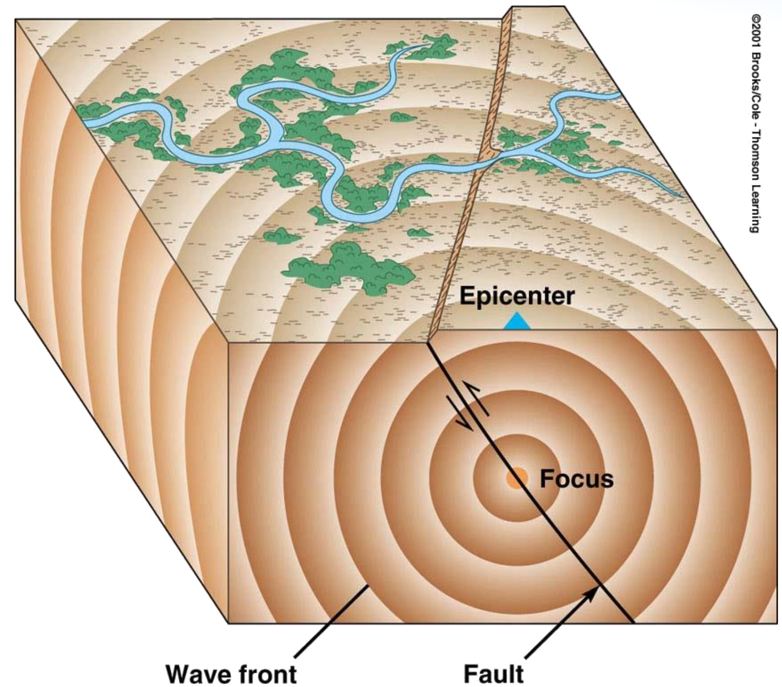
- Fence offset in 1906 quake on San Andreas Fault



Review: Earthquakes and Earthquake Engineering

tic rebound theory





- Because of friction, the blocks do not slide, but are deformed.
- When the stresses within rocks exceed friction, rupture occurs.
- Elastic energy, stored in the system, is released after rupture in waves that radiate outward from the fault.

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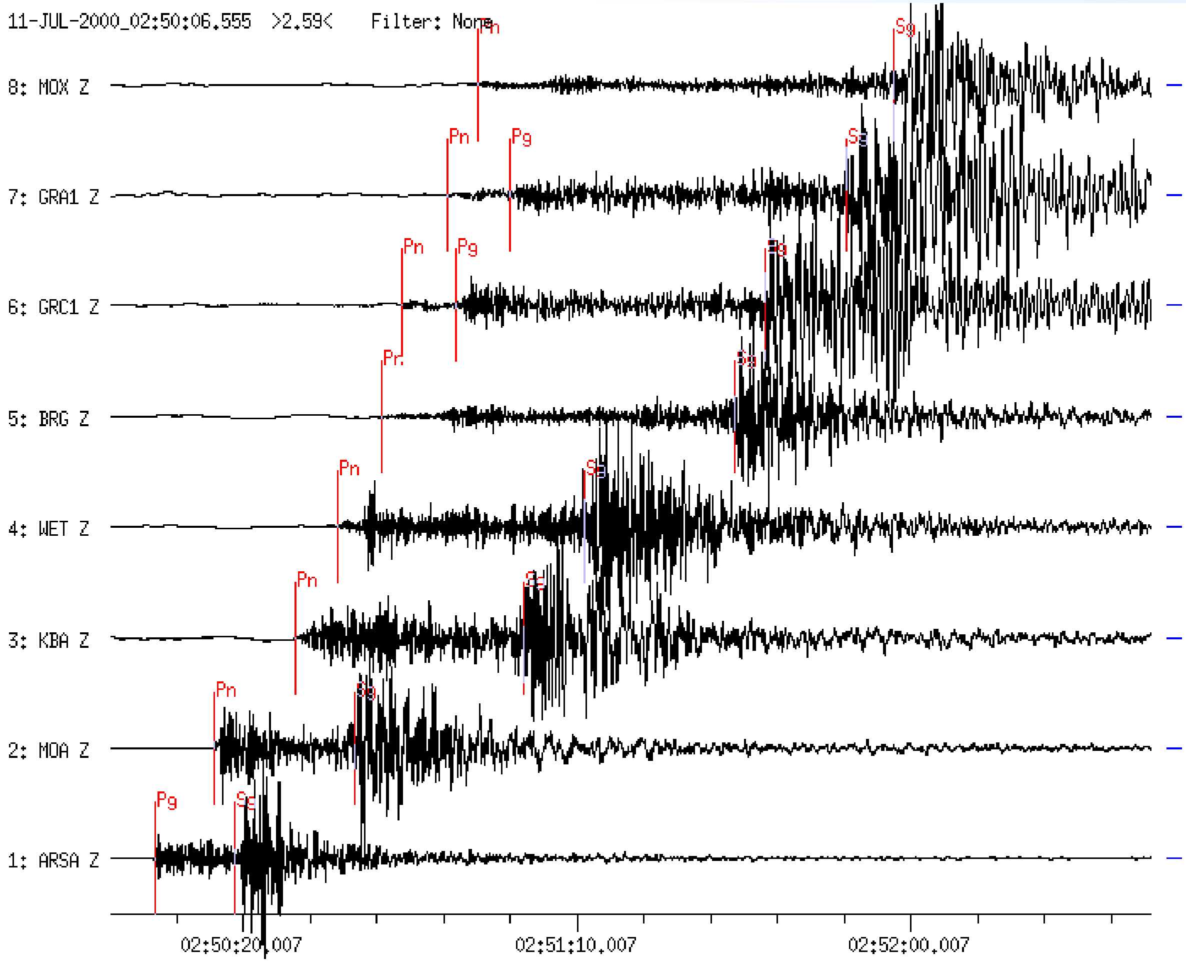
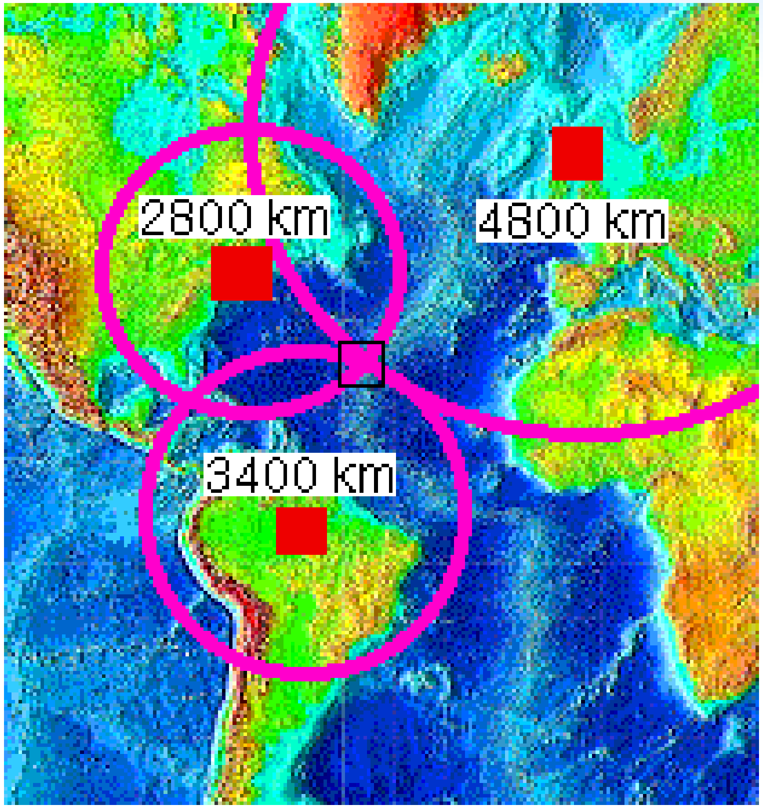


Another example of picking arrival times

Review: Earthquakes and Earthquake Engineering

- After we know the distance of epicentre from at least three stations we may find the epicentre like this
- There are more sofisticated methods of locating positions of earthquake foci. This is a classic example of an *inverse problem.*



Review: Earthquakes and Earthquake Engineering

Formula:

$M = \log(A) + c_1 \log(D) + c_2$

where *A* is amplitude of ground motion, *D* is epicentral distance, and c_1, c_2 are constants.

■ There are many types of magnitude in seismological practice, depending which waves are used to measure the amplitude:

M_L, m_b, M_c, M_s, M_w, ...

■ Increase of 1 magnitude unit means ~32 times more released seismic energy!

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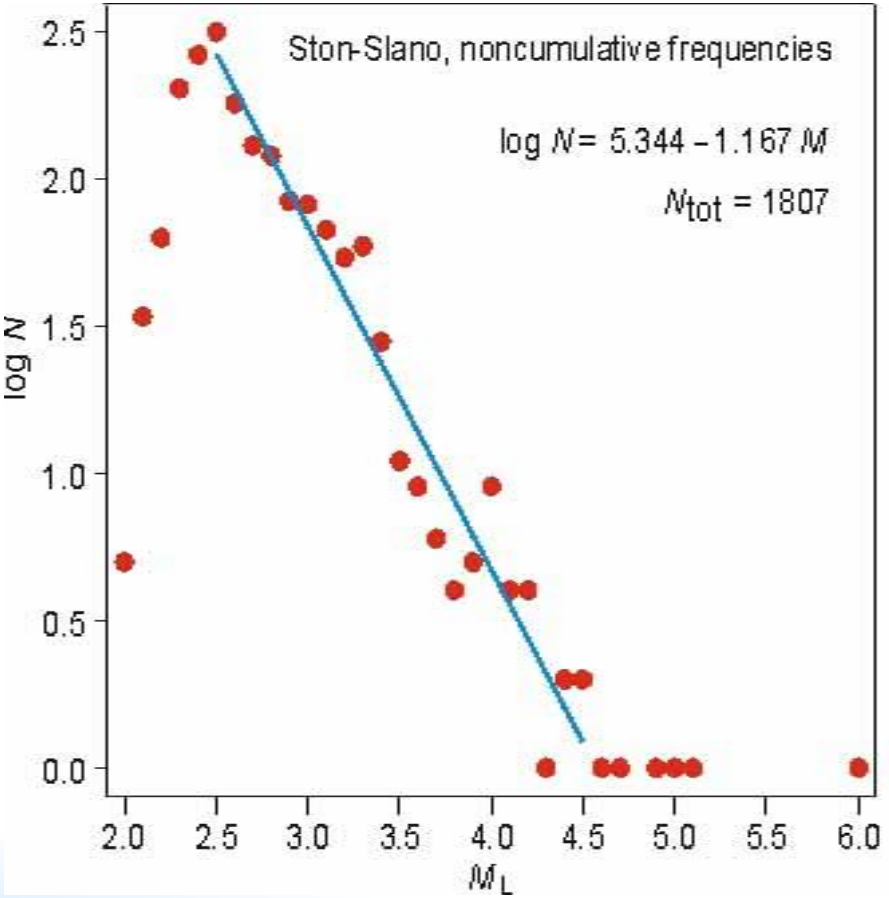

- Gutenberg-Richter frequency-magnitude relation:

  $\log N = a - bM$

- b is approximately constant, $b = 1$ world-wide $\rightarrow$ there are ~10 more times M=5 than M=6 earthquakes

- This shows selfsimilarity and fractal nature of earthquakes.

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Objective

1.4. The objective of this Safety Guide is to provide recommendations on how to meet the requirements established in SSR-1 [1] in relation to the evaluation of hazards generated by earthquakes that might affect a nuclear installation site and, in particular, on how to determine the following:
(a) **The vibratory ground motion hazards** necessary to establish the design basis ground motions and other relevant parameters for the design and safety assessment of **both new and existing nuclear installations**;
(b) The potential for, and the rate of, **fault displacement phenomena** that could affect the feasibility of a site for a new nuclear installation or the safe operation of an existing installation at a site;
(c) The earthquake parameters necessary for assessing the associated **geological and geotechnical hazards (e.g. soil liquefaction, landslides, differential settlements, collapse due to cavities and subsidence phenomena)** and concomitant events (e.g. external flooding phenomena such as tsunamis and fires).

Seismic Hazards and Site Evaluation for Nuclear Installations

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Scope

1.8. **The recommendations for nuclear power plants are applicable to other nuclear installations by means of a graded approach**, whereby these recommendations can be customized to suit the needs of nuclear installations of different types in accordance with the potential radiological consequences of their failure when subjected to seismic loads. **The recommended approach is to start with the recommendations for nuclear power plants and to modify the application of those recommendations until they are commensurate with installations with which lesser radiological consequences are associated.** If **no grading is performed, the recommendations relating to nuclear power plants should be applied to other types of nuclear installation.** The level of detail and the effort devoted to evaluating the seismic hazards at existing installation sites should be commensurate with a number of additional factors (e.g. **the time remaining until the installation is expected to be shut down, the stage of site remediation, the severity of the seismic hazards where the site is located**).

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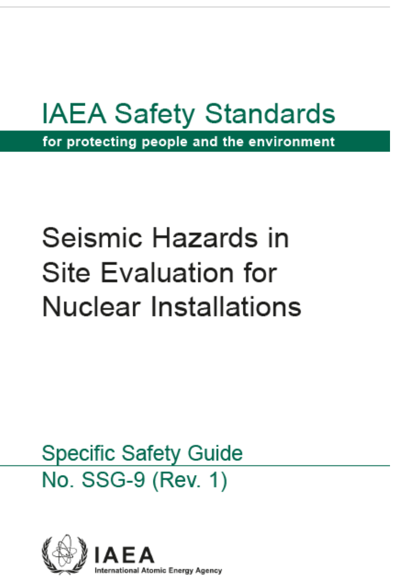
Scope

1.9. For the purpose of this Safety Guide, existing nuclear installations are installations that are (a) **at the operational stage** (including long term operation and extended temporary shutdown periods); (b) **at a pre-operational stage** for which the construction of structures, the manufacturing, installation and/or assembly of components and systems, and commissioning activities are significantly advanced or fully completed; or (c) **at a temporary shutdown, permanent shutdown or decommissioning stage**, **with radioactive material still within the installation** (e.g. in the reactor core or the spent fuel pool).

Seismic Hazards and Site Evaluation for Nuclear Installations



Scope

1.10. Earthquakes generate several direct and indirect phenomena, from **vibratory ground motions to associated geological and geotechnical hazards,** such as permanent ground displacement (e.g. **soil liquefaction, slope instability, tectonic and non-tectonic subsidence, cavities leading to ground collapse, differential settlements**), to subsequent concomitant events such as seismically induced fires and floods. This Safety Guide provides guidance on how to consistently characterize and define the seismic parameters necessary for evaluating the geological and geotechnical hazards and concomitant events as described in IAEA Safety Standards Series No. **NS-G-3.6, Geotechnical Aspects of Site Evaluation and Foundations for Nuclear Power Plants** [3], and IAEA Safety Standards Series

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2. General Aspects of SHA

2.1.The following requirements are established in SSR-1 [1]:

Requirement 15: Evaluation of fault capability

"**Geological faults** larger than a certain size and within a certain distance of the site and that are **significant to safety shall be evaluated** to identify **whether these faults are to be considered capable faults**. **For capable faults**, potential challenges to the safety of the nuclear installation in terms of **ground motion and/or fault displacement hazards shall be evaluated**."

…….

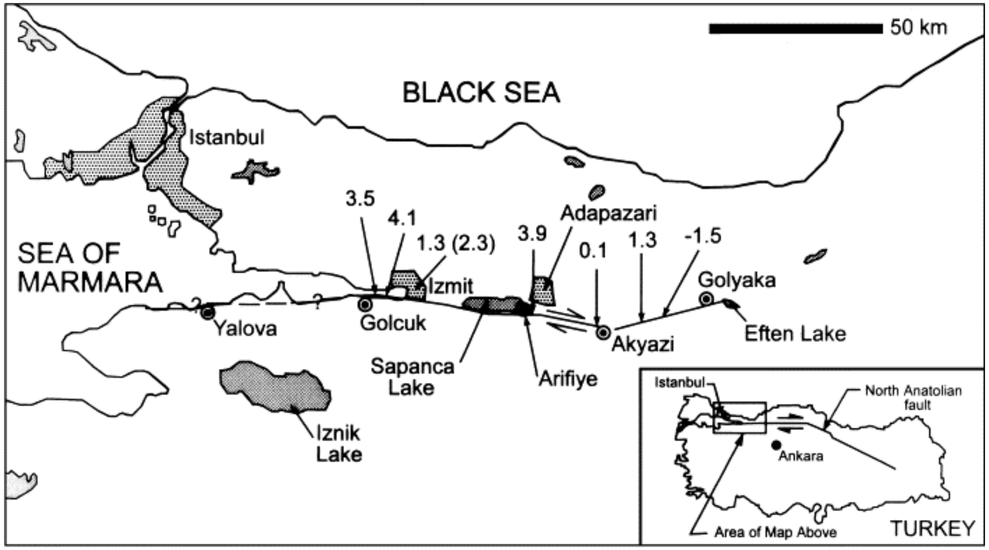
Requirement 16: Evaluation of ground motion hazards

"An evaluation of **ground motion hazards shall be conducted** to provide the input needed for the seismic design or safety upgrading of the structures, systems and components of the nuclear installation, as well as the input for performing the **deterministic and/or probabilistic safety analyses** necessary during the lifetime of the nuclear installation."

Review: Fault Displacement

Slip rate: mm/year

Slip per event: Average and maximum slip per event

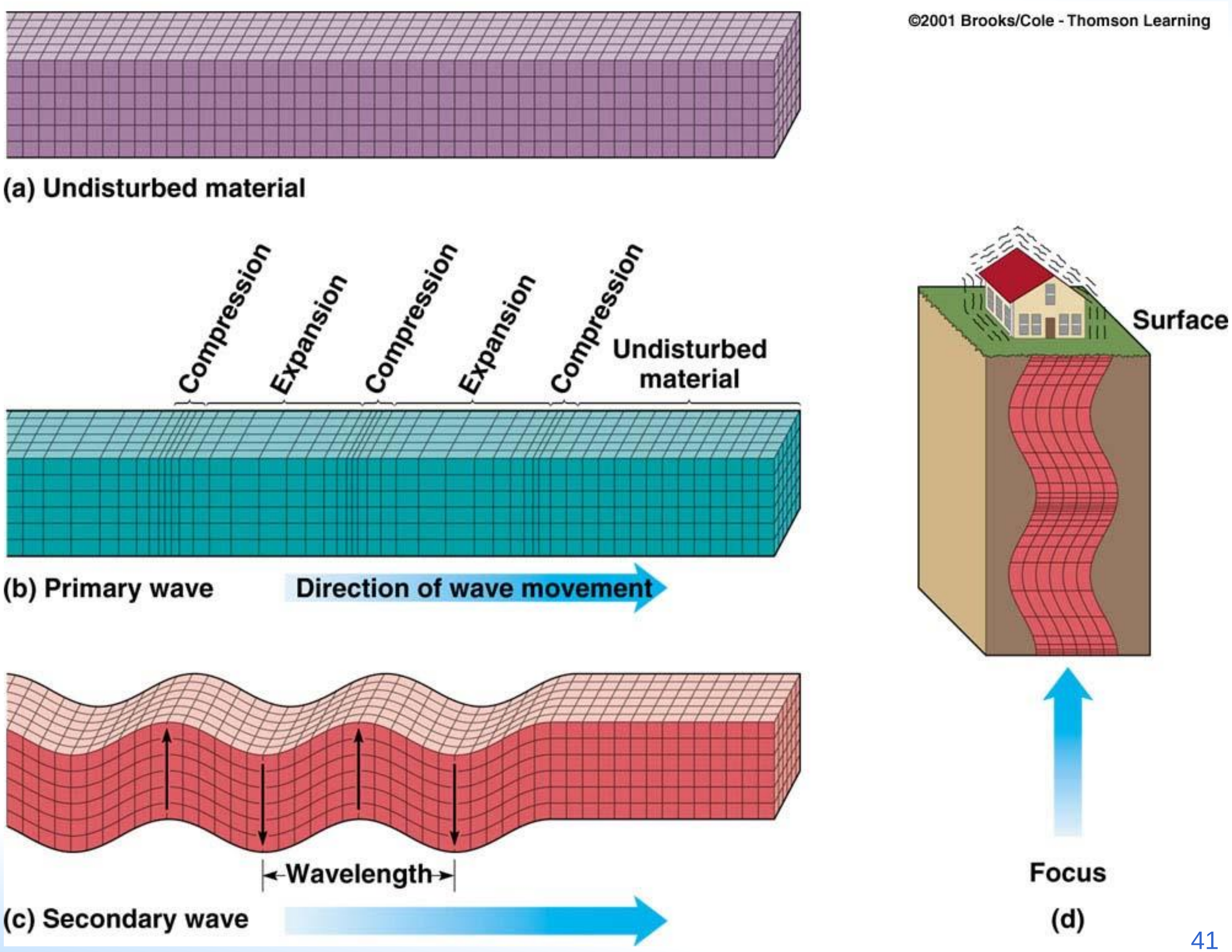


Review: Earthquakes and Earthquake Engineering

Elastic waves – Body waves

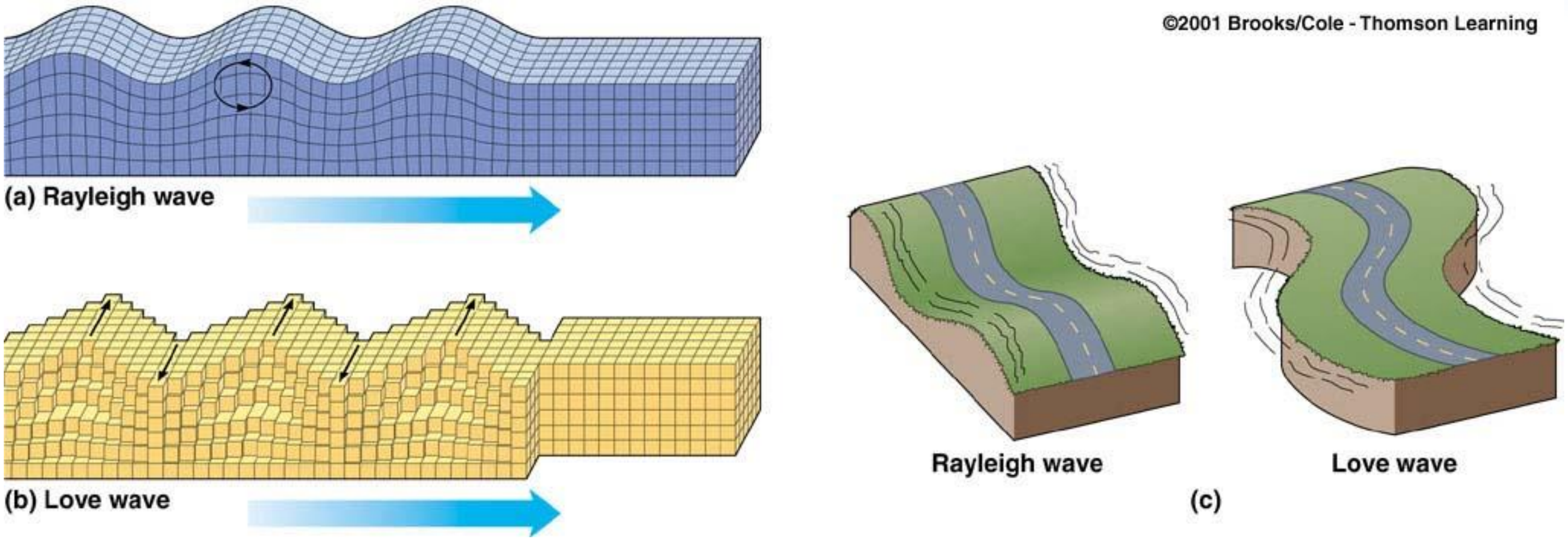
P-waves:

S-waves:



Review: Earthquakes and Earthquake Engineering

Elastic waves – Surface waves

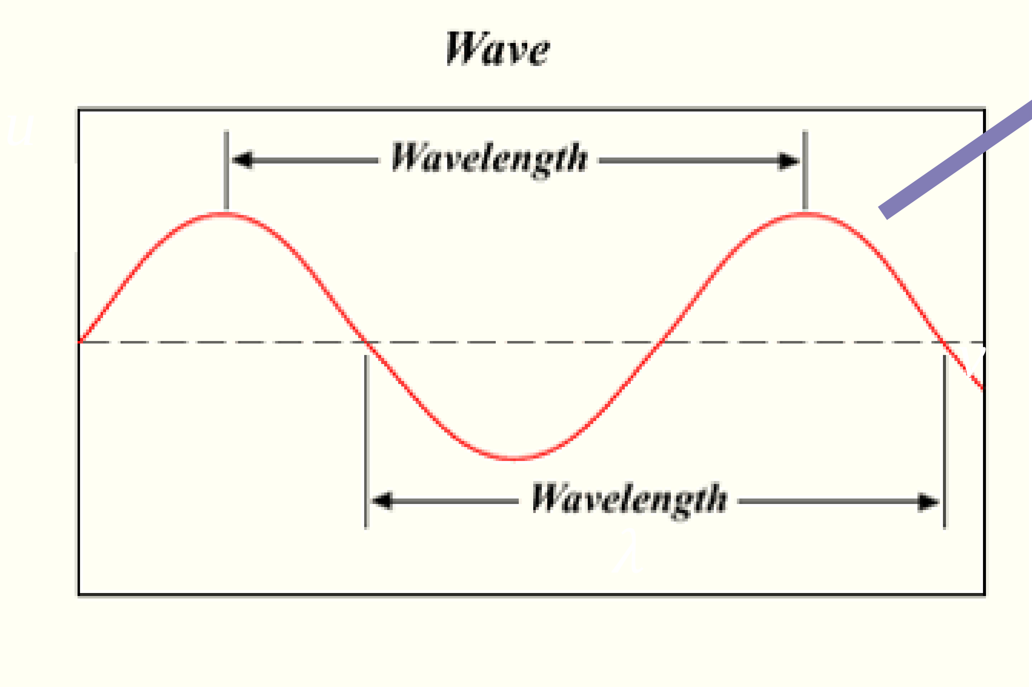


Surface waves: Rayleigh and Love waves

- Their amplitude diminishes with the depth.
- They have large amplitudes and are **slower** than body waves.
- These are dispersive waves (large periods are faster).

Review: Wave Propagation: Definitions

- Wave propagation



$$u: u_{max} sin w_n(t)$$

$$T: period = time/cycle$$

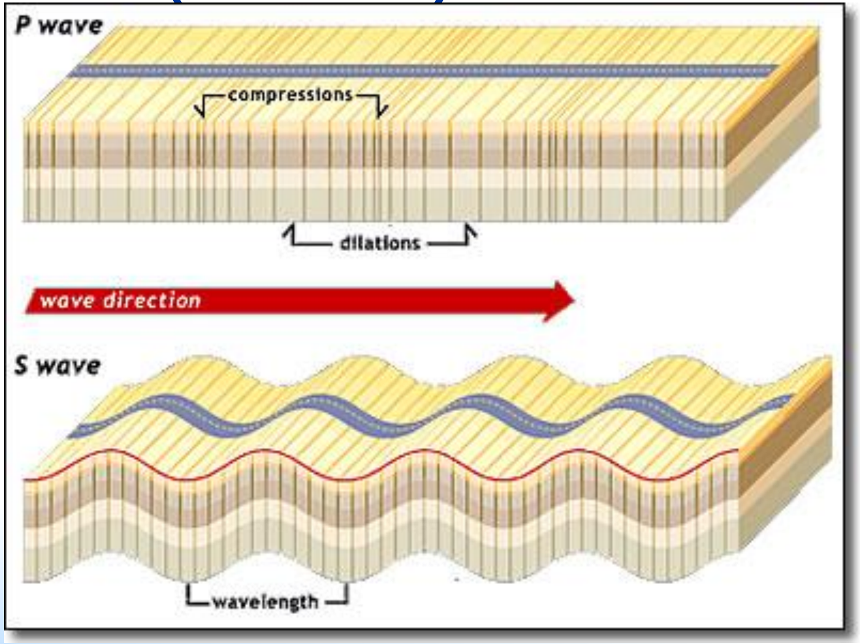
$$v = \frac{\lambda}{T}$$

$$w: circular\ freq. = 2\pi f$$

$$f: 1/T$$

Review: Types of Waves

- Body Wave
- P (waves) compression
- S (waves) shear



$$V_P = \sqrt{\frac{2G(1-v)}{p(1-2v)}}$$

$$V_S = \sqrt{\frac{G}{\rho}} \rightarrow G = \rho V_S^2$$

$$\frac{V_P}{V_S} = \sqrt{\frac{2(1-v)}{(1-2v)}} = 1.5 - 2.0$$

Typical granit rocks

V_P=5-6 km/s

V_S=3-4 km/s

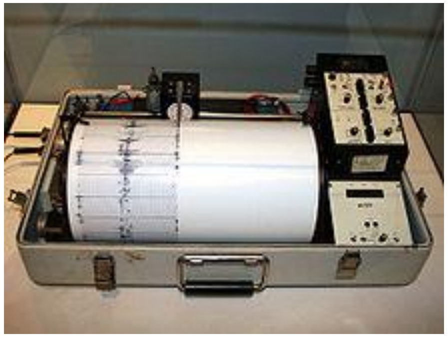
Water

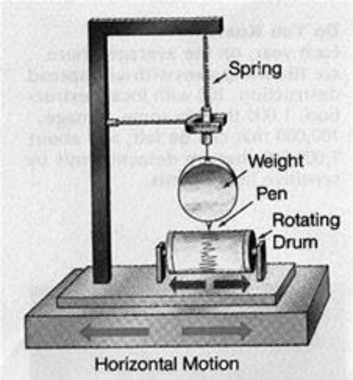
V_P=1.5 km/s

V_S=0 km/s

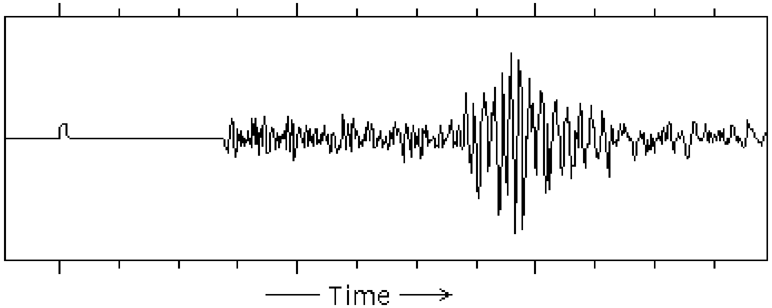
Review: Some Definitions

- Seismograph

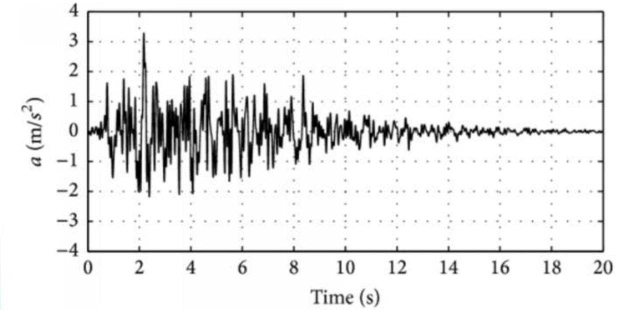




- Seismogram



- Accelerogram



Review: Earthquakes and Earthquake Engineering

Seismographs

- Modern digital broadband seismographs are capable of recording almost the whole seismological spectrum (50 Hz – 300 s).

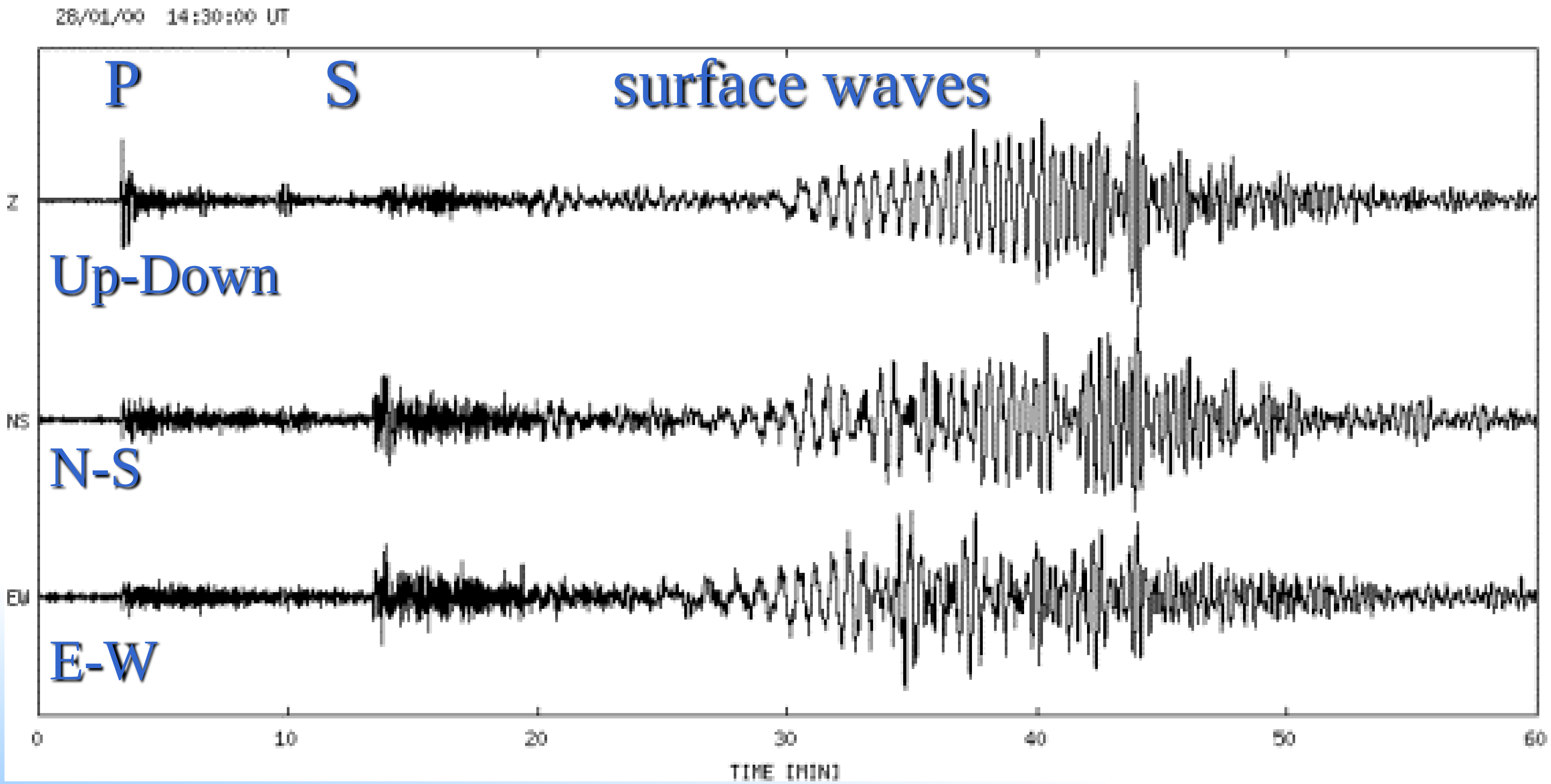
- Their resolution of 24 bits (high dynamic range) allows for precise recording of small quakes, as well as unsaturated registration of the largest ones.

Review: Earthquakes and Earthquake Engineering

Seismogram

Earthquake in Japan Station in Germany

Magnitude 6.5



Review: Earthquakes and Earthquake Engineering

Vibratory Ground Motion

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2. General Aspects of SHA

2.4. The evaluation of seismic hazards for a nuclear installation site should be done through the implementation of a specific project plan for which clear and detailed objectives are defined, and with a project organization and structure that provides for **coherency and consistency in the database** and a reasonable basis on which to compare results for all types of seismic hazard. This project plan should include an independent peer review. It should be carried out by a **multidisciplinary team of experts, including geologists, seismologists, geophysicists, seismic hazard specialists, engineers and possibly other experts (e.g. historians) as necessary**. The members of the team for the seismic hazard assessment project and the independent peer review should demonstrate expertise and experience commensurate with their role in the project. Figure 1 shows the seismic hazard assessment process as a whole and the general steps and sequence to be followed.

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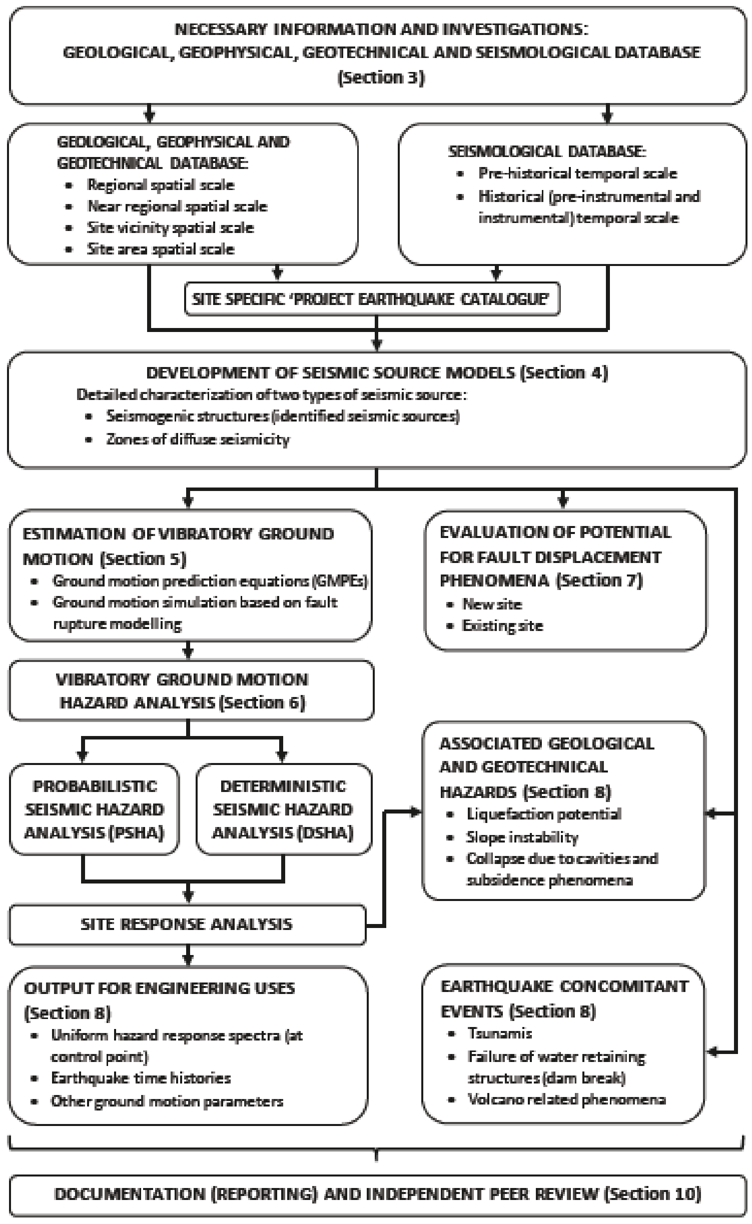

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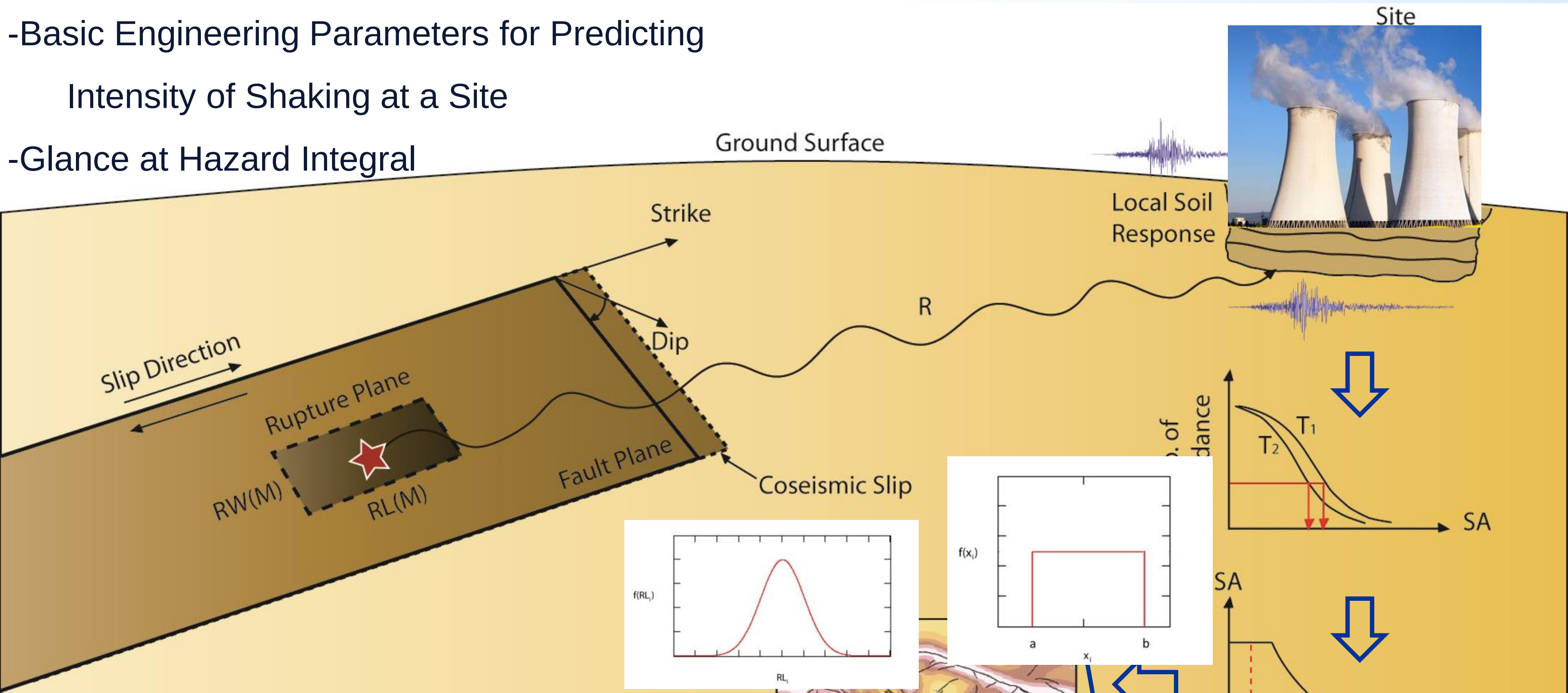
Review: Seismic Hazard Assessment Framework

IAEA

- -Basic Engineering Parameters for Predicting
  Intensity of Shaking at a Site
- -Glance at Hazard Integral



Hazard Integral

$$\upsilon_i(A \ge a) = N_i(M_{\min}) \cdot P_i(A \ge a \mid E_i(m > M_{\min}))$$

$$P_i(A > a \mid E_i(m \ge M_{\min})) = \int_{R_L=0}^{R_L=R_{\max}} \int_{x=0}^{x=1} \int_{m=M_{\min}}^{m=M_{\max}} P_i(A > a \mid m, r(x, R_L)) \cdot f_{M_i}(m) \cdot f_{R_{L,i}}(m) \cdot f_{x_i}(x) \cdot dm\, dx\, dR_L$$

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2. General Aspects of SHA

2.5.The general approach to seismic hazard assessment should be directed towards the **realistic identification, quantification, treatment and reduction of uncertainties** through all stages of the project. Experience shows that the most effective way of achieving this is to **collect sufficient reliable and relevant site specific data**. There is generally a compromise between the time and effort needed to compile a detailed, reliable and relevant database and the degree of uncertainty that should be taken into consideration at each step of the process. Thus, **applying a lower level of effort in developing the database for characterization of the seismic sources, fault capabilities and ground motions will result in increased uncertainty** in the final results obtained.

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2. General Aspects of SHA

2.6.Therefore, an adequate method for identification, quantification and treatment of the uncertainties should be formulated at the beginning of the project. In general, significant uncertainties are associated with the seismic hazard assessment process. Basically, **two types of uncertainty** are identified for practical application in seismic hazard assessment: (i) **the aleatory variability** of the seismic process, which is inherent in phenomena that occur in a random manner and as such cannot be reduced, even by collecting more data, and (ii) **the epistemic uncertainty**, which is attributable to incomplete knowledge about a phenomenon (therefore affecting the ability to model it) and which can be reduced through the acquisition of additional data (including site specific data), further research and interaction between experts considering the diversity of their professional judgement [2].3

2.7. Site specific, sufficient and reliable data should be collected in the seismic hazard assessment process. However, part of the data used indirectly in the seismic hazard analysis might not be site specific (in particular, the data on strong motions used to develop **ground motion prediction equations (GMPEs)**). Therefore, relevant uncertainties should be taken into consideration.

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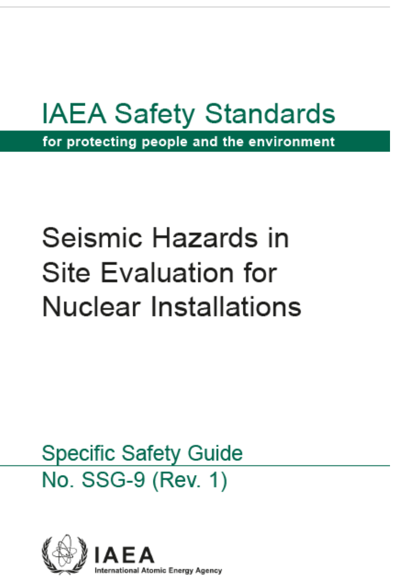
2. General Aspects of SHA

2.8.One of the main sources of epistemic uncertainty in seismic hazard assessment is the differences in interpretation of the available data owing to the diversity of professional judgement of the experts participating in the hazard assessment process. Care should be taken to avoid bias in these interpretations. **Expert judgement should not be used as a substitute for acquiring new data**. The project team for the seismic hazard assessment should evaluate, without bias, all hypotheses and models supported by the data compiled and should then develop an integrated model that takes into account both existing knowledge and uncertainties in the data. Where it is required to evaluate much longer periods (lower exceedance frequencies) than the data permit, knowledge of the regional and local geodynamics and neotectonics can support the use of expert judgement.

Seismic Hazards and Site Evaluation for Nuclear Installations



2. General Aspects of SHA

2.9.**Structured expert interactions should be employed to avoid artificial influence of uncertainty estimates on the results**. To address the diversity of scientific interpretations, the centre, body and range of the technically defensible interpretations should be properly captured [6]. For this purpose, **multidisciplinary teams of experts** with appropriate qualifications in each of the relevant areas should be involved in developing a model that robustly represents the epistemic uncertainties relating to methods and models employed in the seismic hazard assessment. Where an approach makes use of expert elicitation, care should be exercised to ensure that professional judgements made by experts are supported, so far as is practicable, by the available earth science data. Also, adequate consideration should be given to uncertainties using suitable (e.g. conservative, best estimate) and credible models, methods and scenarios — based on the concept of technically defensible interpretations — as appropriate for the evaluation framework (i.e. deterministic or probabilistic) and the target confidence levels. **The composition of the peer review panel should also reflect the size and complexity of the project generally.**

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2. General Aspects of SHA

2.10. A set of quality assurance documents should be prepared and properly updated during the seismic hazard assessment process. All technical references used in the process will be useful, since the guidance they provide might be interpreted in different ways. An unambiguous set of project specific quality documents (e.g. **quality plan, work plan and procedures) should be prepared so that the set contains all the criteria applicable to the project at hand; documentation recording all expert interpretations should also be included**. More detailed recommendations on this topic are provided in Section 10.

2.11. As indicated in para. 2.8, uncertainties that cannot be reduced by means of site specific investigations (e.g. uncertainties arising from the use of GMPEs derived for other parts of the world) do not permit hazard values to decrease below certain threshold values. For this reason, and irrespective of any lower apparent seismic hazard associated with the site, **a minimum vibratory ground motion level should be recognized as the lower limit to be used for seismic design**, safety assessment and/or seismic safety evaluation of any nuclear installation, and that minimum level should be adopted when applying the recommendations in SSG-67 [5].

Seismic Hazards and Site Evaluation for Nuclear Installations

3. Database and Information and Investigations

3.1. A comprehensive and integrated database of **geological, geophysical, geotechnical and seismological information** should be compiled in a coherent form for use in evaluating and resolving issues relating to hazards generated by earthquakes.

3.2.It should be ensured that each element of each individual database has been investigated as fully as possible before integration of the various elements into **a unique consolidated database** is attempted. The integrated database should **include all relevant information**, not only geological, geophysical, geotechnical and seismological data but also any other information relevant to evaluating the vibratory ground motion, the fault displacement phenomena, the associated geological and geotechnical hazards, and the concomitant events affecting the site.

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3. Database and Information and Investigations

3.1. A comprehensive and integrated database of **geological, geophysical, geotechnical and seismological information** should be compiled in a coherent form for use in evaluating and resolving issues relating to hazards generated by earthquakes.

3.3.The data and information to be acquired for the geological, geophysical, geotechnical and seismological **database should cover a geographical region** and a temporal scale commensurate with the potential of the seismic hazards to affect the safety of the nuclear installation at the site.

3.4. In relation to the **geographical area of interest to be investigated**, SSR-1 [1] states:

"Requirement 5: Site and regional characteristics

"**The site and the region shall be investigated** with regard to the characteristics that could affect the safety of the nuclear installation and the potential radiological impact of the nuclear installation on people and the environment.

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3. Database and Information and Investigations

3.6.**The size of the geographical area at the regional scale** for which the geological, geophysical, geotechnical and seismological database should be compiled **may differ depending on the geological and tectonic setting**, and the recommendations provided in para. 2.3 should be used to define the appropriate size of the region to be investigated.

3.7.The geological, geophysical and geotechnical investigations for evaluating the seismic hazards at the site should be conducted on **four spatial geographical scales — regional, near regional, site vicinity and site area** — leading to progressively more detailed investigations, data and information. The detail and type of these data are determined by the different spatial geographical scales. The first three scales of investigation lead, primarily, to progressively more detailed geological and geophysical data and information. The site area investigations are mainly aimed at developing the geophysical and geotechnical database for evaluation of vibratory ground motion and fault displacement.

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3. Database and Information and Investigations

3.8. With the completion of the geological, geophysical and geotechnical investigations **at the four spatial scales**, all seismogenic features that have been identified and characterized, including assessment of the uncertainties for all fault parameters, should be documented finally and in a systematic way to **ensure consistency and completeness**, so that similar attributes for all seismic sources can be compiled in the '**project fault catalogue**' (also known as the 'project fault portfolio').

3.9.The seismological database should include all available information and data on earthquake events that have occurred in the region, and such information and data should cover the **pre-historical and historical temporal scales**. The historical temporal scale should be further subdivided into **pre-instrumental and instrumental periods**.

3.10.**In offshore regions and other areas for which seismological data are poor, adequate investigations should be conducted** to fully analyse the tectonic characteristics of the region and to compensate for any lack of or deficiency in the seismological data.

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3. Database and Information and Investigations

3.11.In investigations **to evaluate the potential for earthquake generated tsunamis, the geological and seismological investigations should also include the study of seismic sources located at very great distances** from the site. Thus, the sources of earthquakes that can generate relevant seismic hazards and relevant tsunami hazards at the site might not be the same. For tsunamis generated by earthquake induced submarine landslides, the models used to calculate the ground motion inducing the landslide should be consistent with those models used in the seismic hazard assessment for the nuclear installation.

3.12.New techniques that have recently emerged in the acquisition and processing of data (e.g. **remote sensing, age dating, use of dense seismic observation networks**) for the identification and characterization of seismic sources should be implemented. It is also possible that new types of data might be generated as a result of these technological developments. While it is recommended that state of the art, new, updated and recognized technological developments be implemented, such developments should first be checked for adequacy and effectiveness before being used in a nuclear installation site evaluation project.

Seismic Hazards and Site Evaluation for Nuclear Installations

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3. Database and Information and Investigations

3.13.As earthquakes produce observable effects on the environment, **palaeoseismological studies should be performed**, as necessary, at any of the four spatial scales to achieve the following:

(a) To identify the **seismogenic structures** on the basis of recognition of effects of past earthquakes in the region.
(b) To improve the **completeness of earthquake catalogues** for large events, using identification and age dating of geological markers such as fossils. For example, observations of trenching across the identified potential capable faults may be useful in estimating the amount of displacement (e.g. from the thickness of colluvial wedges) and its rate of occurrence (e.g. by age dating of the sediments). Also, studies of palaeo-liquefaction, palaeo-landslides and palaeo-tsunamis can provide evidence of the recurrence and intensity of earthquakes.
(c) To estimate the **potential maximum magnitude** (and the associated uncertainty) of a given seismogenic structure, typically based on the maximal dimensions of the structure and the displacement per event (estimated from the trenching) as well as the cumulative effect of all seismogenic structures (estimated from the seismic landscape).

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3. Database and Information and Investigations

3.14.To achieve consistency in the presentation of information, the data should be compiled in a **geographical information system with adequate metadata**. All data should be stored in a uniform reference frame to facilitate comparison and integration.

3.15.When a seismic hazard assessment is performed during the lifetime of the nuclear installation (e.g. for a periodic safety review or a seismic probabilistic safety assessment), **the existing database should be updated** in accordance with the recommendations provided in paras 3.1–3.14 above as part of the seismic hazard re-evaluation process.

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Regional investigations

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3.16. The purpose of obtaining **geological and geophysical data on a regional scale is to provide knowledge of the general geodynamic setting of the region and the current tectonic regime, as well as to identify and characterize those geological features evaluated from investigations**, such as lithology, geomorphology, stratigraphy and fault investigations, that might influence or relate to the seismic hazard at the site.

3.17. Thus, the extent of the geographical area of interest at a regional scale should be defined in accordance with the recommendations provided in para. 3.6 and by considering the potential sources of all hazards generated by earthquakes that might affect the safety of the nuclear installations at the selected site. The size of the region to be investigated when assessing vibratory ground motion hazards should be large enough to incorporate all seismogenic structures that could affect the nuclear installation: **the extent of this region is typically a few hundred kilometres in radius, or in keeping with the national requirements of the State.**

Seismic Hazards and Site Evaluation for Nuclear Installations

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Regional investigations

3.18.**Existing data from any type of published or unpublished geological or geophysical source** (e.g. data from the literature; data on the country as a whole; remote sensing data; data derived from existing galleries or road cuts, geophysical surveys or geotechnical characteristics) should be searched and, if necessary, confirmed by direct observation through geological field reconnaissance visits.

3.19.Where **existing data are insufficient to properly characterize the identified potential geological features** relevant to the seismic hazard at the site, **further investigations should be considered**; if necessary, these data should be interpreted using reasonable and defensible hypotheses. It may be necessary to complement the data by acquiring new geological and geophysical data of sufficient detail, similar to the level of detail for the near region. If needed, identification and analysis of geological and geomorphological evidence (i.e. palaeoseismology; see para. 3.13) of pre-historical and historical earthquakes, including geodynamic investigations, should also be performed for this purpose.

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Regional investigations

3.20.The data collected at the regional scale **should have a resolution that can reveal any features considered to be significant for the analysis of the seismic hazard**, with appropriate cross-sections. The collected data and the results obtained should have a resolution consistent with maps at the appropriate scale. The data should be organized in the project geographical information system within the layer of regional scale information, and a summary report should be prepared to describe the studies and investigations performed and results obtained, particularly in relation to the seismogenic structures identified at this stage of the studies.

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Near regional investigations

3.21. Geological, geophysical and geotechnical investigations should be conducted in more detail in the near region to **provide more specific information** than that available from the regional studies, with the following objectives:
(a) To define the seismotectonic characteristics of the near region;
(b) To determine the most recent movements of the seismogenic structures and/or potential capable faults identified in the near region;
(c) To determine the amount and nature of displacements, rates of activity and evidence relating to the segmentation of such seismogenic structures.

3.22. The near regional studies should include **a geographical area typically not less than 25 km in radius from the site boundary**, although this dimension should be adjusted to reflect local seismotectonic conditions. For new nuclear installation sites for which the exact layout of the buildings and structures has not been defined, the near regional area should be defined from the boundary of the prospective site area.

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Site vicinity investigations

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3.27. In addition to the information collected at the regional and near regional scales, more specific geological, geophysical and geotechnical studies should be conducted in the site vicinity with the objective of providing **a more completed database for this smaller area regarding the definition and characterization in greater detail of the neotectonic history** of the identified seismogenic structures (e.g. faults), especially to determine the potential for and the rate of fault displacement at the site (fault capability) and to identify conditions of potential geological and/or geotechnical instability and associated earthquake generated hazards that might affect the nuclear installation.

3.28.Site vicinity studies should cover a geographical area sufficient to encompass all faults and other seismotectonic features requiring detailed geophysical investigation; **this area is typically not less than 5 km** (see para. 1.12 of SSR-1 [1]) in radius from the site boundary. For new nuclear installation sites for which the exact layout of the buildings and structures has not been defined, the 5 km radius should be defined from the boundary of the prospective site area.

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Site area investigations

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3.32. Additional geological, geophysical, geotechnical and seismological site specific studies should be conducted in the nuclear installation site area with the primary objective of providing (a) detailed knowledge for assessing the potential for **permanent ground displacement** phenomena associated with earthquakes (e.g. surface fault rupture, liquefaction, subsidence or collapse due to subsurface cavities) and (b) information on the **static and dynamic properties of rock and soil materials** beneath the structure's foundations (e.g. P wave and S wave velocities, seismic quality factor Q,5 density) to be used in the site response analysis to assess the vibratory ground motions that might affect the safety of the structures, systems and components of the nuclear installation.

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3. Database and Information and Investigations
GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE

Site area investigations

3.33. The site area studies **should include the entire area covered by the nuclear installation**. For a proposed new site for a nuclear installation, at the site evaluation stage the exact layout of the units and/or installations might not yet be known and, for this reason, the entire prospective site area should be considered. For the existing site of an operating nuclear installation for which seismic safety re-evaluation is required, the site area will generally be well defined. If construction is planned for additional nuclear installation units on the existing site area, this should be taken into consideration in defining the extent of the site area.

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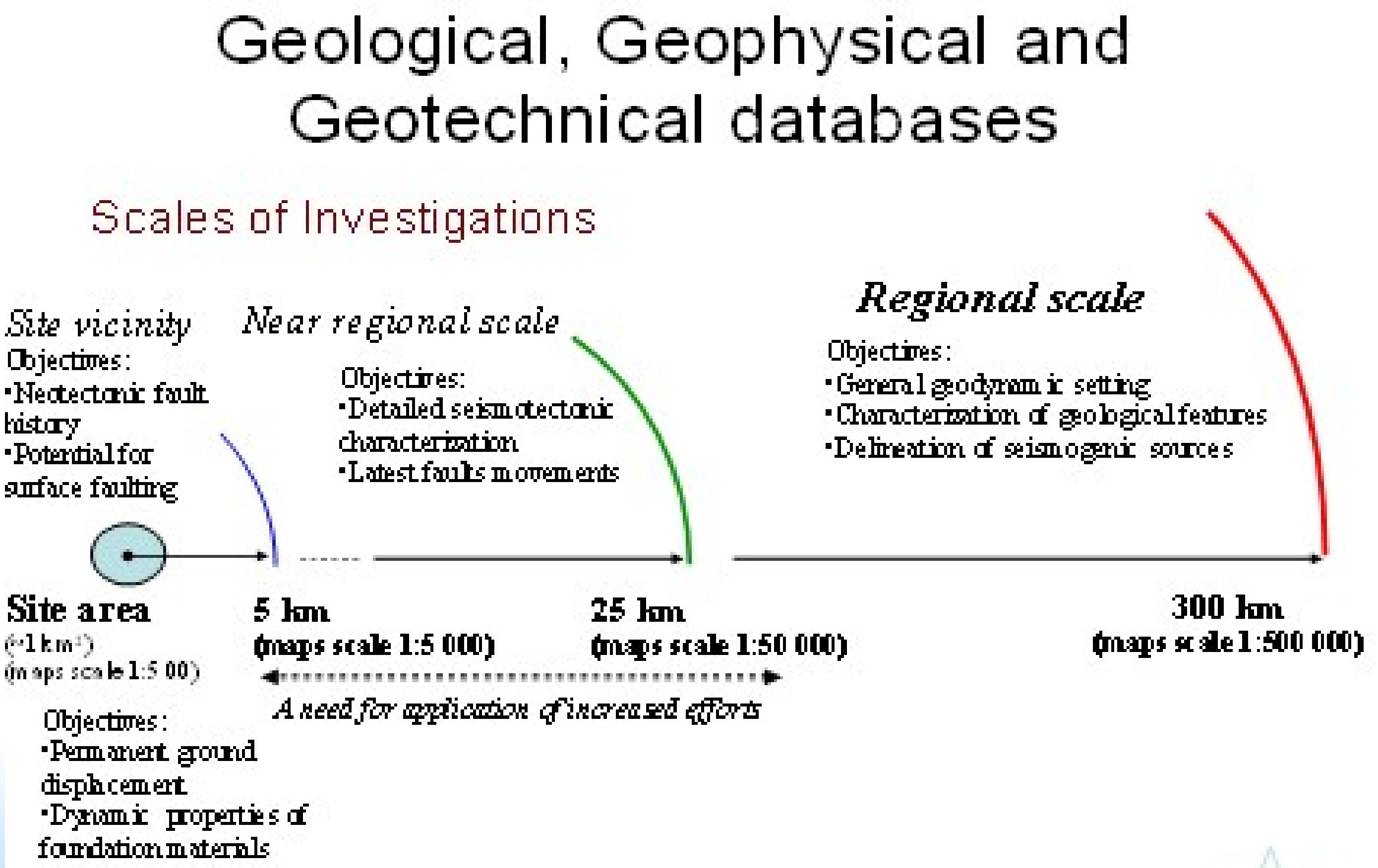
3. Database and Information and Investigations

GEOLOGICAL, GEOPHYSICAL AND GEOTECHNICAL DATABASE



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3. Database and Information and Investigations
SEISMOLOGICAL DATABASE

3.36. To enable reliable characterization of events that occur with very long recurrence periods (or very low annual frequencies of exceedance), the seismological database should include information on past events that might have generated seismic hazards at the site. The database should recognize two types of data relating to two temporal scales — historical and pre-historical — as defined below:

(a) Historical period: the period for which there are documented records of earthquake events. This period is further subdivided as follows:
(i) Pre-instrumental (or non-instrumental) period: the period before the development and use of instruments to record earthquake parameters;
(ii) Instrumental period: the period after the development and use of instruments to record earthquake parameters.
(b) Pre-historical period: the period for which there are no documented records of earthquake events. It includes the period in which earthquake evidence might only be retrieved from archaeological sites as described in carvings, paintings, monuments, drawings and other artefacts, including palaeoseismological and geological evidence.

Review: Magnitude Scales

- **Magnitude** arbitrarily defined measure of relative EQ size
- **Energy** proportonal to the size of EQ and is physically relevant parameter
- **Intensity** subjective quantification of EQs based on the level of damage to the built enviroment and people’s perception. It is related to EQ size, but intimately tied to wave propagation and local site response (Mercalli intensity)

$$\boxed{M = \log(A@T)\, f(\Delta, h) + C_S + C_R}$$

T: period of the signal

F: correction for epicentral distance Δ and focal depth h.

C_S: correction for siting of a station (soil or rock)

C_R: source region correction

Review: Magnitude Scales

Richter Magnitude

$$M_L = \log A - 2.48 + 2.76\Delta$$

Surface wave Magnitude

$$M_S = \log A + 1.66 \cdot \log \Delta + 2.0$$

Body Wave Magnitude

$$m_b = \log A - \log T + 0.01 \cdot \log \Delta + 5.9$$

A : The maximum AMPLITUDE of ground displacement in micro meters.

Δ : Seismometer's distance measure to the epicenter

T : The periof of the P wave

Review: Magnitude Scales

- Local (Richter) magnitude M_L
  - Based on peak amplitude of Wood and Anderson seismometer (T=0.8S, G=2080, ʒ=0.7)

$$\boxed{M_L = logA - 2.48 + 2.76\Delta \qquad \text{saturates} \sim 6.5}$$

- Body wave magnitude M_b
  - Based on the amplitude of the P-wave. This magnitude is based on the first few cycles of the P-wave arrival

$$\boxed{M = \log(A@T) + \theta(h,\Delta) \quad \text{saturates} \sim \text{Mb}=5.5\text{-}6.0}$$

A: ground motion amplitude in micrometers

Review: Magnitude Scales

- Surface wave magnitude M_s
  - Beyond ~ 600 km the long period seismograms of shallow EQs are dominated by surface waves (T=20 sec)

$$\boxed{M_s = logA_{20sec} + 1.66log\Delta + 2.0 \quad \text{saturates} \sim 7.5\text{-}8.0}$$

- Moment magnitude M_w
  - Seismic moment $\boxed{M_o = \mu A\bar{D}}$

μ: Shear modulus of rock ($\sim 3x10^{11}\ dyn/cm^2$)

A: area of fault slip (cm^2)

$\bar{D}$: average fault movement

$logM_o = 1.5M_w + 16.05$

Review: Moment Magnitude

Moment Magnitude

$M_0 = \mu \cdot A \cdot \overline{D}$ → Seismic Moment

$M_w = \dfrac{\log M_0}{1.5} - 10.7$ → Moment Magnitude

μ : Shear Modulus of Rock

A : Rupture Area

D : Average fault rupture

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3. Database and Information and Investigations

SEISMOLOGICAL DATABASE

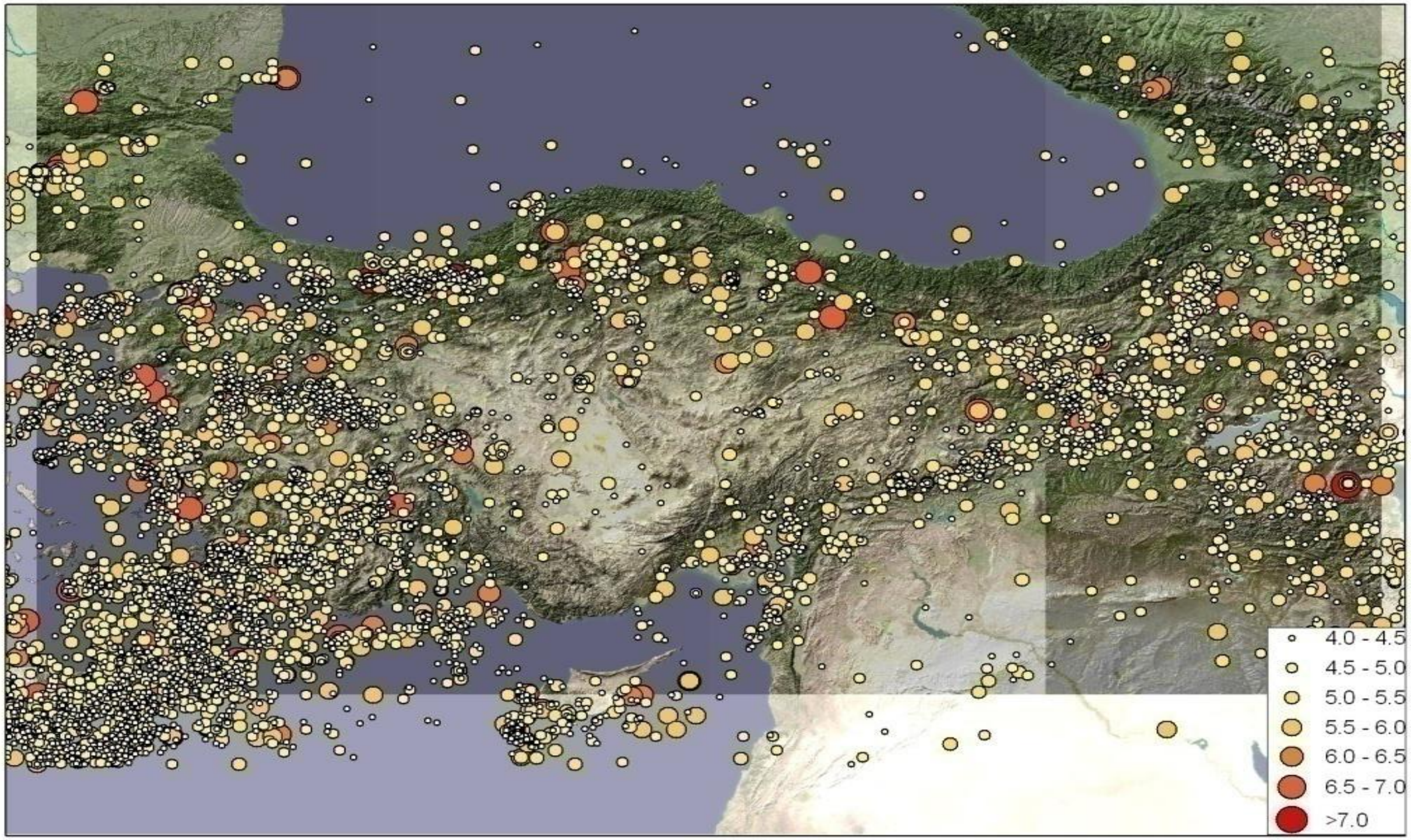
Site specific instrumental data

3.54. To acquire more detailed information on potential seismic sources, it is advantageous to install or have access to **a seismic monitoring network system of high sensitivity seismometers**. This system should be **installed and operated in the near region around the nuclear installation site** and within the site itself. The seismometers should have the capability of **recording micro-earthquakes and sufficiently high frequencies**. The design of the seismic monitoring network system should be suitable for the geological setting and for assessing the seismic hazards at the site. The data obtained from the operation of this system should also be used as a supporting tool in decisions regarding the capability of faults (see Section 7).

3.55. The seismic monitoring network system **should be installed for new sites from the very beginning of the site evaluation stage**. For existing sites for which such systems were not originally deployed, the seismic monitoring network system should be installed from the beginning of the seismic safety re-evaluation programme. These systems should be operated during the whole lifetime of the nuclear installation.

3.56. The operation and data processing of these seismic monitoring network systems should be **linked to any existing regional and/or national seismic monitoring network systems.**

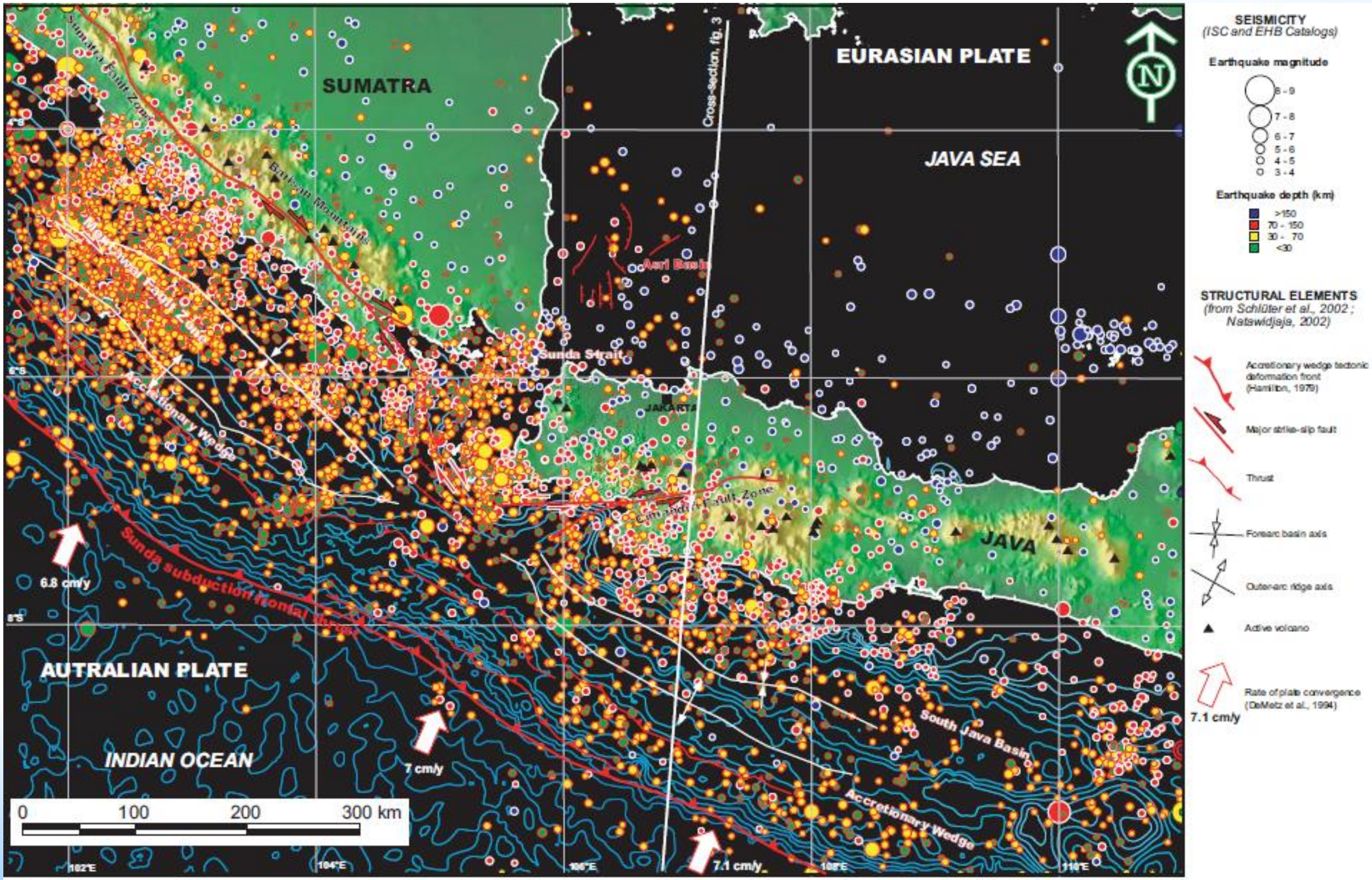
Seismological Database



Macroseismicity distribution for M>4 (KOERI catalogue)

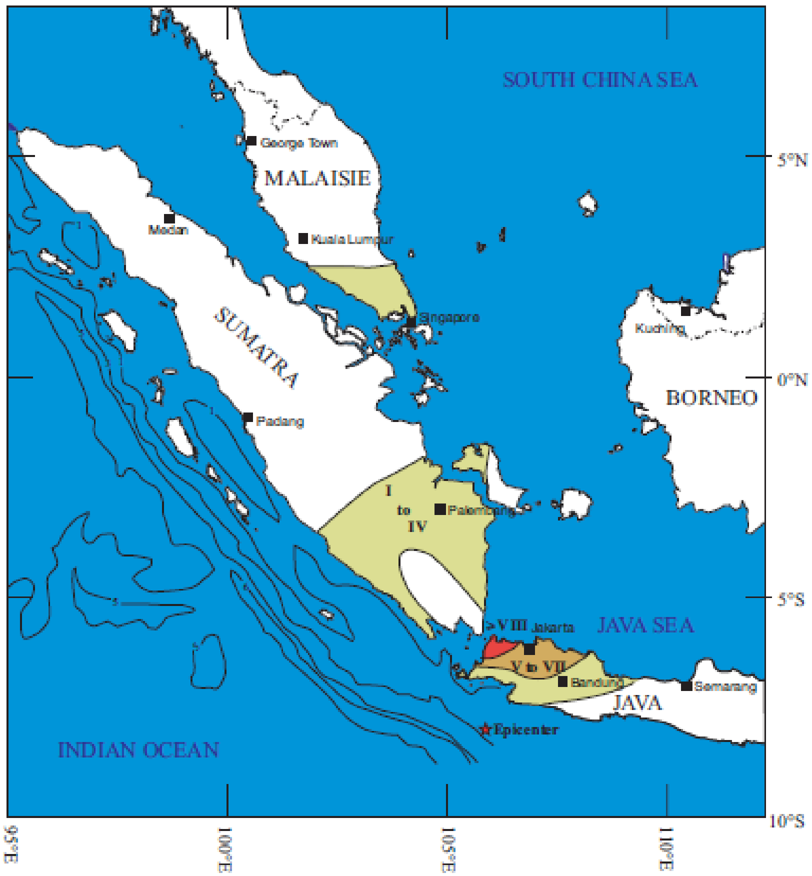
Seismological Database

Catalogue for a PSHA/DSHA: Indonesia case.



Seismological Database

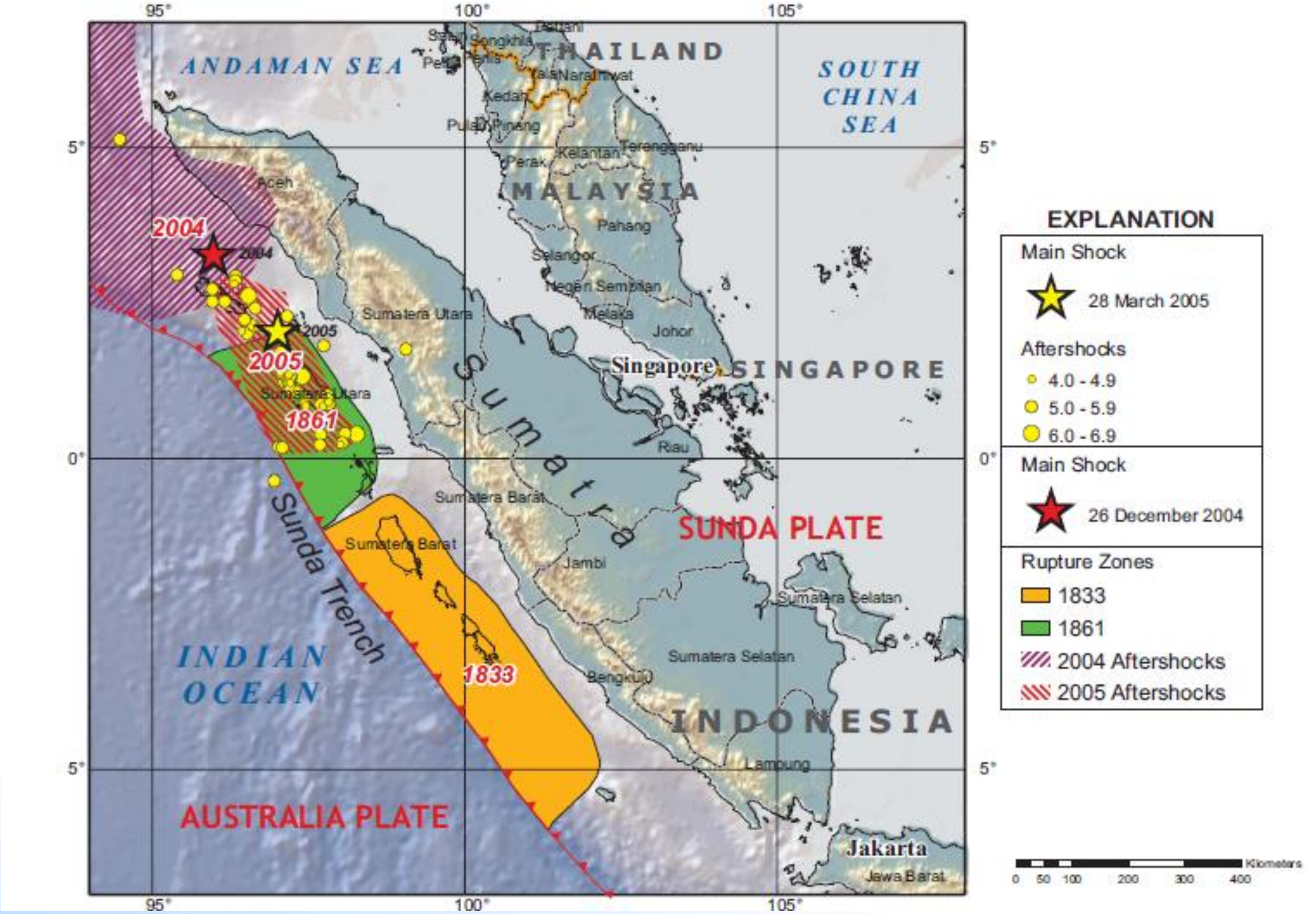
Indonesia case: Historical information: Isoseismal map



Date: February 27, 1903
Hour: 00.43
Magnitude: 7.6 MS, 7.9 (Kanamori and Abe 1979)
Epicenter: 8.00°S; 106.00°E
Depth: 25 km
★ Epicenter
V Regional Intensity (MM)

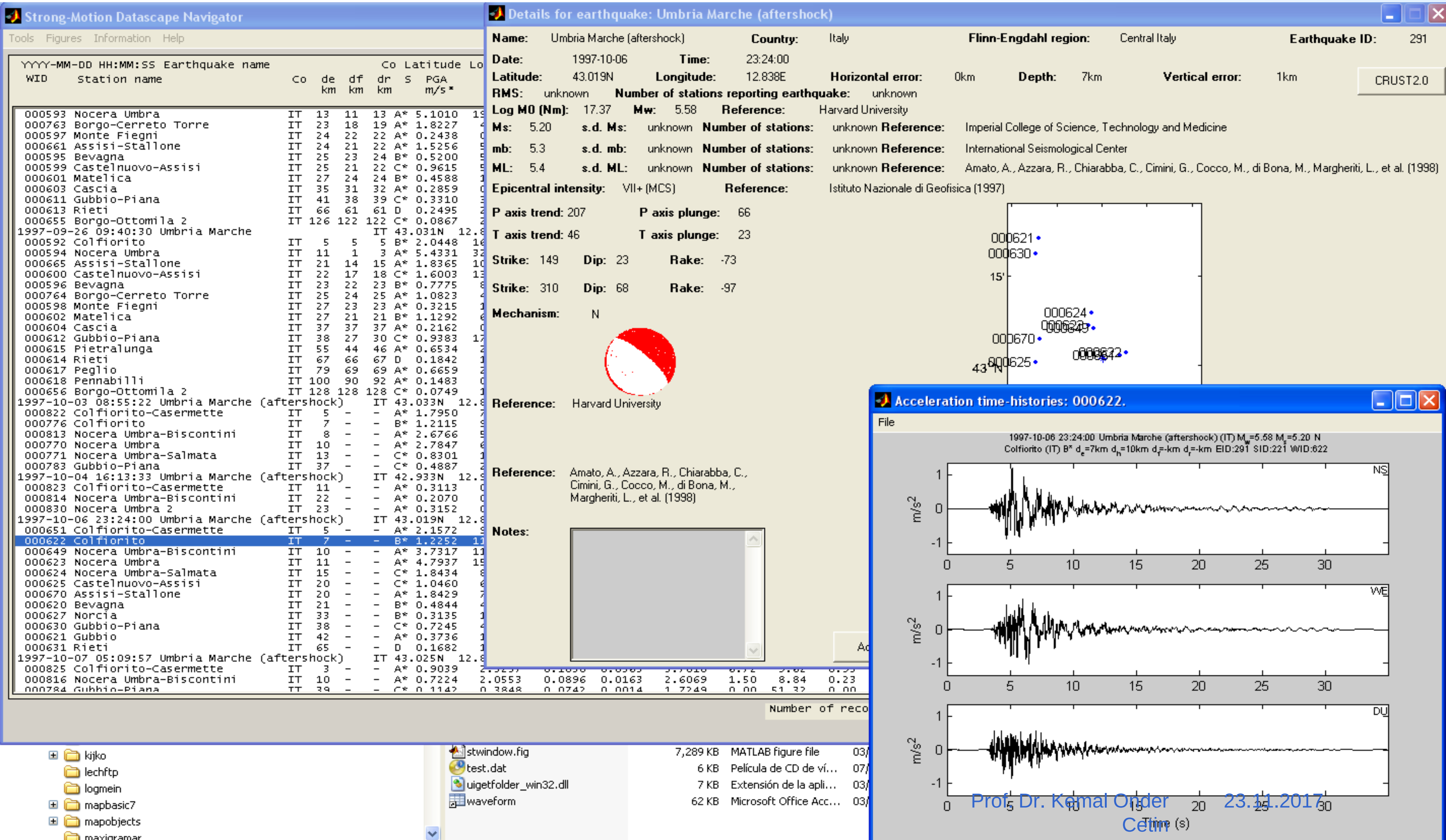
Seismological Database

Indonesian case: Large historical earthquakes and rupture zones due to large earthquakes along the Sumatra subduction . Source: USGS



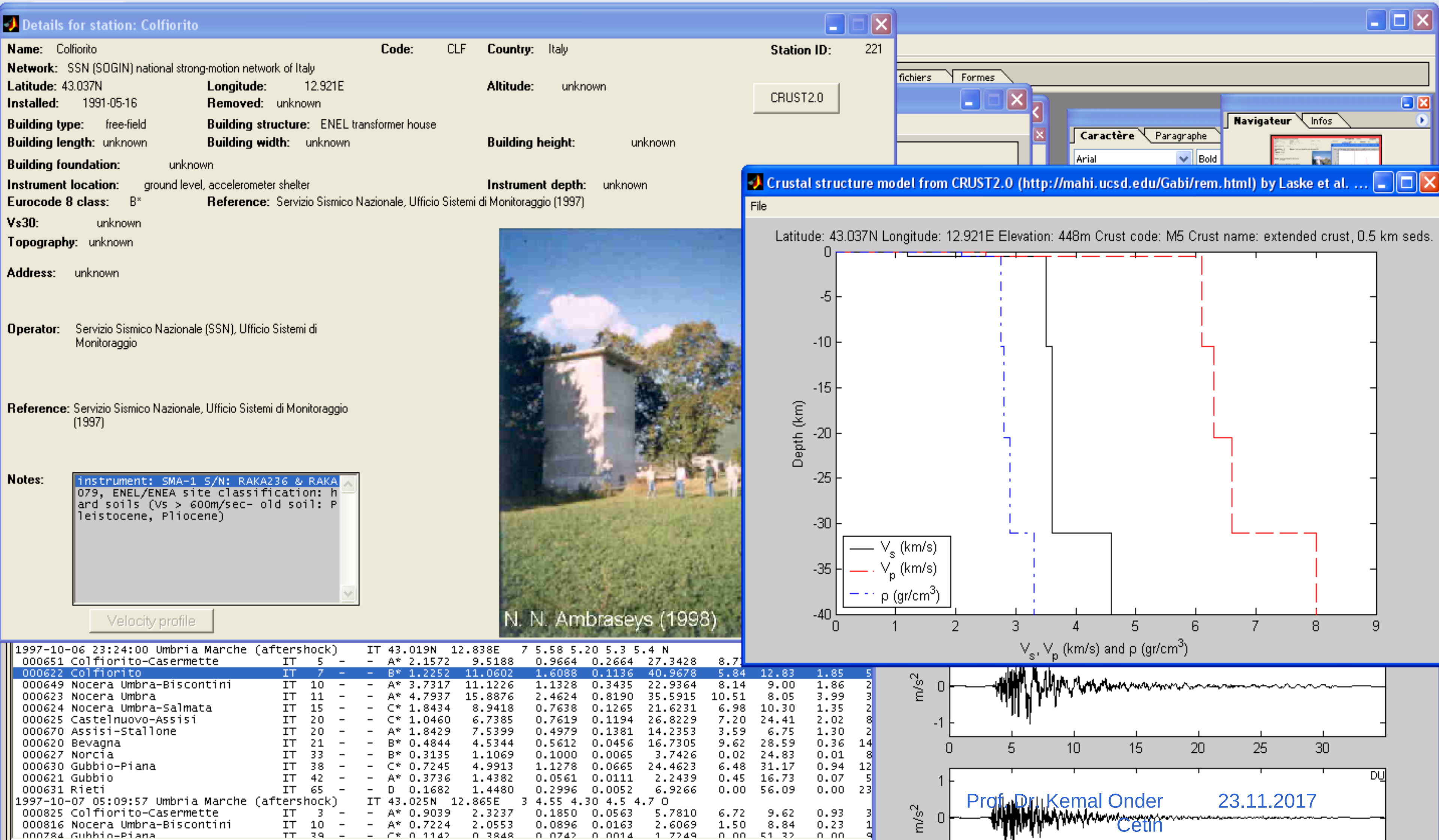
Seismological Database

Example of strong motion database:



Seismological Database

Example of strong motion database:



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4. Development of Seismic Source Models

4.1.The **link between the integrated geological, geophysical, geotechnical and seismological database and the assessment of the seismic hazards is the seismic source model**, which should be based on a coherent merging of the individual databases, including due consideration of any available seismotectonic models that may exist or be postulated at the regional scale. The seismic source model constitutes the conceptual and mathematical representation of the physical nature of the seismic sources identified on the basis of the information compiled in the indicated databases and seismotectonic models. One or several seismic source models can be postulated. In the development of such models, all relevant interpretations of the available data should be taken into account, with due consideration of all the uncertainties involved. These models include detailed characterization of the seismic sources and should be developed to be used specifically for the seismic hazard assessment, applying either deterministic or probabilistic approaches.

4.2.The process for developing a seismic source model **starts with the integration of the elements of seismological, geophysical, geological and other relevant databases into an integrated database**, as recommended in Section 3, to obtain a coherent model (and potential alternative models).

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4. Development of Seismic Source Models
SEISMOGENIC STRUCTURES (IDENTIFIED SEISMIC SOURCES)

Identification

4.9. **All seismogenic structures that might contribute to the seismic hazards at the site should be included** in the seismic source models, and uncertainties in the models should be evaluated by sensitivity analysis.

4.10. In the evaluation of fault displacement hazards, special attention and consideration should be given to those **seismogenic structures close to the site** that have a potential for surface displacement at or near the ground surface (i.e. capable faults; see Section 7). The data collected for this purpose should be evaluated to see whether they are consistent with the data collected for the vibratory seismic hazard analysis. Any inconsistencies should be reconciled if they could adversely affect either analysis.

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4. Development of Seismic Source Models
SEISMOGENIC STRUCTURES (IDENTIFIED SEISMIC SOURCES)

Characterization

4.13. For seismogenic structures that have been identified as being relevant to determining the earthquake generated hazards for the site, the associated characteristics of such structures should be determined. **The fault geometry (e.g. length, width, depth), orientation (i.e. strike, dip and rake angles), rate of deformation and geological complexity (e.g. segmentation, rupture initiation, secondary faults) should be determined** to the extent possible. Determination of these characteristics should be based on an evaluation of all data and information contained in the geological, geophysical, geotechnical and seismological databases.

4.14. Available information about the seismological and geological history of the rupture of a fault or structure (e.g. **segmentation, fault length, fault width) should be used to estimate the maximum rupture dimensions and/or displacements**. This information, together with magnitude–area scaling relationships, should be used to evaluate the potential maximum magnitude of the seismogenic structure under consideration. Other data that may be used to establish a rheological profile — such as data on heat flow, crustal thickness and strain rate — should also be considered in this estimation.

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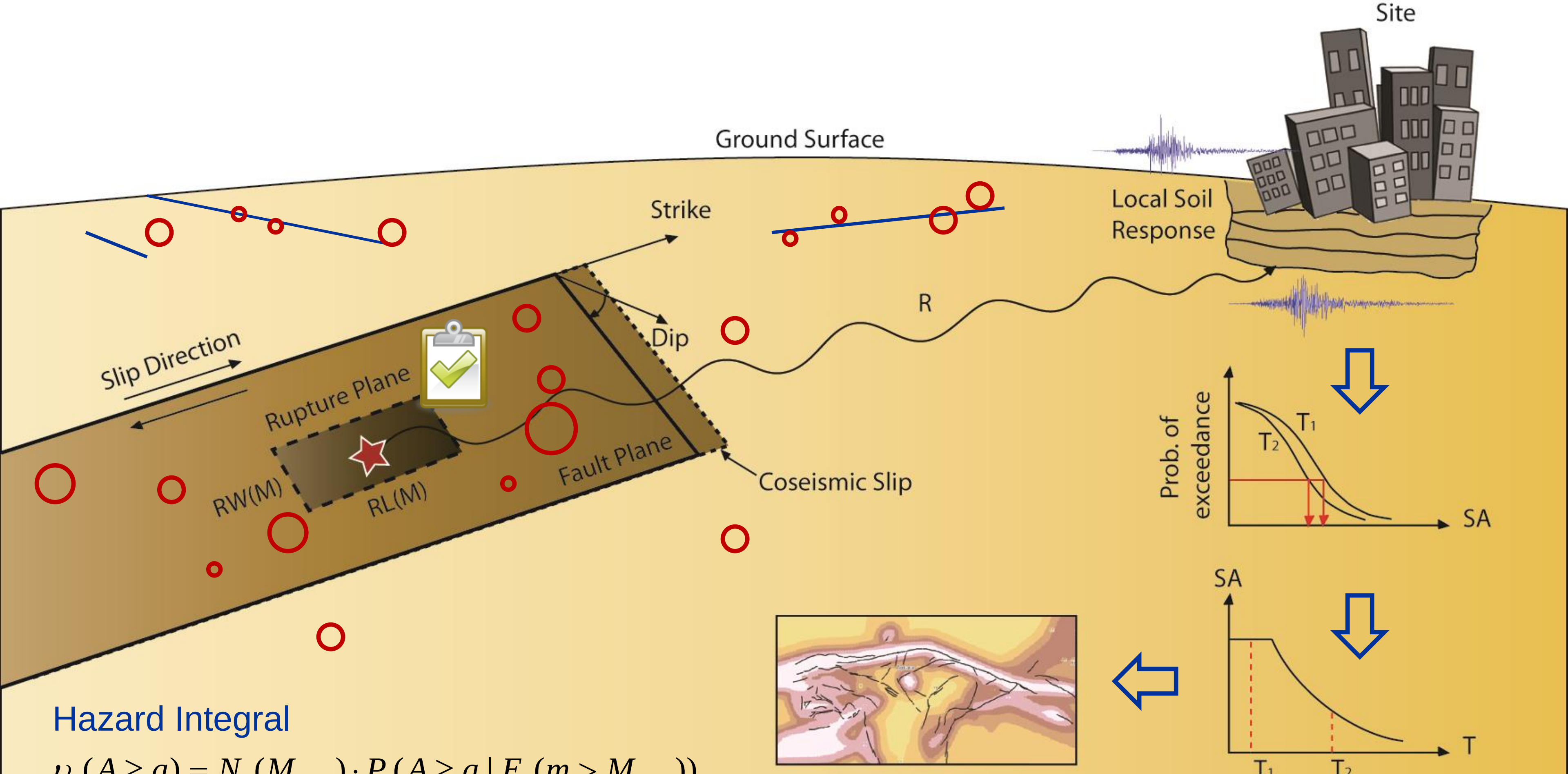
Review Seismic Source Characterization



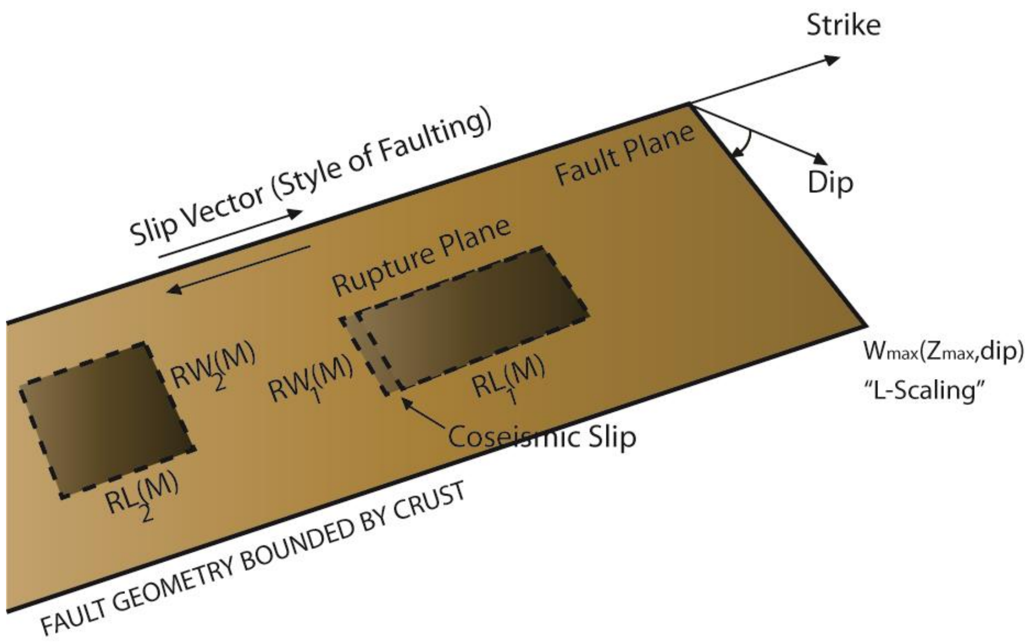
Hazard Integral

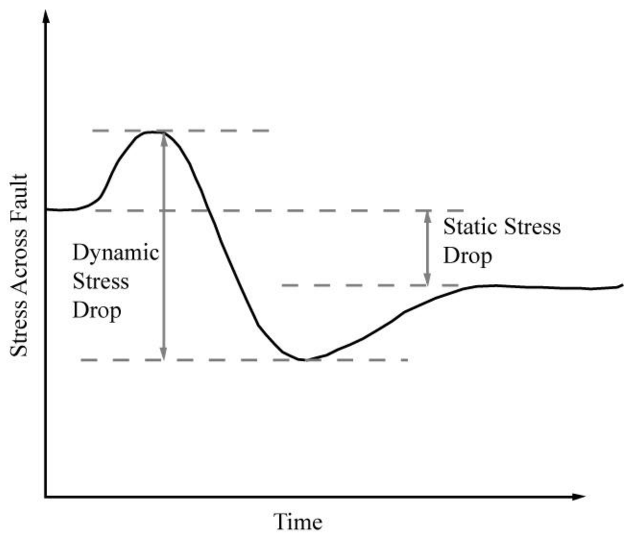
$$\upsilon_i(A \ge a) = N_i(M_{\min}) \cdot P_i(A \ge a \mid E_i(m > M_{\min}))$$

$$P_i(A > a \mid E_i(m \ge M_{\min})) = \int_{R_L=0}^{R_L=R_{\max}} \int_{x=0}^{x=1} \int_{m=M_{\min}}^{m=M_{\max}} P_i(A > a \mid m, r(x, R_L)) \cdot f_{M_i}(m) \cdot f_{R_{L,i}}(m) \cdot f_{x_i}(x) \cdot dm\, dx\, dR_L$$

Review: Magnitude – Rupture Dimension Scaling Model

Basics Concepts





$$M_0 = \mu\, A\, D$$

Coseismic Slip

$$log_{10} M_0 = 1.5M + 16.05$$

$$\Delta\sigma_{circ} = \frac{7 \cdot 10^{-6}}{16} \cdot \pi^{1.5} \cdot \mu \cdot \frac{D}{\sqrt{A}}$$

Seismic Moment | Moment Magnitude | Average Static Stress Drop

M, A, RW, RL, Δσ, D are interrelated, and reported parameter values are DEPENDENT

Review: Magnitude Rupture Dimension Relationships

- Expanded database, enhanced extrapolation at higher magnitude range (M 5.5 – M 8.2)
- Model applies for shallow focus events, SOFP introduced as a descriptive parameter
- Models predict rupture dimensions, preserving the geometrical compatibility conditions for the rectangular assumption
- Data supports the validity of the L-model for shallow crustal regions

<u>Current State of Practice</u>

Given “M” and “SOF” →

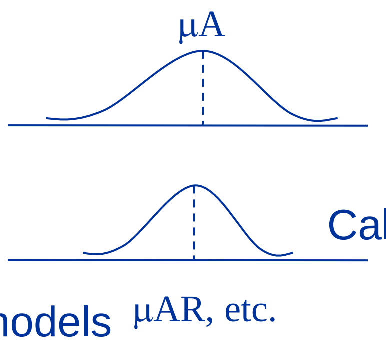
A

Calculate RW,

Calculate A /RW from independent models

<u>Does not neccessarily verify RL predictions</u>

<u>using independent models</u>



<u>Proposed Enhancement</u>

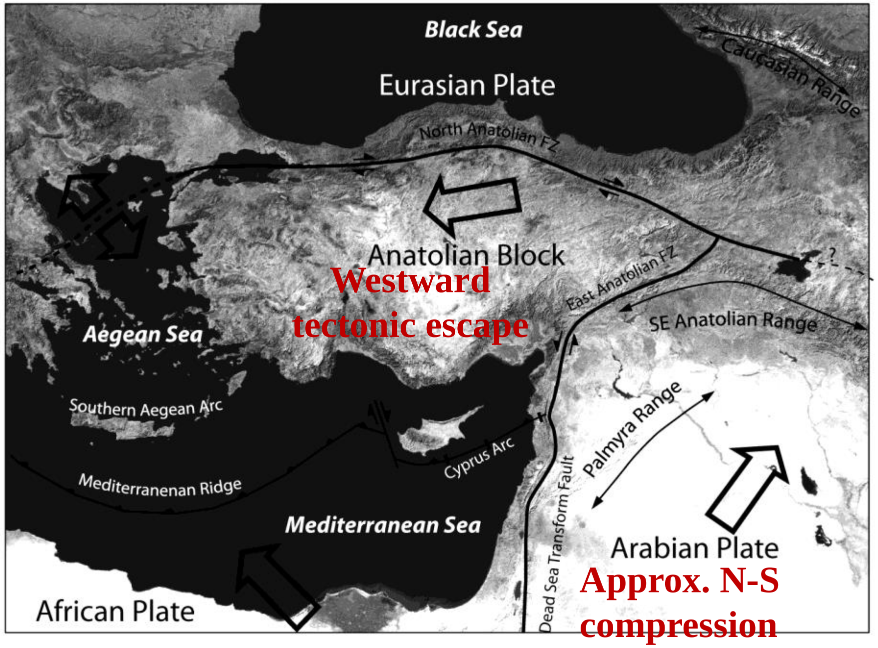
Given “M” and “SOF” → A

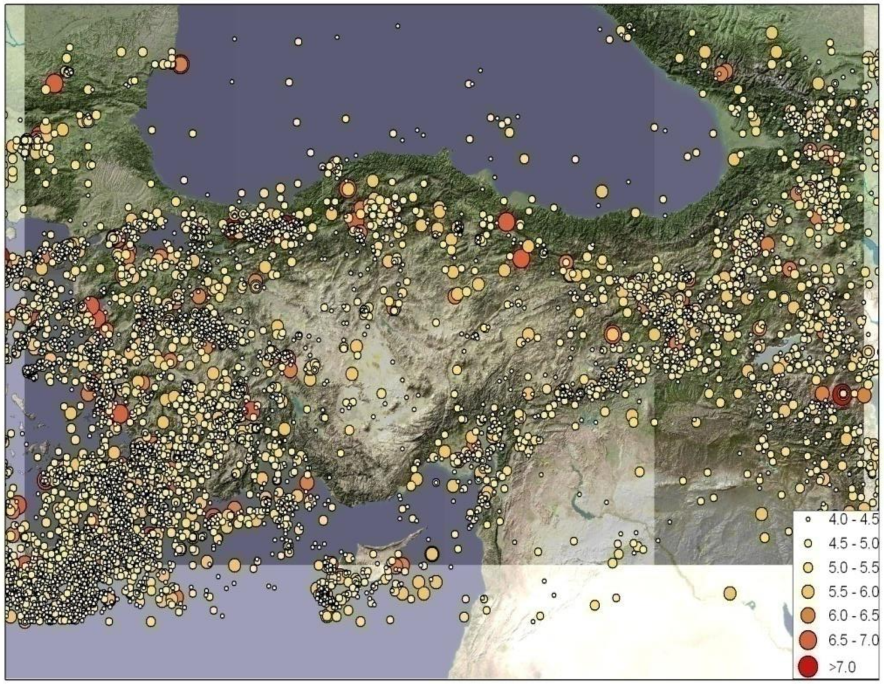
Calculate either A dependent RW, or aspect ratio, AR

Calculate RL, or RL, RW pair using the AR model

<u>Preserves the A=RLxRW relation</u>

Seismic Source Characterization for Turkiye



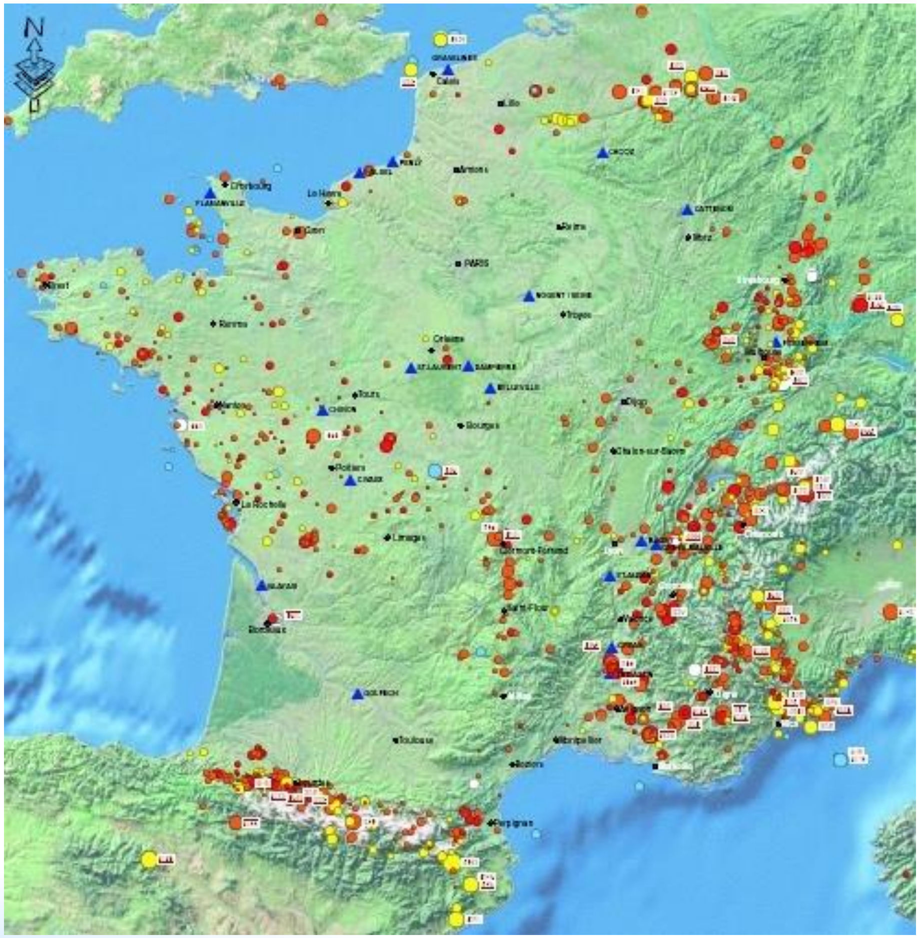


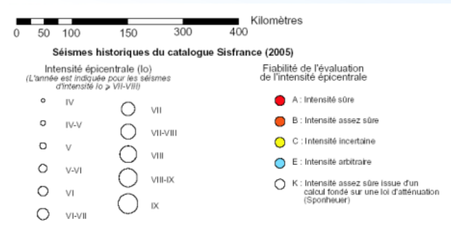
Macroseismicity distribution for M>4 (KOERI catalogu

- → An understanding of regional tectonics
- → Compilation and processing of macroseismicity data
- → Geometric characterization
- → Determination of maximum magnitude (M_{max}) and recurrence parameters
- → Style of faulting, annual slip rate

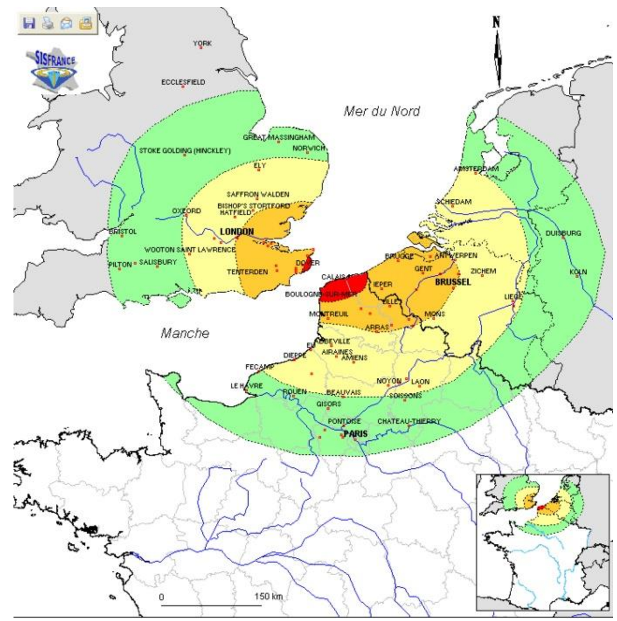
Seismic Source Characterization

Historical catalogue





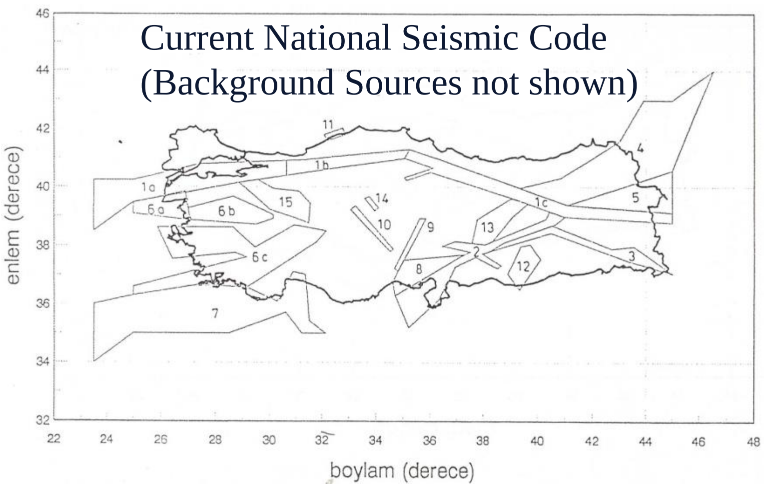
Isoseismal map



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
NUMEVT	QPOS	LONGEPC	LATEPC	COORD_X	COORD_Y	IEPC	QIE	JJ1	MM1	AN1	SECOUSSES	QD	REFEVT	APPELATION
640311.000000000	B	-1.217694000	43.200324000	310700.000000000	1806300.000000000	5.000000000	A	1.000000000	1.000000000	1934.000000000		A	0.000000000	PAYS BASQUE (N. ISPOURE)
260173.000000000	B	4.915877000	45.249633000	802500.000000000	2031000.000000000	5.000000000	A	1.000000000	1.000000000	1937.000000000		A	0.000000000	BAS-PLATEAUX DAUPHINOIS (ST-S
50071.000000000	C	6.599598000	44.483511000	939200.000000000	1951700.000000000	4.000000000	C	1.000000000	1.000000000	1949.000000000		A	0.000000000	QUEYRAS (W. COL DE PARPAILLO
640348.000000000	C	-0.500246000	43.133568000	368800.000000000	1796500.000000000	5.000000000	C	1.000000000	1.000000000	1959.000000000		A	0.000000000	BEARN ([illegible])
1130060.000000000	D	7.150140000	44.300360000	984200.000000000	1933900.000000000	5.500000000	B	2.000000000	1.000000000	1893.000000000		A	0.000000000	PIEMONT (BAGNI DI VINADIO)
290030.000000000	A	-4.001365000	47.933422000	126900.000000000	2345100.000000000	7.000000000	B	2.000000000	1.000000000	1959.000000000		A	0.000000000	CORNOUAILLE (MELGVEN)

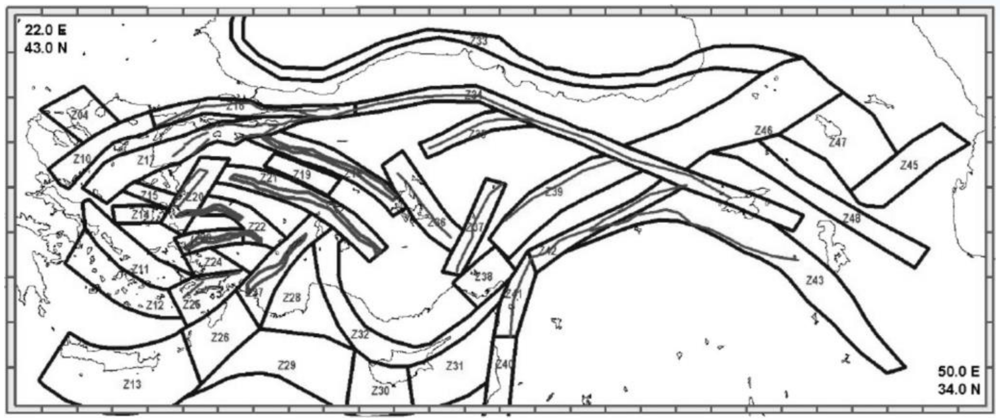
Seismic Source Characterization

Overview of Previous Efforts: “Epistemic Uncertainty is Strongly Pronounced”

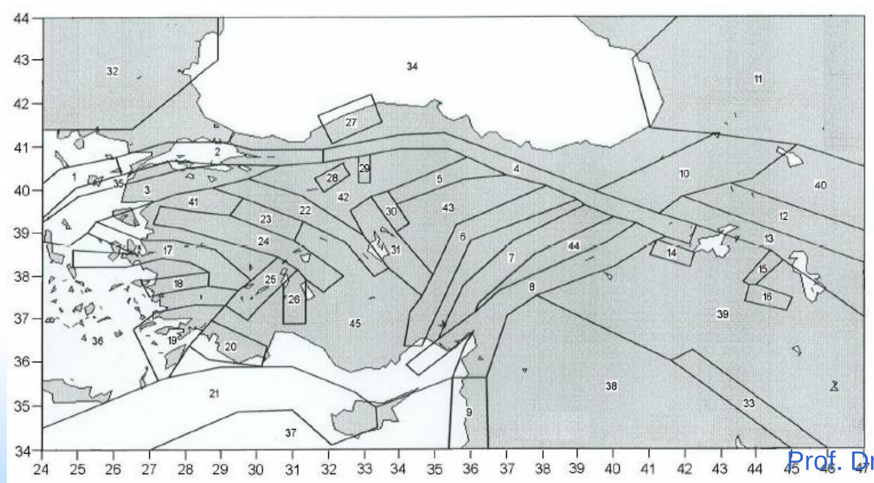


Gülkan et al. (1993)

Basis for many studies with slight modifications



Demircioğlu et al. (2007)

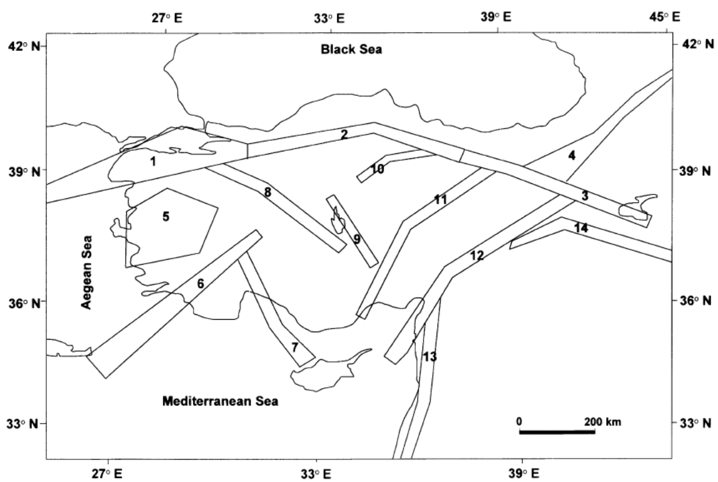


Deniz (2006)

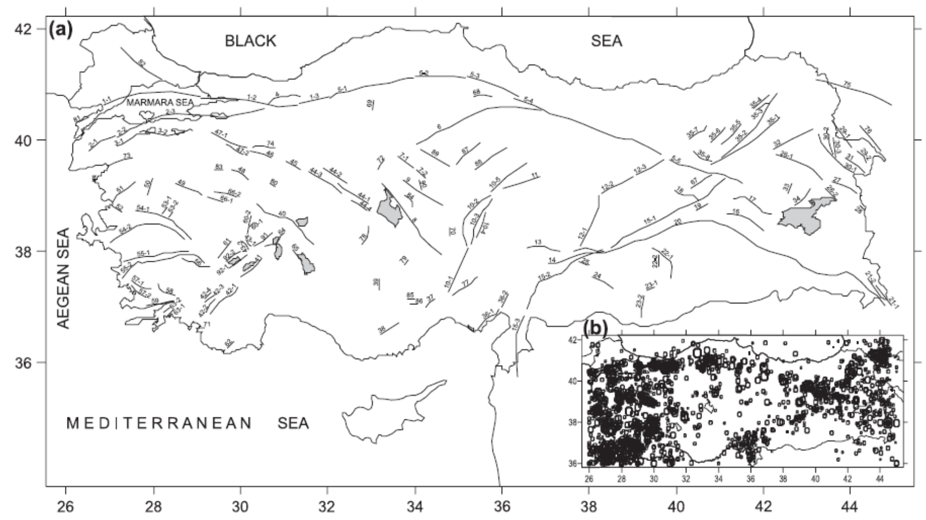
Seismic Source Characterization

Overview of Previous Efforts

Linear sources



Kayabalı (2002)



Ulusay et al. (2004)

TRADE-OFFS IN SOURCE CHARACTERIZATION

Search for perfect fault geometry

Given all geometric details, assignment of descriptive parameters: limitations from <u>unknowns</u>

PLANNED MAJOR CONTRIBUTION

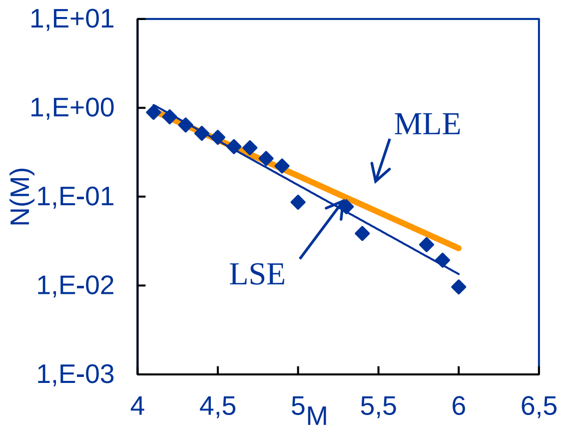
SYSTEMATIC APPROACH IN SOURCE CHARACTERIZATION

Seismic Source Characterization for Turkiye

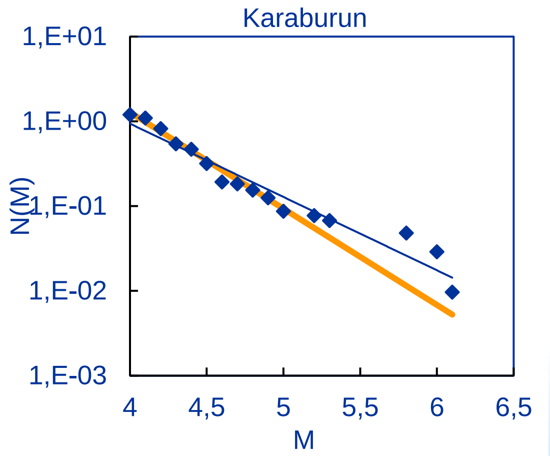
Review: Seismic Source Characterization

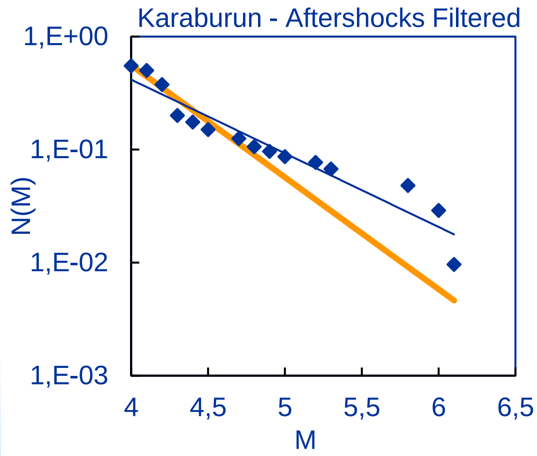
Recurrence Parameters (from Instrumental Seismicity Records)

Choice of regression method and effect of aftershock filtering



- Fault Length
- $M_{max,obs}$
- M_{max}
- “a” and “b” values for LSE and MLE





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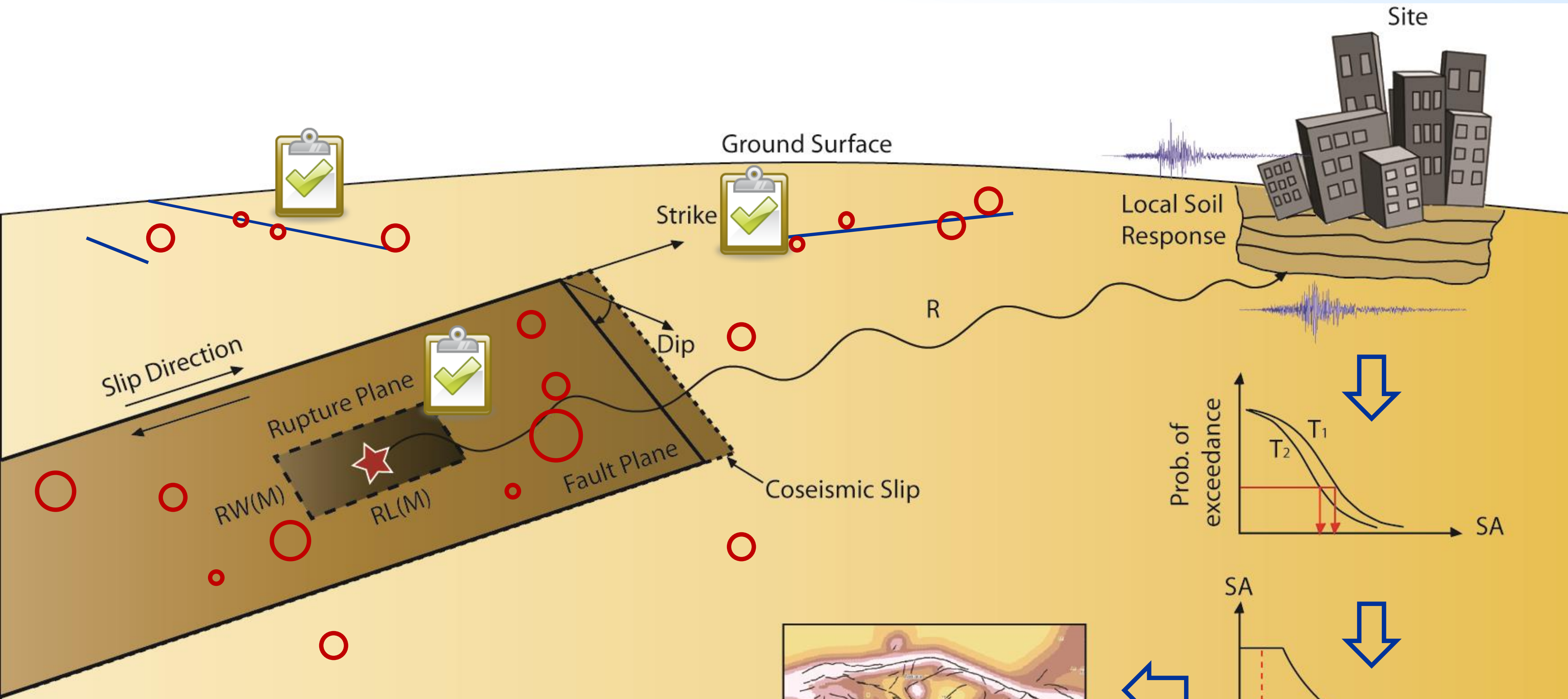
5. Methods for Estimating Vibratory Ground Motion

5.1. The variability associated with the prediction of vibratory ground motions from future earthquakes is typically one of the largest sources of uncertainty in seismic hazard assessment. Currently available methods for estimating ground motions include **GMPEs, which are primarily empirical, and direct simulation methods, which involve physics-based scaling to interpolate a smaller amount of data**. These alternative methods are described in paras 5.17–5.23. Given the significant epistemic uncertainty currently inherent in ground motion prediction, multiple relationships and/or methodologies should be used. However, the evaluation of ground motion using different methods should be done in a consistent and complementary manner.

5.6. GMPEs **specify the median value of vibratory ground motion amplitude on the basis of a limited number of explanatory variables, such as earthquake magnitude, distance from rupture plane (with respect to the site), site conditions and style of faulting.** The model may be in the form of an equation or a table. Even for models that are primarily based on empirical data, simulation results are

Review: Ground Motion Prediction Model



Hazard Integral

$$\upsilon_i(A \ge a) = N_i(M_{\min}) \cdot P_i(A \ge a \mid E_i(m > M_{\min}))$$

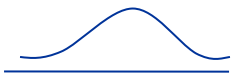
$$P_i(A > a \mid E_i(m \ge M_{\min})) = \int_{R_L=0}^{R_L=R_{\max}} \int_{x=0}^{x=1} \int_{m=M_{\min}}^{m=M_{\max}} P_i(A > a \mid m, r(x, R_L)) \cdot f_{M_i}(m) \cdot f_{R_{L,i}}(m) \cdot f_{x_i}(x) \cdot dm\, dx\, dR_L$$

Review: Ground Motion Prediction Models

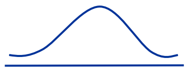
Overview

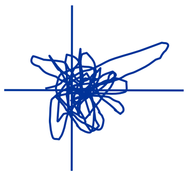
$S_A = f\,(T, M, R, \text{Site, SOF, etc.}) \pm \varepsilon$

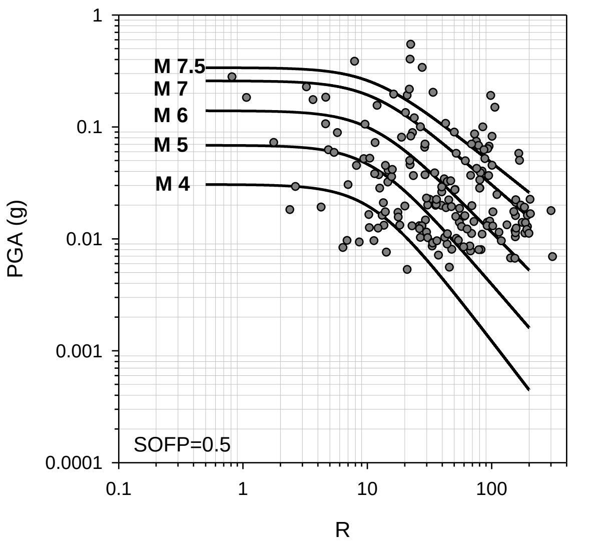
$\mu M_i, \sigma M_i$



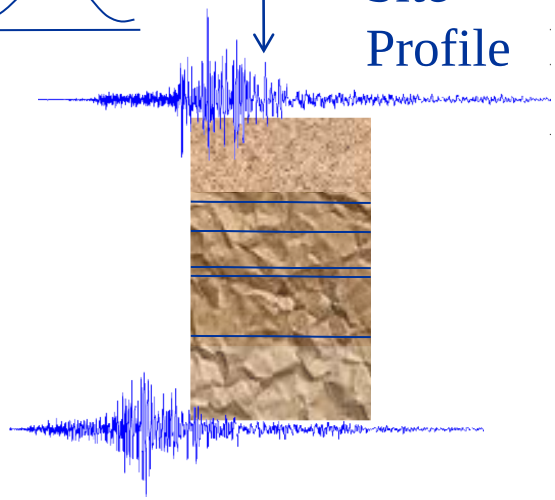
$\mu R_i, \sigma R_i$







Site Profile



Compilation of raw accelerometric data

Record processing

Defining the relations between different definitions of horizontal ground motion

Quantifying parameter uncertainty in M and R

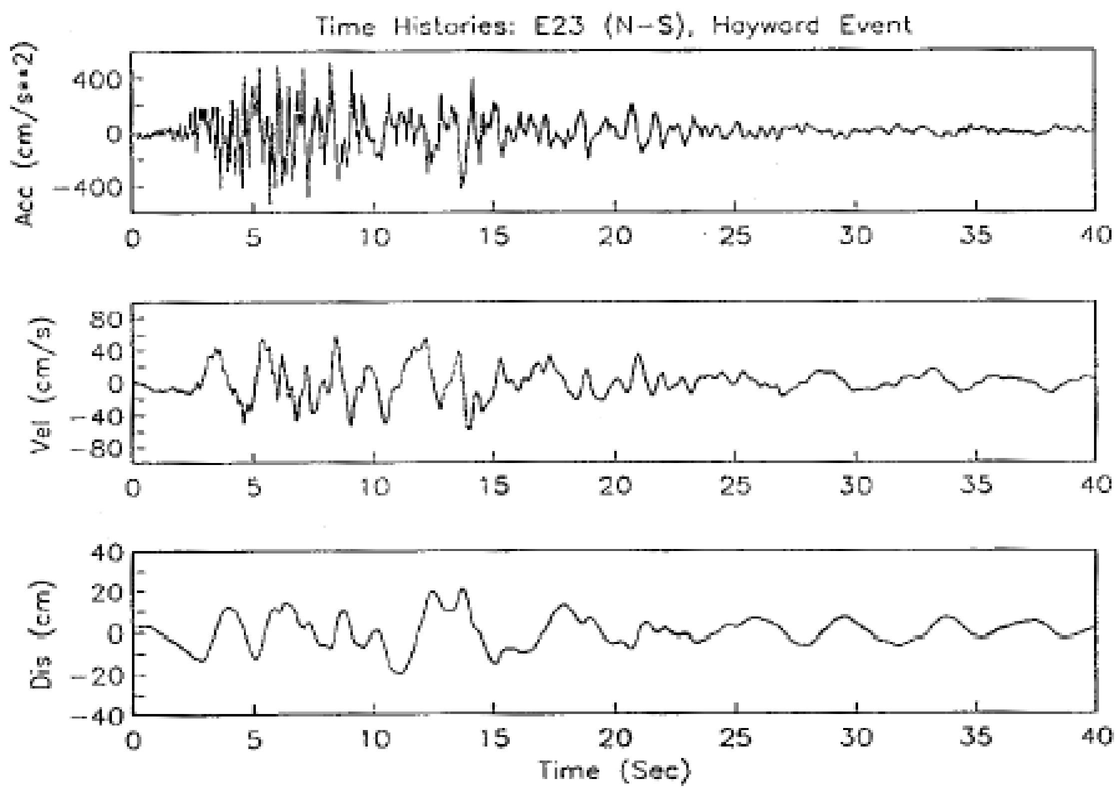
Framework for modeling local ground response with limited site information

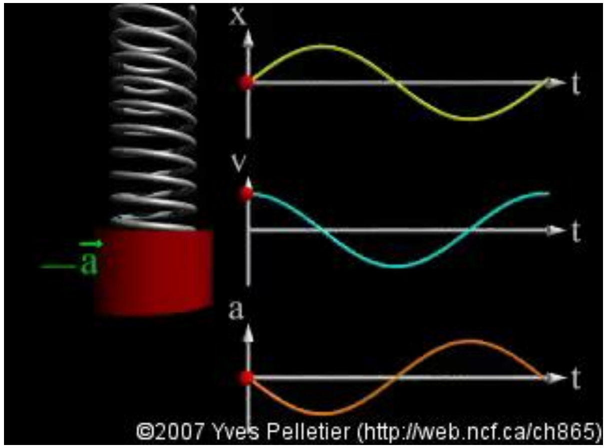
Local ground response model $f(pga_{rock}, V_{s30})$

Removing effects of uneven sampling

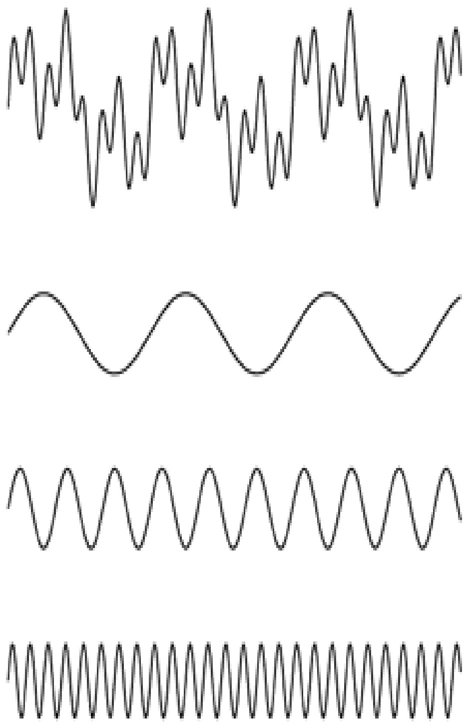
Review: Intensity Measures

Acceleration-Velocity-Displacement Time History





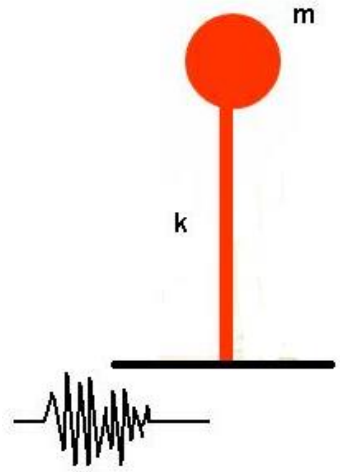
Review: Frequency Content

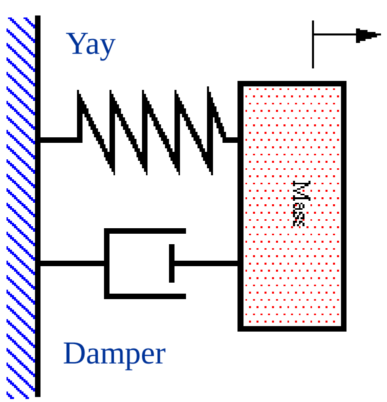


Fourier Transformation

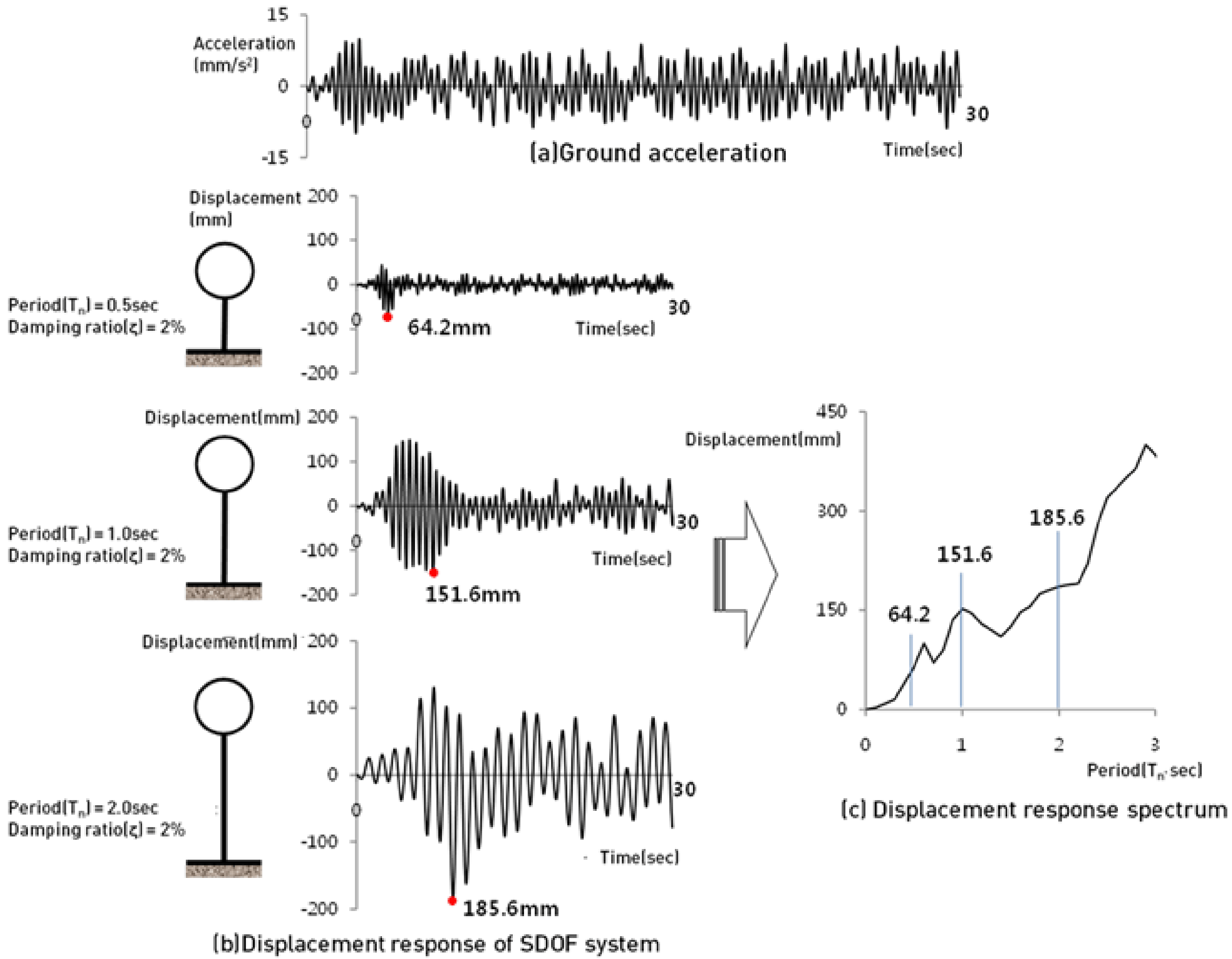
$$x(t) = c_0 + \sum_{n=1}^{\infty} c_n \sin(\omega_n t + \phi_n)$$

Single degree of Freedom System

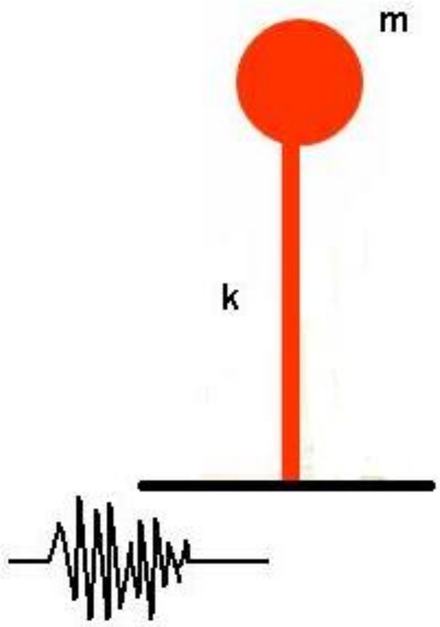


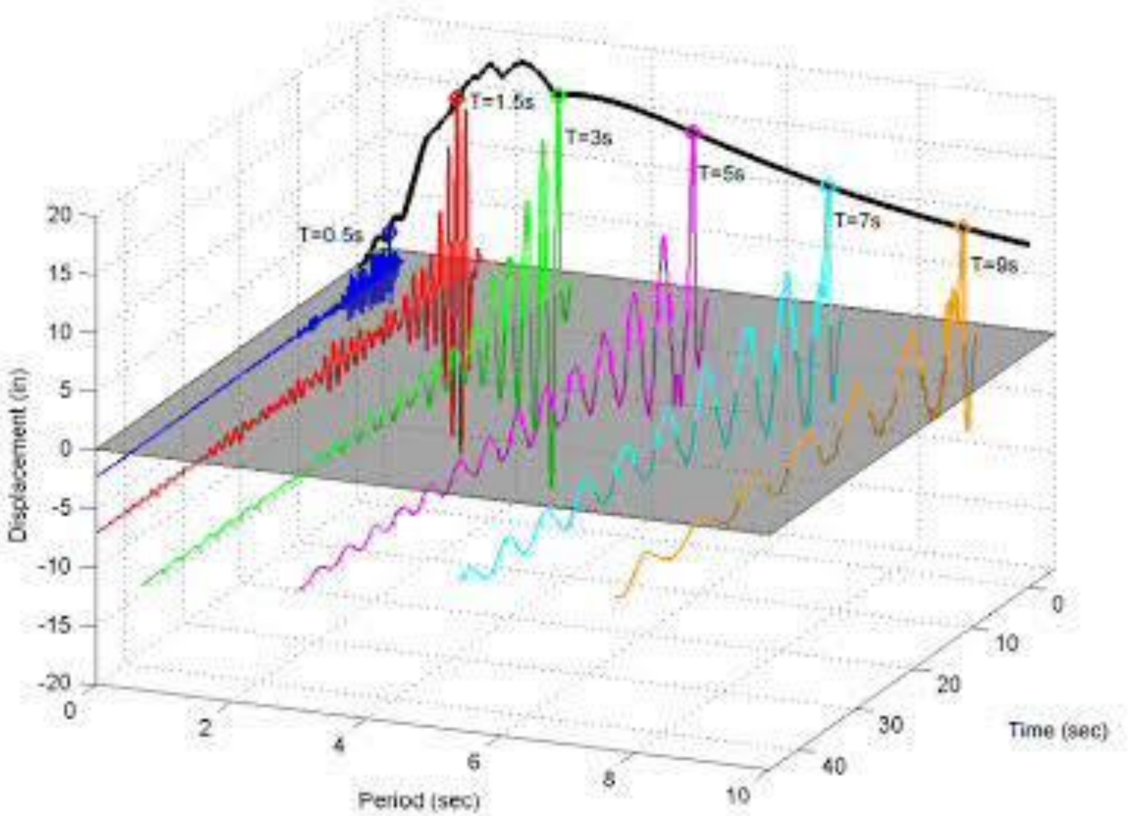


Review: Response Spectrum

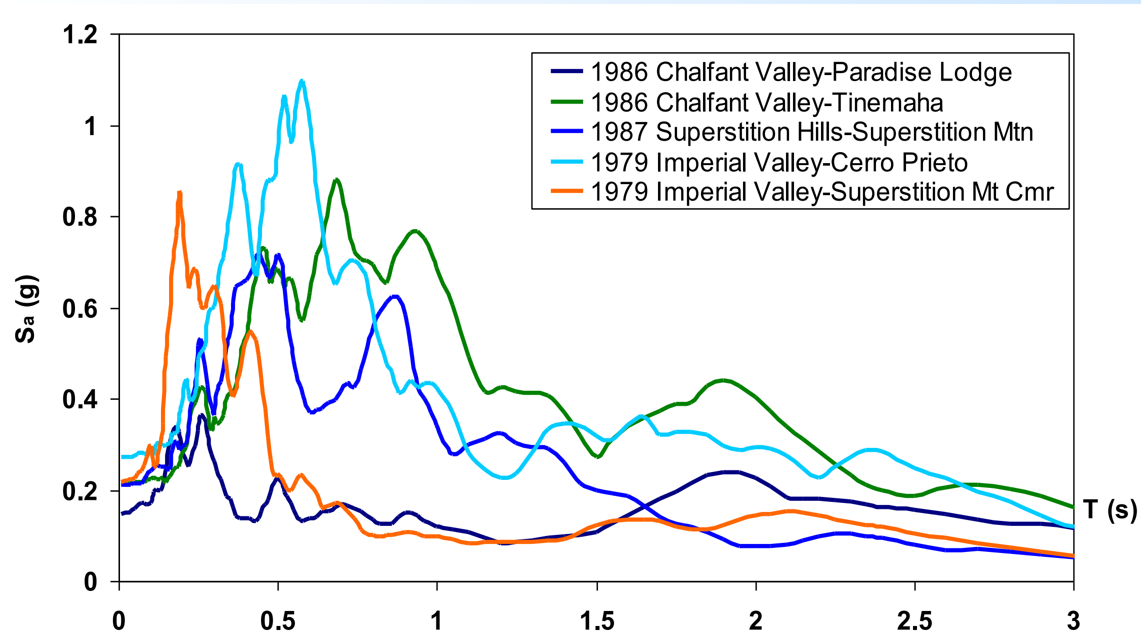


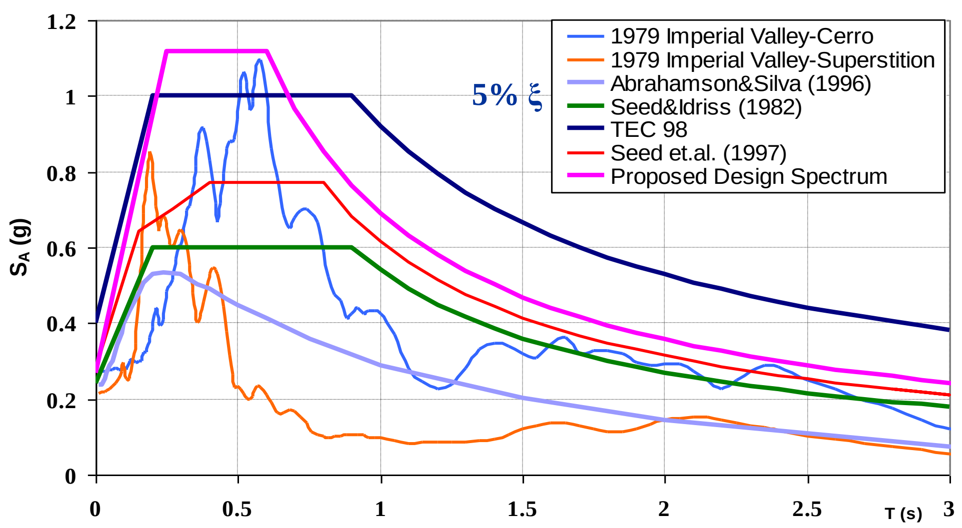
Review: Response Spectrum

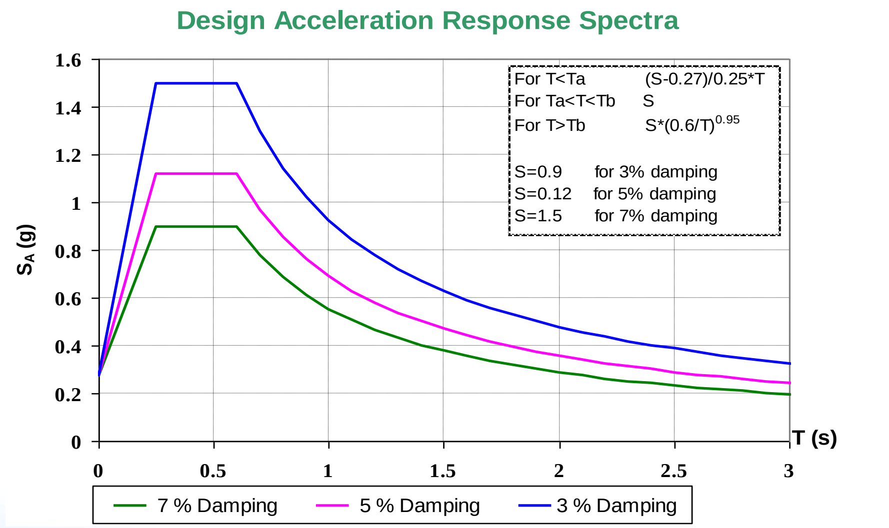




Review: Response Spectra



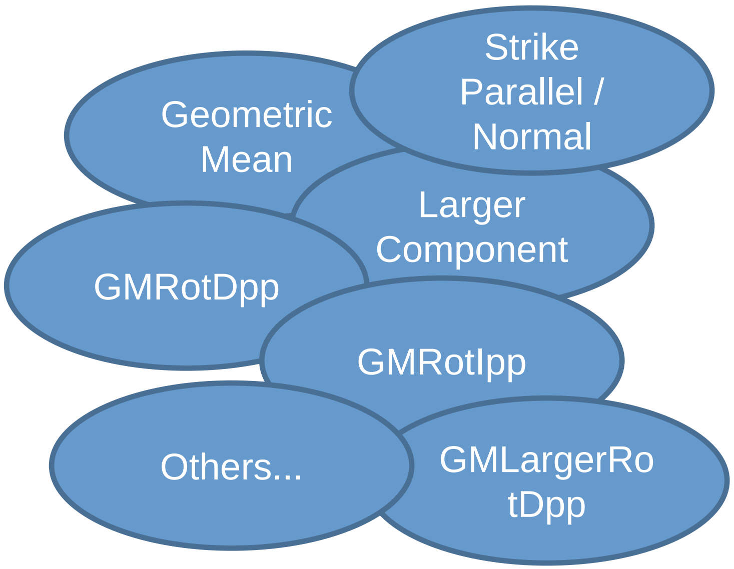




Review: Ground Motion Prediction Model

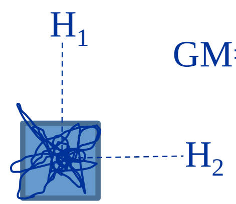
DATA PROCESSING: Relationships Between Different Definitions of Horizontal Ground Motion

Components



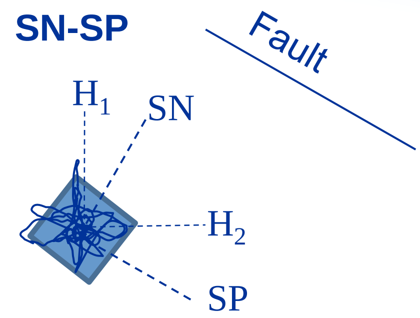
Quick Definitions

Geometric Mean (GM)

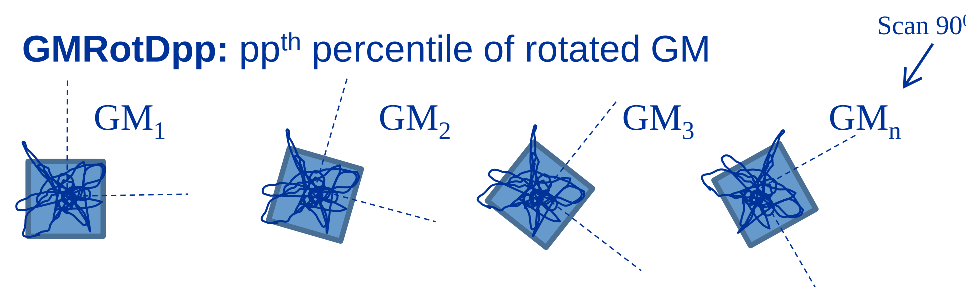


$GM=(H_1*H_2)^{1/2}$

SN-SP



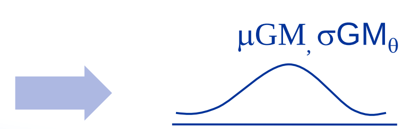
GMRotDpp: ppth percentile of rotated GM

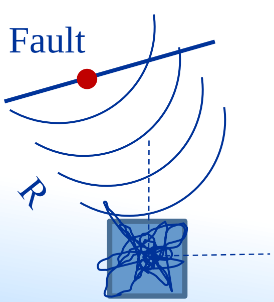


Calculate ppth percentile of GM's : GMRotD50 for median

Optimize to yield a single rotation angle through all T:

GMRotIpp



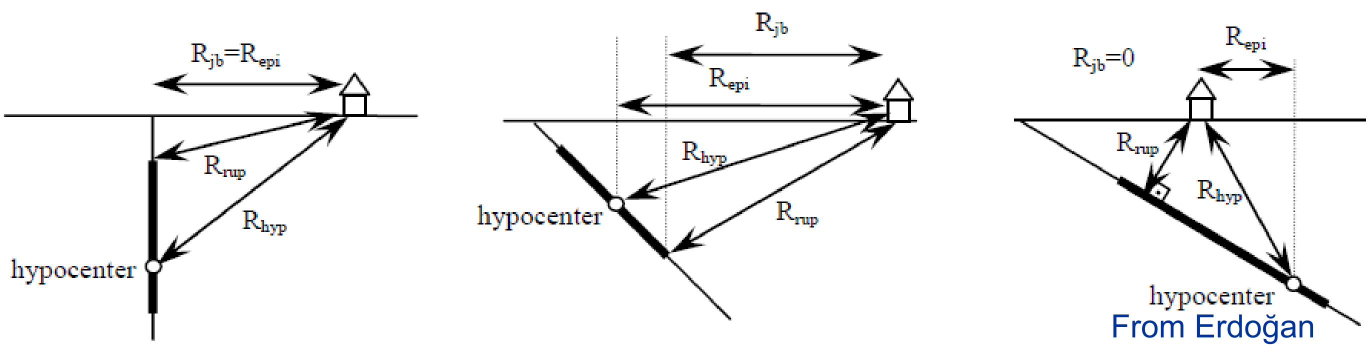


SGM Station

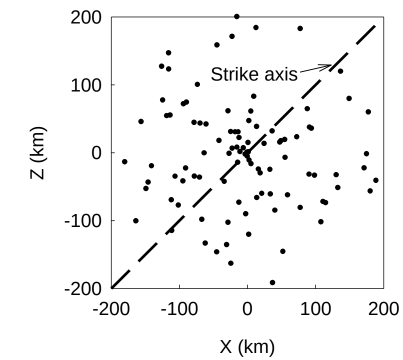
f(Structure, design Procedure)

Review: Ground Motion Prediction Model

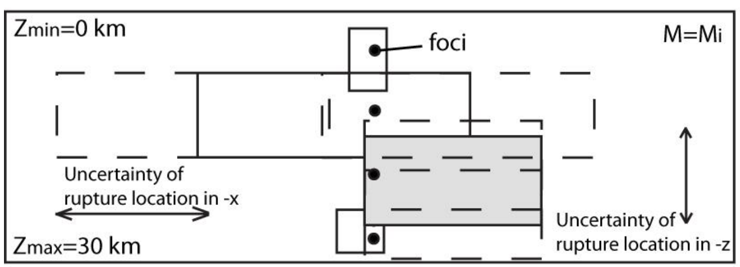
DATA PROCESSING: Relations Among Distance Metrics, and Modeling Uncertainty in Parameter Estimation

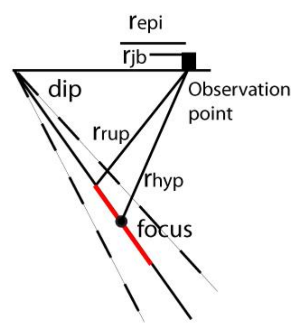


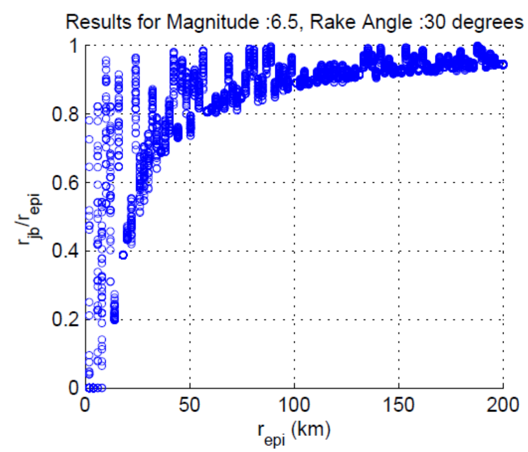
From Erdoğan (2008)



Re-evaluation Using Batch Simulations







Variables:

Observation points, M(RW, RL), δ, SOF, z → >500000 simulated geometry (Uncertainty in rupture location along x and z (on the fault plane))

Double truncated at 3σ

Review: Ground Motion Prediction Model

DATA PROCESSING: Site Classification and 1-D Ground Response Analyses

→ **1997 Series** → **2008 NGA Series** →

"Rock"-"Soil" | Vs_{30} | V_{s30} or Site Classes "A,B,C,D" | Nonlinear f of shaking intensity and V_{s30}

Available Sources or Site Classification → Critical Reviewing and Cross Comparison

-Kalkan and Gülkan (2004)

- Zare and Bard (2002)

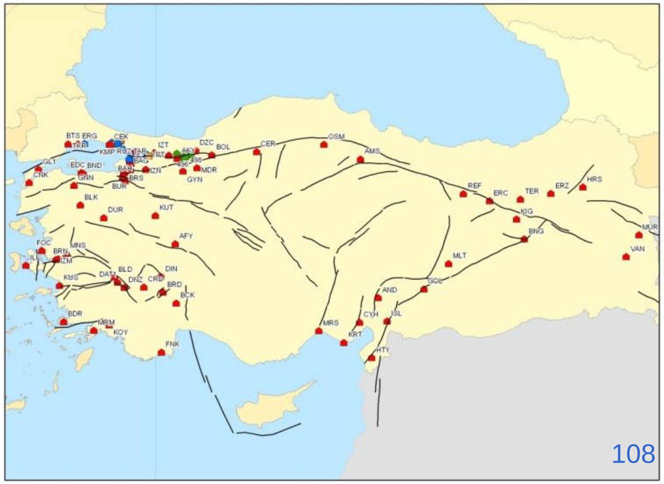
- Rosenblad et al. (2003)

- ESDB (European Strong Motion Database)

- Sandıkkaya (2008) → **Most recent work, however does not cover our database completely**

- Geological – Topographical Maps
- Spoken communication in resolving location/deinstallation /reinstallation conflicts
- Deep water well logs (DSI) on alluvial basins

Preliminary classification: NEHRP Site Classes



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5. Methods for Estimating Vibratory Ground Motion

5.8. The **selection of candidate GMPEs** to be used in the seismic hazard assessment should be based on the following general criteria:

(a) The GMPEs should be **current and well established**, supported by an adequate quantity of properly processed data.

(b) They should have been **determined by appropriate regression analysis** to avoid an error in a subjectively fixed coefficient propagating to the other coefficients.

(c) They should be **consistent with the types of earthquake** and the attenuation characteristics of the site region.

(d) They should **match the tectonic environment of the site region** as closely as possible.

(e) They should **make use of available local ground motion data** as much as possible in their definition. If it is necessary to use GMPEs from elsewhere, they should be calibrated by comparing them with as much local strong motion data as possible. If no suitable data are available from the region of interest, a qualitative justification should be provided for why the selected GMPEs are suitable.

(f) They should be consistent with the **physical characteristics of the control point location.**

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5. Methods for Estimating Vibratory Ground Motion

GROUND MOTION SIMULATION METHODS

5.17. Ground motion simulations provide results that **can be used to refine and calibrate empirical GMPEs** to directly develop ground motion prediction models and to develop ground motions for specific scenario events. Several simulation methods exist. **Any simulation approach used should be carefully validated and calibrated** against available recorded data from the region of interest.

5.18. One **commonly used approach utilizes a stochastic simulation methodology** based on simple parametric models that represent the physical properties of the seismic source and the propagation and attenuation of seismic energy. This methodology can represent the source either as a point source or as a finite fault with rupture that evolves in space and time. This methodology should include the development of region specific parametric models for source, path and site effects, which need to be calibrated with empirical data from the region of interest.

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6. Vibratory Ground Motion Hazard Analysis

6.1. The approach to be used for assessing the vibratory ground motion hazard at the nuclear installation site **should be defined at the beginning of the seismic hazard assessment project.** The vibratory ground motion hazard may be evaluated by using probabilistic and/or deterministic methods of seismic hazard analysis (see paras 6.8 and 6.15). The choice of the approach will depend on the national regulatory requirements and the specifications of the end user of the evaluation, which should be documented in the project work plan (see Section 10).

6.5. Consideration should be given during the hazard analysis to appropriate **treatment of the interface between the vibratory ground motion hazard analysis and the site response analysis**. This is normally considered by specifying a control point or layer beneath the site where the seismic hazard analysis specifies the ground motion; the site response analysis and/or soil–structure interaction analysis then takes this as its input motion (see SSG-67 [5]).

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6. Vibratory Ground Motion Hazard Analysis

PROBABILISTIC SEISMIC HAZARD ANALYSIS

6.8. A probabilistic approach should be used when the safety of the nuclear installation against earthquake loading needs to be demonstrated with explicit **consideration of the likelihood of occurrence of the relevant seismic hazards** (e.g. vibratory ground motion level). Probabilistic approaches consider **the rates of recurrence of seismic events for all seismic sources with magnitudes between a bounded minimum magnitude and the estimated potential maximum magnitude**. In these cases, the annual frequency of exceedance for different levels of the relevant hazard parameters (e.g. the **peak ground acceleration**) should be estimated to define an appropriate design basis and/or to perform a seismic probabilistic safety assessment.

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6. Vibratory Ground Motion Hazard Analysis
PROBABILISTIC SEISMIC HAZARD ANALYSIS

6.9. Evaluation of the vibratory ground motion hazard by probabilistic methods should include the following steps:

(1) Selection of **the level of effort**, resources and details to be applied in the seismic hazard assessment project, considering the safety significance of the nuclear installation, the technical complexity and the uncertainties in the hazard inputs, regulatory requirements and oversight, and the amount of contention within the related scientific community.

(2) Development of **a detailed work plan** with careful consideration of the experts who will constitute the project team and of the project reviewers who will participate in the independent peer review. If a participatory peer review is envisaged in the project plan, the work plan should enable technical meetings to be held involving experts from the project team and the review team to discuss topics relating to **(a) the hazard determination and the availability and quality of the compiled data, (b) alternative interpretations and (c) feedback for implementation of the project**. If a participatory peer review is not included in the project plan, its non-inclusion should be justified.

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6. Vibratory Ground Motion Hazard Analysis
PROBABILISTIC SEISMIC HAZARD ANALYSIS

6.9. Evaluation of the vibratory ground motion hazard by probabilistic methods should include the following steps:

(3) Compilation of the integrated geological, geophysical, geotechnical and seismological database, as recommended in Section 3, and **development of the seismic source models for the site region** in terms of the defined seismic sources, including uncertainty in their boundaries and dimensions, as recommended in Section 4. **A 'zoneless' approach** [8] is an alternative scheme to avoid boundary issues, but its application should be adequately justified.

(4) For each seismic source identified in the seismic source models, estimation of the potential maximum magnitude values, **evaluation of the rate of earthquake occurrence and derivation of the magnitude–frequency relationship**, together with the individual associated uncertainties.

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6. Vibratory Ground Motion Hazard Analysis
PROBABILISTIC SEISMIC HAZARD ANALYSIS

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6.9. Evaluation of the vibratory ground motion hazard by probabilistic methods should include the following steps:

(5) **Selection of the appropriate GMPEs** for the site region and assessment of the uncertainties in both the mean and the variability of the ground motion as a function of earthquake magnitude and distance from the seismic source to the site. The physics based simulation techniques described in Section 5 are alternative methods for evaluating the ground motion using a sufficient number of calculated time histories to define the centre, body and range of the technically defensible interpretations. The selection and/or adjustment of the GMPEs should be done with consideration of their use in site response analysis (i.e. consideration of step (7) will be necessary).

(6) Establishment of **analysis models (e.g. logic trees) and performance of hazard calculations**, including sensitivity analysis in a phased approach, starting with a preliminary analysis round and discussion of the preliminary results and ending with a final analysis round that will provide the necessary deliverables defined in accordance with the needs of the end user of the evaluation.

Seismic Hazards and Site Evaluation for Nuclear Installations

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6. Vibratory Ground Motion Hazard Analysis

PROBABILISTIC SEISMIC HAZARD ANALYSIS

6.9. Evaluation of the vibratory ground motion hazard by probabilistic methods should include the following steps:

(7) Performance of the **site response analysis** in cases where site response functions are not included in the ground motion evaluation.

(8) Elaboration, **review and confirmation of the final report**, including all necessary deliverables.

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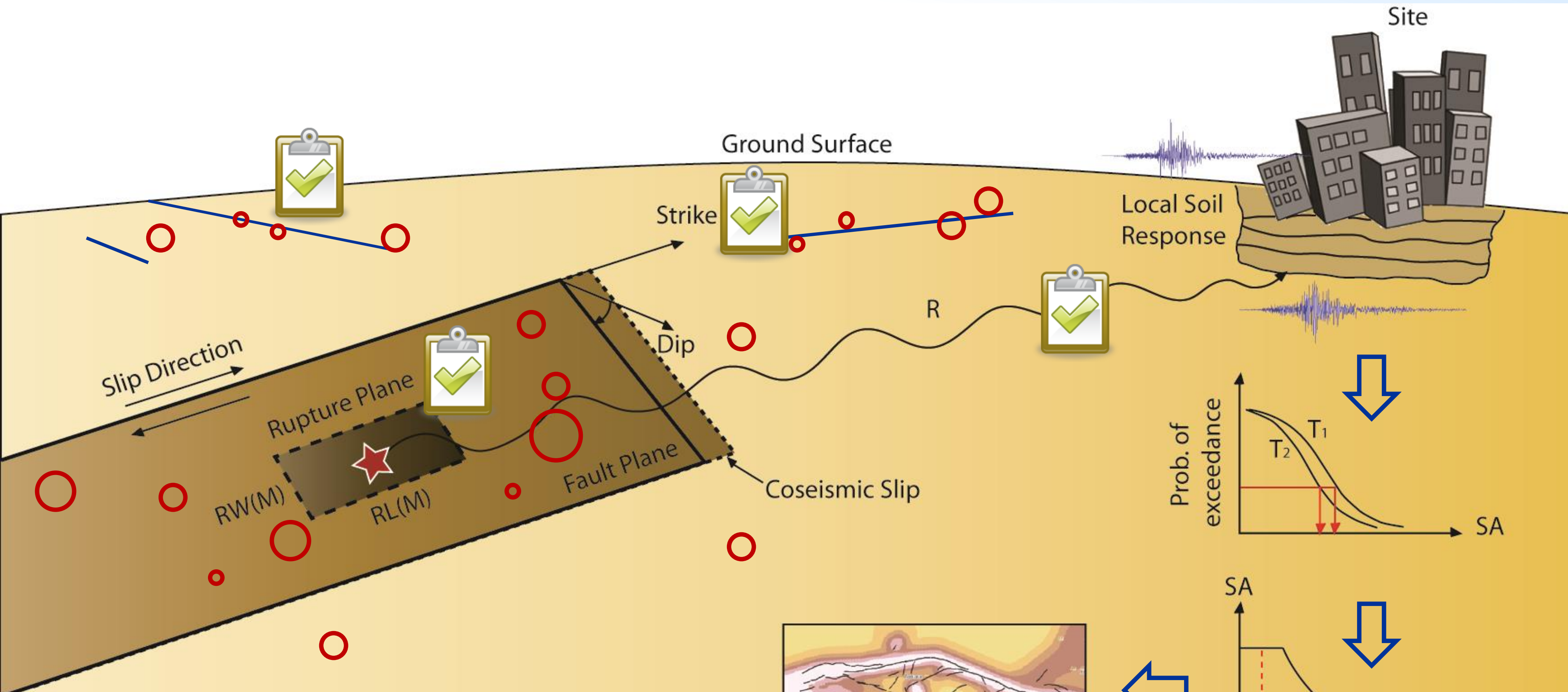
Review: PSHA Software



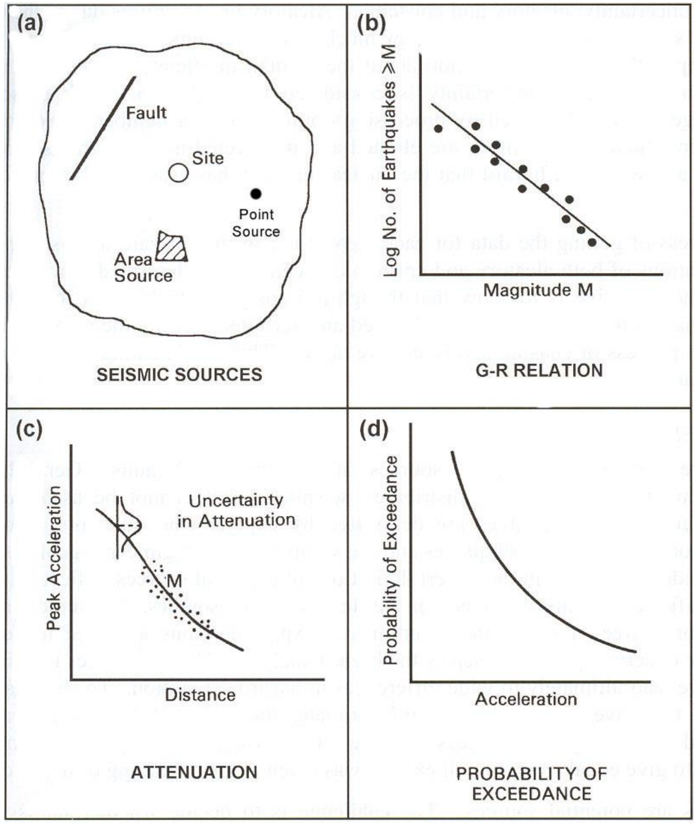
Hazard Integral

$$\upsilon_i(A \ge a) = N_i(M_{\min}) \cdot P_i(A \ge a \mid E_i(m > M_{\min}))$$

$$P_i(A > a \mid E_i(m \ge M_{\min})) = \int_{R_L=0}^{R_L=R_{\max}} \int_{x=0}^{x=1} \int_{m=M_{\min}}^{m=M_{\max}} P_i(A > a \mid m, r(x, R_L)) \cdot f_{M_i}(m) \cdot f_{R_{L,i}}(m) \cdot f_{x_i}(x) \cdot dm\,dx\,dR_L$$

Review: PSHA Software Development

PSHA Workflow



Hazard Integral for a Linear Source

$$v_i(Sa > z) = N_i(M_{min}) \int_{RL=0}^{RL_{max}} \int_{E_x=0}^{1} \int_{m=M_{min}}^{M_{max}} \int_{\varepsilon=\varepsilon_{min}}^{\varepsilon_{max}} f_{RL_i}(m, RL) f_{E_{x_i}}(m, E_x) f_{m_i}(m) f_\varepsilon(\varepsilon) P(Sa > z|m, r(RL, E_x), \varepsilon)\, dRL\, dE_x\, dm\, d\varepsilon$$

Deaggregation Expression

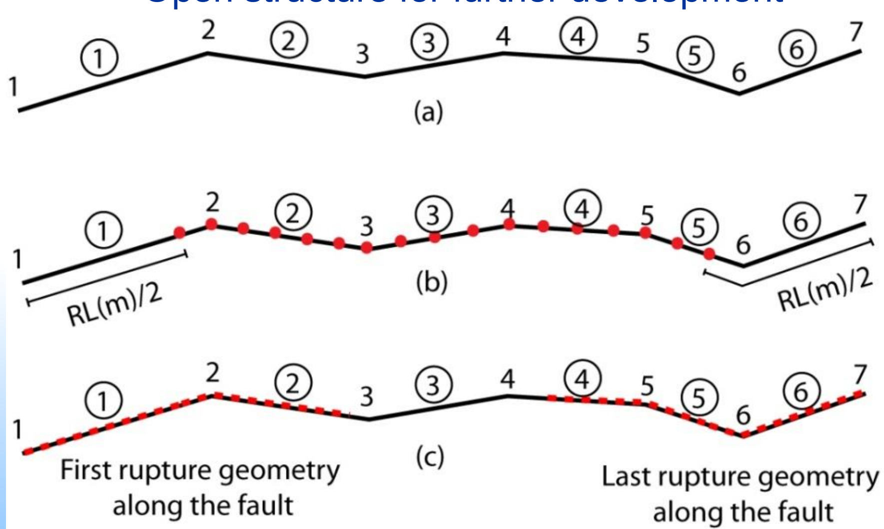
$$DH(Sa > z, M_1 < M < M_2, R_1 < R < R_2, \varepsilon_1 < \varepsilon < \varepsilon_2) = \frac{\sum_{i=1}^{nsources} N_i(M_{\min}) \int_{r=R_1}^{R_2} \int_{m=M_1}^{M_2} \int_{\varepsilon=\varepsilon_1}^{\varepsilon_2} f_{m_i}(m) f_{r_i}(r) f_\varepsilon(\varepsilon) P(Sa > z|m, r, \varepsilon)\, dr\, dm\, d\varepsilon}{v(Sa > z)}$$

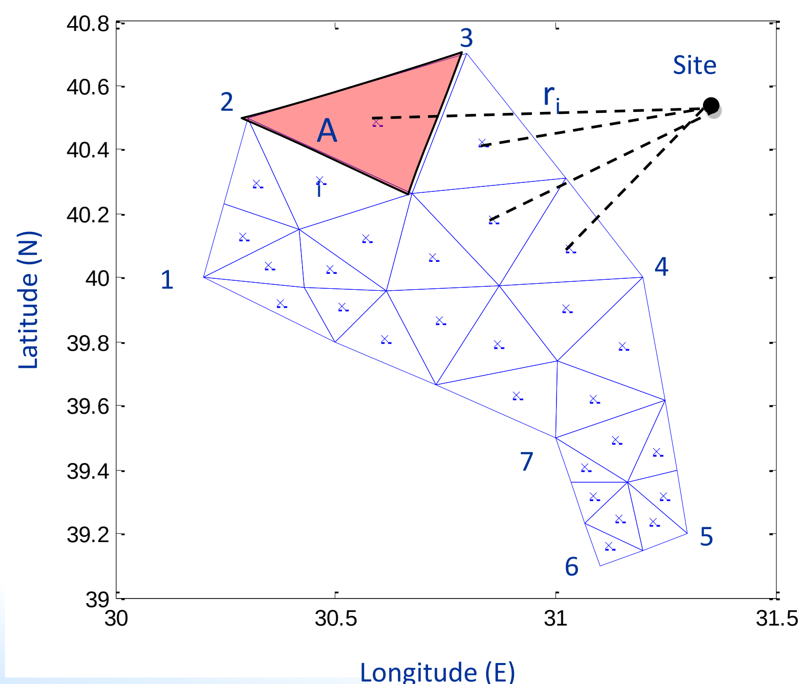
Review: PSHA Software

IAEA

Capabilities at a Glance

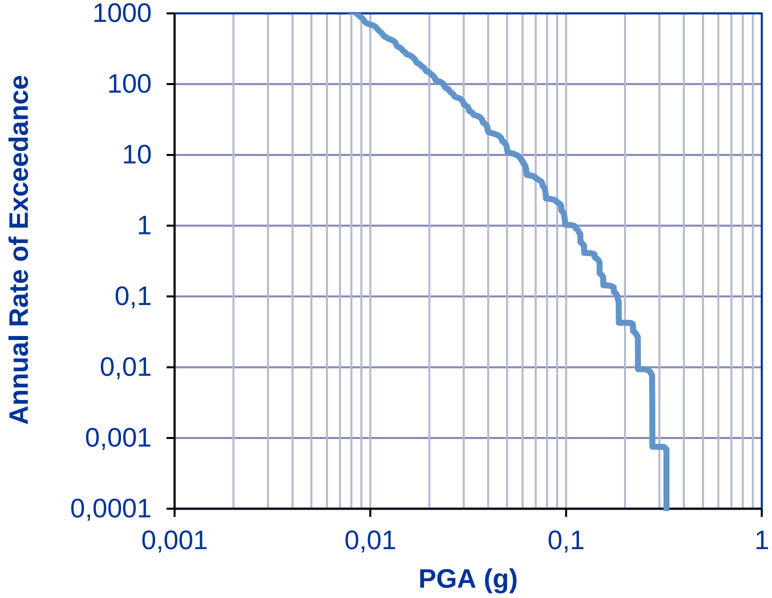
- Seismic source geometry in form of polylines, point source (polygon), and fault planes (currently under verification)
- Geometry input and source parameters (a,b, M_{max}, etc) read directly from SHP shapefile.
- Multiple earthquake sources
- Truncation of distributions at desired sigma values
- Define a distance threshold to exclude sources not likely to contribute to hazard at a site
- Poisson assumption used in time projection
- Deaggregation of hazard for M,R,ε pairs
- Open structure for further development



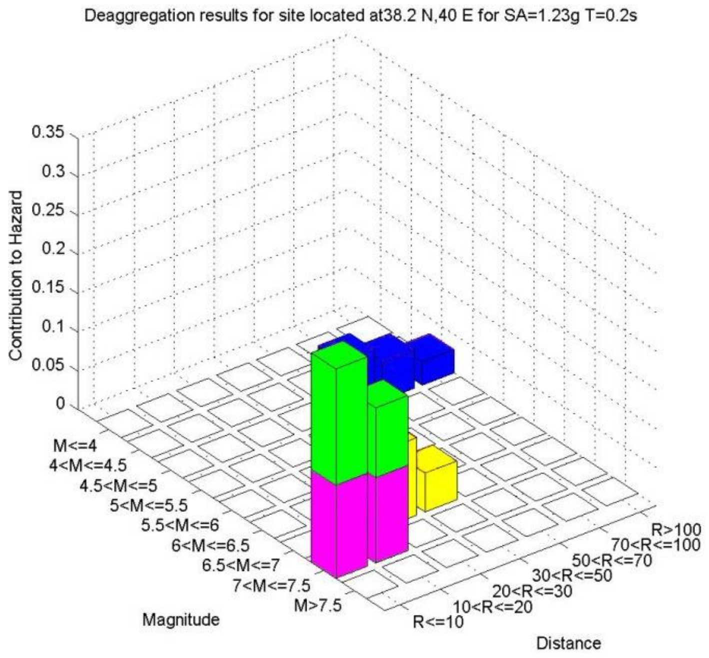


Review: PSHA Software

Sample Hazard Curve



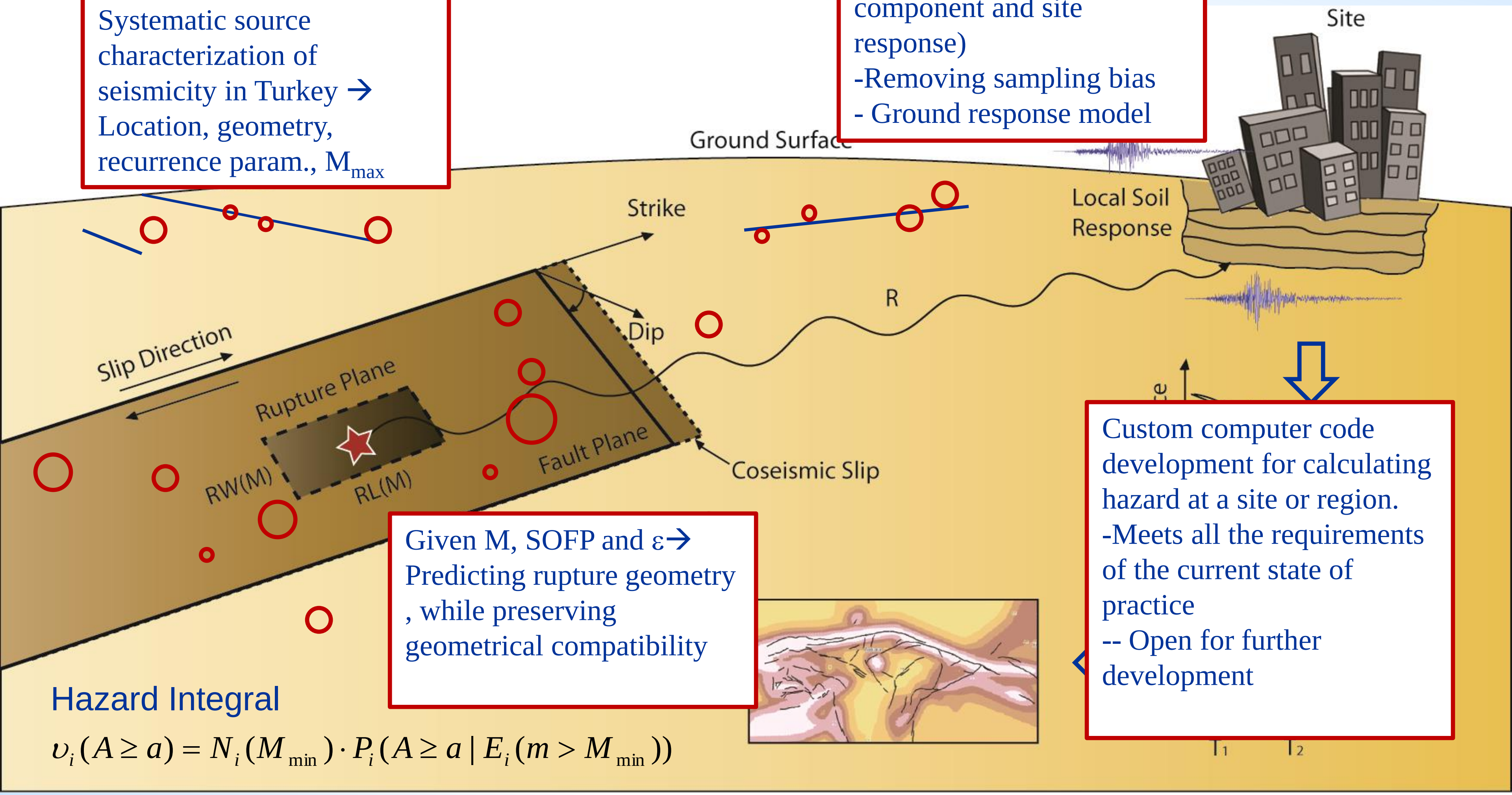
Sample Deaggregated Hazard



Review: PSHA Outputs

Systematic source characterization of seismicity in Turkey → Location, geometry, recurrence param., M_{max}

Ground motion prediction equation with particular emphasis on →
- Quantifying uncertainty in M,R, SA (due to rotational component and site response)
-Removing sampling bias
- Ground response model



Given M, SOFP and ε→ Predicting rupture geometry , while preserving geometrical compatibility

Custom computer code development for calculating hazard at a site or region.
-Meets all the requirements of the current state of practice
-- Open for further development

Hazard Integral

$$\upsilon_i(A \geq a) = N_i(M_{\min}) \cdot P_i(A \geq a \mid E_i(m > M_{\min}))$$

$$P_i(A > a \mid E_i(m \geq M_{\min})) = \int_{R_L=0}^{R_L=R_{\max}} \int_{x=0}^{x=1} \int_{m=M_{\min}}^{m=M_{\max}} P_i(A > a \mid m, r(x, R_L)) \cdot f_{M_i}(m) \cdot f_{R_{L,i}}(m) \cdot f_{x_i}(x) \cdot dm\, dx\, dR_L$$

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6. Vibratory Ground Motion Hazard Analysis

DETERMINISTIC SEISMIC HAZARD ANALYSIS

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6.15. A **deterministic approach can be used** as an alternative to the probabilistic approach. Care should be taken to **select a conservative scenario of the relevant seismic hazards** (e.g. a conservative level for the vibratory ground motion hazard) in line with national practice. In these cases, conservative values of the key hazard parameters should be estimated to define an appropriate design basis for the nuclear installation, corresponding to established safety margins in accordance with application of the concept of defence in depth. **The deterministic approach assumes single individual values** (i.e. occurring with a probability of 1) for key parameters, leading to a single value for the result, as defined in IAEA Safety Standards Series No. SSG-3, Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants [12].

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6. Vibratory Ground Motion Hazard Analysis

DETERMINISTIC SEISMIC HAZARD ANALYSIS

6.18.If **both probabilistic and deterministic assessments are performed**, the results from **both should be compared**. This will enable the deterministic results, including the design basis ground motion, to be calibrated against the probabilistic results, allowing some risk and performance insights to be developed. A further calibration exercise should be performed against the **deaggregation analysis to** determine the characteristics of the design basis ground motion at the site (see para. 6.11).

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6. Vibratory Ground Motion Hazard Analysis

SITE RESPONSE ANALYSIS

6.19. Once the vibratory ground motion analysis has been **conducted for the selected reference site location** and elevation, a **site response analysis should be performed that takes into account the detailed and specific geophysical and geotechnical information** about the soil profiles in the site area. **The aim of the site response analysis is to obtain the vibratory ground motion parameters at the free surface at the top of the soil profile and/or at other locations in the profile**, such as the bottom level of the basemat of selected structures and buildings important to safety.

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7. Evaluation of the Potential for Fault Displacement at the Site

GENERAL

7.1. In relation to evaluation of fault capability, SSR-1 [1] states (footnote omitted):
"Requirement 15: Evaluation of fault capability "**Geological faults larger than a certain size and within a certain distance of the site and that are significant to safety shall be evaluated** to identify whether these faults are to be considered capable faults. For capable faults, potential challenges to the safety of the nuclear installation in terms of ground motion and/or fault displacement hazards shall be evaluated."

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7. Evaluation of the Potential for Fault Displacement at the Site

CAPABLE FAULTS

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7.4. On the basis of the geological, geophysical, geodetic and/or seismological data, a fault should be considered capable if the following conditions apply:

(a) If the fault shows evidence of past movement (e.g. significant deformations and/or dislocations) within such a period that it is reasonable to conclude that further movements at or near the surface might occur over the lifetime of the site or the nuclear installation, the fault should be considered capable**. In highly active areas,** where both seismic and geological data consistently reveal short earthquake recurrence intervals, **evidence of past movements in the Upper Pleistocene to the Holocene** (i.e. the present) might be appropriate for the assessment of capable faults. **In less active areas,** it is likely that much longer periods (e.g. the Pliocene to the Holocene (i.e. the present)) are appropriate. In areas where the observed activity is between these two rates (i.e. not as highly active as plate boundaries and not as stable as cratonic zones), **the length of the period to be considered should be chosen on a conservative basis (e.g. the Quaternary with possible extension to the Pliocene**, depending on the area's tectonic activity level).

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7. Evaluation of the Potential for Fault Displacement at the Site

CAPABLE FAULTS

7.4. On the basis of the geological, geophysical, geodetic and/or seismological data, a fault should be considered capable if the following conditions apply:

(a) One way to calibrate the time frame for fault capability would be to **check whether the site is in the deformed area of major regional faults**. Longer time frames should be used when the site is far away from the potentially deformed areas of these regional structures.

(b) If the capability of a fault cannot be assessed as indicated in (a) because it is not possible to obtain reliable geochronological data by any available method, the **fault should be considered capable if it could be structurally linked with a known capable fault** (i.e. if a structural relationship with a known capable fault has been demonstrated such that the movement of one fault might cause movement of the other fault at or near the surface).

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8. Parameters Relating To Vibratory Ground Motion Hazards, Fault Displacement Hazards And Other Hazards Associated With Earthquakes

VIBRATORY GROUND MOTION HAZARDS

Parameters and control point

8.1.Irrespective of the method applied (i.e. a probabilistic approach, a deterministic approach, or both), the **vibratory ground motion hazards at the site should be defined by means of appropriate parameters, such as spectral representations and time histories.**

8.2.In principle, the vibratory ground motion parameters should **be defined at the control point** established by the needs of the end user of the evaluation (see Section 10). Usually, **the control point is defined at free field conditions** (i.e. at the ground surface, at key embedment depths or at bedrock level). **In cases where surface soil layers will be completely removed, the parameters should be defined at the level of the outcrop that will exist after removal.** Consideration should be given to appropriate treatment of the interface between the defined reference ground motion and the site response analysis.

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8. Parameters Relating To Vibratory Ground Motion Hazards, Fault Displacement Hazards And Other Hazards Associated With Earthquakes

VIBRATORY GROUND MOTION HAZARDS

Site response analysis

8.3. The site response analysis, performed as recommended in paras 6.19–6.24, provides the vibratory ground motion parameters at locations relevant for the design and safety assessment of the nuclear installation (e.g. at the free field ground surface, at foundation level).

Spectral representations

8.4. The vibratory ground motion hazard, calculated as recommended in Section 6, should be characterized by **response spectra in horizontal and vertical components at the control point**.

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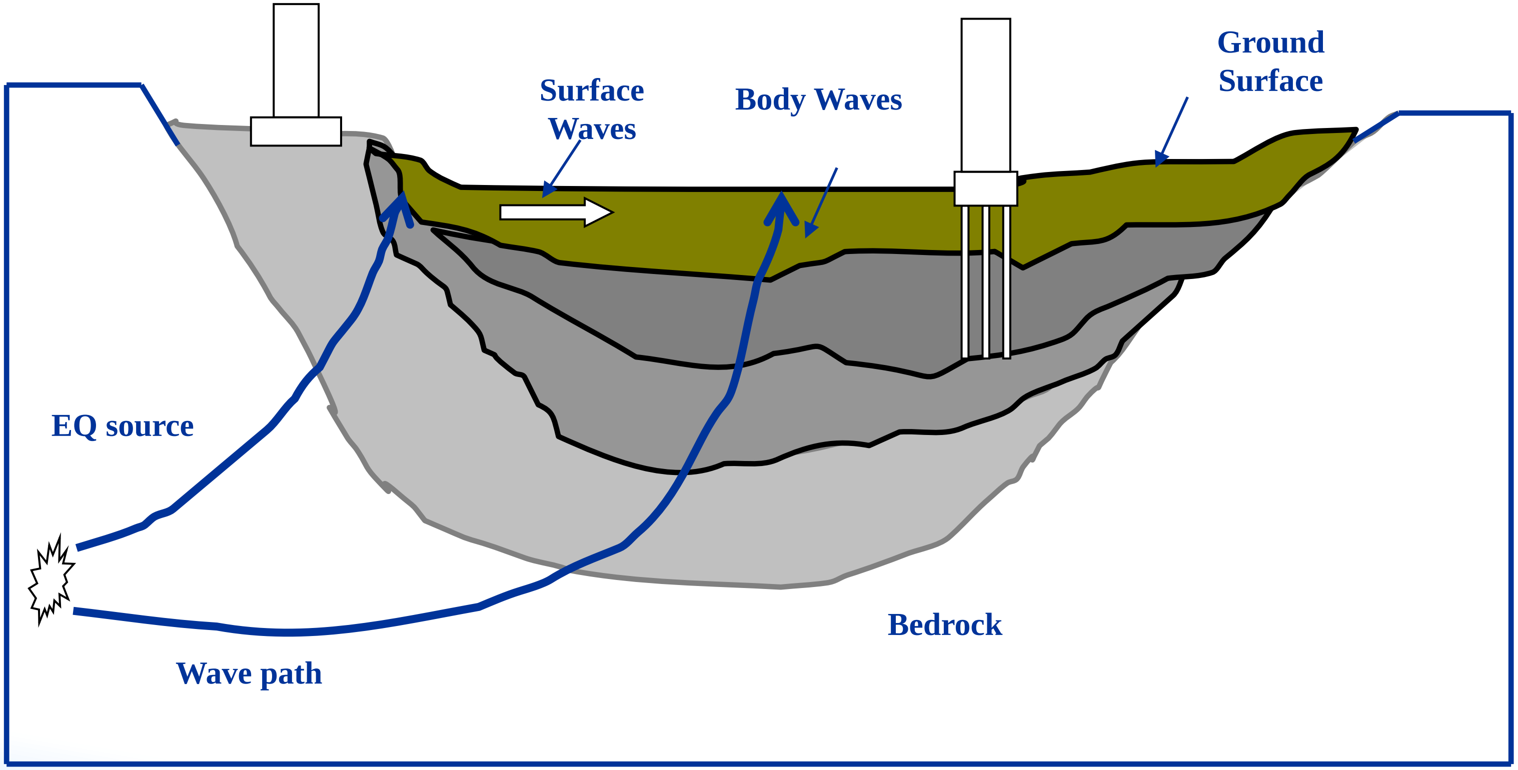
Review: Soil Site Response



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8. Parameters Relating To Vibratory Ground Motion Hazards, Fault Displacement Hazards And Other Hazards Associated With Earthquakes

VIBRATORY GROUND MOTION HAZARDS

Uniform hazard response spectra

8.5. A uniform hazard response spectrum is developed by selecting the values of the response spectral ordinates that **correspond to the annual frequencies of exceedance of interest from the seismic hazard curves** for individual frequencies or periods. One or more uniform hazard response spectra may be developed from the results of the probabilistic seismic hazard analysis and any subsequent site response analyses that have been performed.

Response spectra based on scenario earthquakes

8.6. In deterministic seismic hazard analyses, as well as after the deaggregation process in the probabilistic seismic hazard analyses, **scenario earthquakes should be used to realistically represent the frequency content of ground motions**. Scenario earthquakes from the deaggregation process for the results of probabilistic seismic hazard analyses should be associated with annual frequency of exceedance values.

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8. Parameters Relating To Vibratory Ground Motion Hazards, Fault Displacement Hazards And Other Hazards Associated With Earthquakes
VIBRATORY GROUND MOTION HAZARDS

Time histories

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8.9. Time histories should satisfactorily reflect all the prescribed ground motion parameters as embodied in the response spectra or other spectral representation, with the addition of other parameters such as duration, phase and coherence. **The number of time histories to be used in the detailed analyses and the procedure to be used in generating those time histories will depend on the type of analysis to be performed and should be specified by the end user of the evaluation** (see Section 10) on the basis of the different types of engineering analysis to be conducted in the design or safety assessment stages.

8.10. Significant progress has been made in ground motion simulation based on fault rupture modelling with wave propagation paths and site effects (e.g. by use of empirical Green's function methods). Ground motions obtained in this way for regions for which pertinent parameters are available can be employed to complement the more traditional methods. **Time histories should be applied carefully, especially when developed for soils that are expected to respond non-linearly.**

8. Parameters Relating To Vibratory Ground Motion Hazards, Fault Displacement Hazards And Other Hazards Associated With Earthquakes

VIBRATORY GROUND MOTION HAZARDS

Time histories

8.11. In using response spectra to develop design time histories, it should be ensured that the time histories include **the appropriate energy content represented by the design ground motions**. This could be done by calculating the corresponding power spectral density functions.

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9.1 The evaluation of seismic hazards for nuclear installations other than nuclear power plants should be commensurate with **the complexity of such installations**, with the potential radiological hazards and with the hazards due to other materials present on the site.

9.2. The recommended method for applying the graded approach is to **start with attributes relating to nuclear power plants** and, **if possible**, to commensurately **adjust these for installations with which lesser radiological consequences are associated**. If this approach is **not practicable** for a nuclear installation other than a nuclear power plant, **then the recommendations relating to nuclear power plants should be applied**.

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SCREENING PROCESS

9.3. **Prior to adopting a graded approach**, a **conservative screening process should be applied** in which it is assumed that the **entire radioactive inventory of the installation is released** by the potential seismically initiated accident. If the potential result of **such a radioactive release is that unacceptable consequences would not be likely** — for workers or the public (i.e. doses to workers and to the public would be below the dose limits established by the regulatory body) or for the environment — and if no other specific requirements are imposed by the regulatory body for such an installation, **the installation may be excluded from** the requirement to undertake **a full seismic hazard assessment**. If, even after such a result is reached, some degree of seismic hazard assessment is considered necessary, **national seismic codes for hazardous and/or industrial facilities** should be used.

9.4. If the **results of the conservative screening process show that the potential consequences of such a release would be unacceptable**, a seismic hazard **assessment of the installation should be carried out**, starting from the recommendations relevant to nuclear power plants.

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SCREENING PROCESS

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9.5. The conservative screening process described in para. 9.3 should consider the **likelihood that a seismic event will result in an event with radiological consequences**. This likelihood will highly **depend on the following factors** relating to the characteristics of the nuclear installation (e.g. its purpose, layout, design, construction and operation):

(a) The **amount, type and status of the radioactive inventory** at the site (e.g. whether solid, liquid and/or gaseous; whether the radioactive material is being processed or only stored);

(b) The intrinsic hazard associated with the physical processes (e.g. nuclear chain reactions) and chemical processes (e.g. for fuel processing purposes) that take place at the installation;

(c) The **thermal power of the nuclear installation**, if applicable;

(d) The **configuration of the installation** for different kinds of activity;

(e) The **distribution of radioactive sources** in the installation (e.g. for research reactors, most of the radioactive inventory will be in the reactor core and the fuel storage pool, whereas for fuel processing and storage facilities it might be distributed throughout the installation);

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SCREENING PROCESS

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9.5. The conservative screening process described in para. 9.3 should consider the likelihood that a seismic event will result in an event with radiological consequences. This likelihood will highly depend on the following factors relating to the characteristics of the nuclear installation (e.g. its purpose, layout, design, construction and operation):

(f) The **changing nature of the configuration and layout** of installations designed for experiments (such activities have an associated intrinsic unpredictability);
(g) The **need for active safety systems** and/or operator actions for the prevention of accidents and for mitigation of the consequences of accidents, and the characteristics of engineered safety features for the prevention of accidents and for mitigation of the consequences of accidents (e.g. the containment and containment systems);
(h) The **characteristics of the structures of the nuclear installations** and the **means of confinement of radioactive material**;
(i) The **characteristics of the processes** or of the engineering features that might show **a cliff edge effect** in the event of an accident;

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SCREENING PROCESS

9.5. The conservative screening process described in para. 9.3 should consider the likelihood that a seismic event will result in an event with radiological consequences. This likelihood will highly depend on the following factors relating to the characteristics of the nuclear installation (e.g. its purpose, layout, design, construction and operation):

(j) The **characteristics of the site** that are **relevant to the consequences of the dispersion** of radioactive material to the atmosphere and the hydrosphere (e.g. size and demographics of the region);
(k) The **potential for on-site and off-site contamination**.

9.6. Depending on the criteria applied by the regulatory body, **some or all of the factors** in para. 9.5 **should be considered** when applying the conservative screening process. For example, the fuel damage, the radioactive release or the doses to workers and the public could be factors that warrant special consideration.

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SCREENING PROCESS

9.7. The application of the graded approach should be based on the following information:

(a) The **existing safety analysis report** for the installation, which should be the primary source of information;
(b) The **results of a probabilistic safety assessment**, if one has been performed;
(c) The characteristics specified in para. 9.5.

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CATEGORIZATION PROCESS

9.8. If the **conservative screening process indicates that a seismic hazard assessment of the installation is to be carried out** (see para. 9.5), a process for categorizing the installation should be undertaken. This **categorization may be performed at the design stage or later**. If the categorization has been performed, the **assumptions** on which it was based **should be reviewed and verified**. In general, the criteria for **categorization should be based on the radiological consequences** of a radioactive release from the installation, ranging from very low to potentially severe consequences. **As an alternative**, the categorization may **consider the radiological consequences within the installation itself**, within **the site of the installation**, and **for the public and the environment**.

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CATEGORIZATION PROCESS

9.9. Three or more categories may be defined on the **basis of national practice** and criteria, as well as the information described in para. 9.7. As an example, the following categories may be defined:

(a) **The lowest hazard category**, which includes those nuclear installations for which **national building codes** for conventional installations (e.g. essential facilities such as hospitals) or **for hazardous facilities** (e.g. petrochemical or chemical plants) should be applied as a minimum;
(b) The **highest hazard category**, which includes **installations for which standards and codes for nuclear power plants** should be applied;
(c) There is often **at least one intermediate category between (a) and (b),** corresponding to a hazardous installation for which, at a minimum, codes dedicated to hazardous facilities should be applied.

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9. Evaluation Of Seismic Hazards For Nuclear Installations Other Than Nuclear Power Plants

VIBRATORY GROUND MOTION HAZARD ANALYSIS AND ASSOCIATED ASPECTS

Vibratory ground motion hazard analysis

9.10. The vibratory ground motion hazard analysis for installations categorized as recommended in paras 9.8 and 9.9 should be performed in accordance with the following:

(a) For the **least hazardous installations**, the input ground motion for the **design may be taken from national building codes and maps**.

(b) For installations **in the highest hazard category**, methodologies for seismic hazard assessment as described in Sections 3–8 of this Safety Guide (i.e. **recommendations applicable to nuclear power plants**) **should be used**.

(c) For installations categorized **in the intermediate hazard category**, the following approach might be applicable:

(i) If the seismic hazard assessment is typically performed using methods similar to those described in this Safety Guide, **a lower input ground motion than that evaluated for (b) may be adopted** for designing these installations, in accordance with the safety requirements for the installation.

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VIBRATORY GROUND MOTION HAZARD ANALYSIS AND ASSOCIATED ASPECTS
Vibratory ground motion hazard analysis

9.10. The vibratory ground motion hazard analysis for installations categorized as recommended in paras 9.8 and 9.9 should be performed in accordance with the following:

(c) For installations categorized in the intermediate hazard category, the following approach might be applicable:

(ii) If the database and **the methods recommended in this Safety Guide are found to be disproportionately complex**, time consuming and demanding for the nuclear installation in question, **simplified methods for seismic hazard assessmen**t (that are based on a more restricted data set) **may be used**. In such cases, **the input ground motion** finally adopted for designing the installation should be **commensurate with the reduced database** and **the simplification of the methods**, with account taken of the fact that both factors **tend to increase uncertainties**.

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VIBRATORY GROUND MOTION HAZARD ANALYSIS AND ASSOCIATED ASPECTS

Vibratory ground motion hazard analysis

9.11. The **design basis ground motion levels** for nuclear installations other than nuclear power plants **should be decided in the context of the approach to hazard assessment** recommended in para. 9.10.

9.12. The **recommendations relating to seismic instrumentation** installed on the site (see paras 3.54–3.59) should be **applied in a manner commensurate with the category of the installation**, as defined in para. 9.9.

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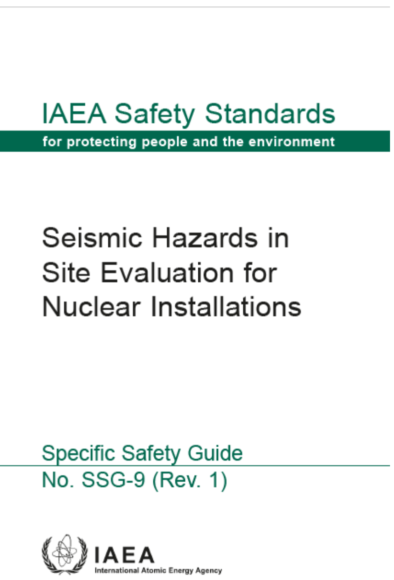
9. Evaluation Of Seismic Hazards For Nuclear Installations Other Than Nuclear Power Plants

VIBRATORY GROUND MOTION HAZARD ANALYSIS AND ASSOCIATED ASPECTS

Geological and geotechnical aspects associated with seismic hazards

9.13. With regard to the **geological and geotechnical aspects** associated with seismic hazards, **the same considerations** used **for nuclear power plants should apply to other types of nuclear installation**. If reliable evidence demonstrates that **fault displacement phenomena arising from these aspects could occur** within the site vicinity and/or site area, **a detailed and specific fault displacement assessment should be conducted**. The **site may still be considered suitable** on the basis of **specific established suitability criteria**, and **design bases should be established to ensure the safety of the nuclear installation** through design, construction and operation measures.

Summary of Recommended Graded Approach in SSG-9 Rev-1 for Others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Vibratory Ground Motion Hazard Analysis

STEP 1: SCREEN (Para. 9.3): Assume that the entire radioactive inventory is released by the potential seismically initiated accident and assess acceptability of the consequences for workers and the public:

If consequences are acceptable

↓

Use national seismic codes for hazardous and/or industrial facilities: Discard the “nuclear” practice

Observations: Unlikely that an SMR passes the screening criteria.

Summary of Recommended Graded Approach in SSG-9 Rev-1 for Others

Vibratory Ground Motion Hazard Analysis

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STEP 2: CATEGORIZE (Para. 9.8): When the first screen shows that consequences of releasing the entire radioactive inventory may be unacceptable, a process for categorizing the installation should be undertaken:

Radiological hazard categories (Para. 9.9):
Three or more categories may be defined

Lowest hazard category:
Use national building codes

Intermediate hazard category:
No clear set of rules

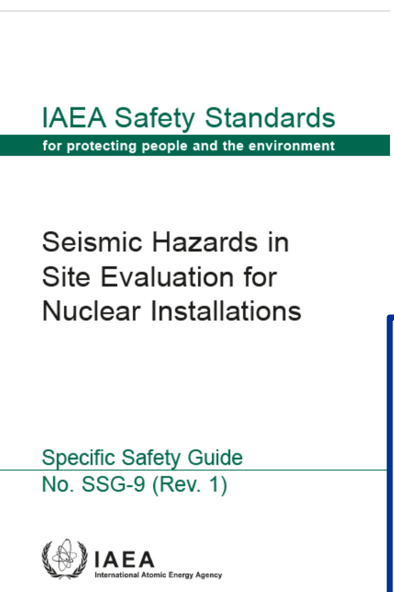
Highest hazard category
Use same as for regular NPPs

Observations: No quantitative guidance is provided to define the limits

Summary of Recommended Graded Approach in SSG-9 Rev-1 for Others

Vibratory ground motion hazard analysis

INTERMEDIATE HAZARD CATEGORY: (Para. 9.10): Two remarks:



Seismic hazard assessment results for a regular NPP is available:
e.g.: Existing NPP site

→ A lower input ground motion may be adopted for the installation.

The methods for a regular NPP are found disproportionally complex, time consuming and demanding:
e.g.: Conservative approach not preferred

→ Simplified methods based on a more restricted data set may be used

Observations:

1. Methods for interpolating and extrapolating PSHA or DSHA results exist
2. Reduced database and simplified methods tend to increase uncertainties

Simplified PSHA
Graded Approach in SSG-9 Rev-1 for Others

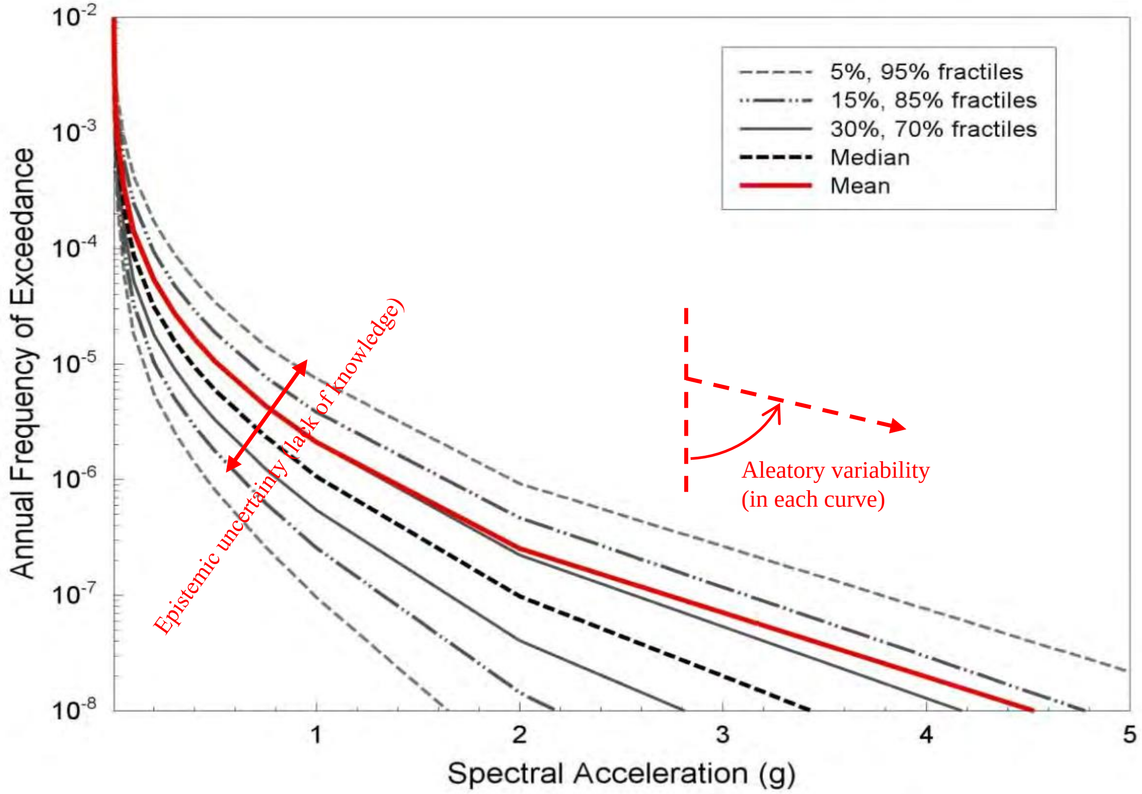


Figure 4. Seismic hazard curves in the deep bedrock horizon for spectral accelerations at a response period of 0.1s. The design motions at the surface elevation are obtained through convolution of these hazard curves with site amplification factors.

(Figure adapted from *Bommer et al*, SMiRT-22, 2013)

Summary of Recommended Graded Approach in SSG-9 Rev-1 for Others

Fault Displacement Hazard Analysis

(Para. 9.13): the same considerations used for regular NPPs should apply to all radiological hazard categories (i.e. no grading):

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Reliable evidence demonstrates that fault displacement phenomena could occur within the site vicinity and/or site area

→ Detailed and specific fault displacement assessment conducted.

→ The site may still be considered suitable, on the basis of specific established suitability criteria.

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Thank you!