Training Course
on the IAEA Safety Standards Overview

SSG-9 (Rev.1)

Seismic Hazards in Site Evaluation for Nuclear Installations

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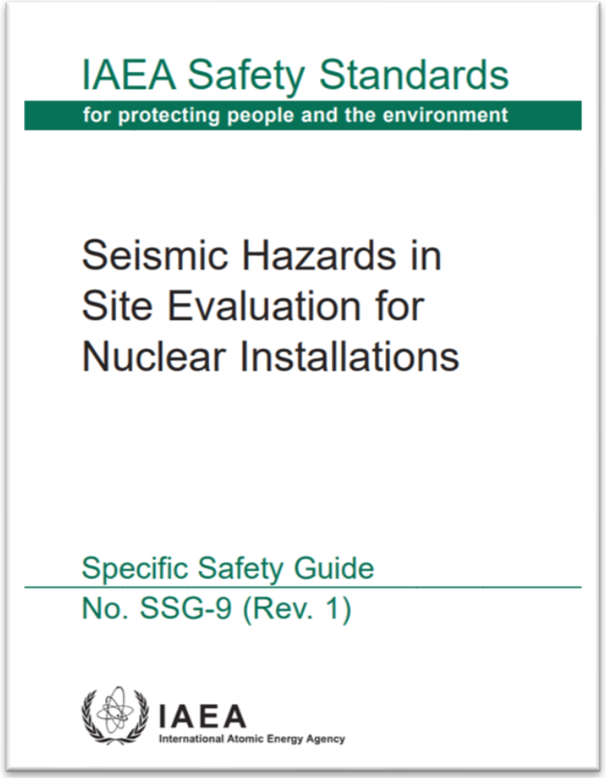
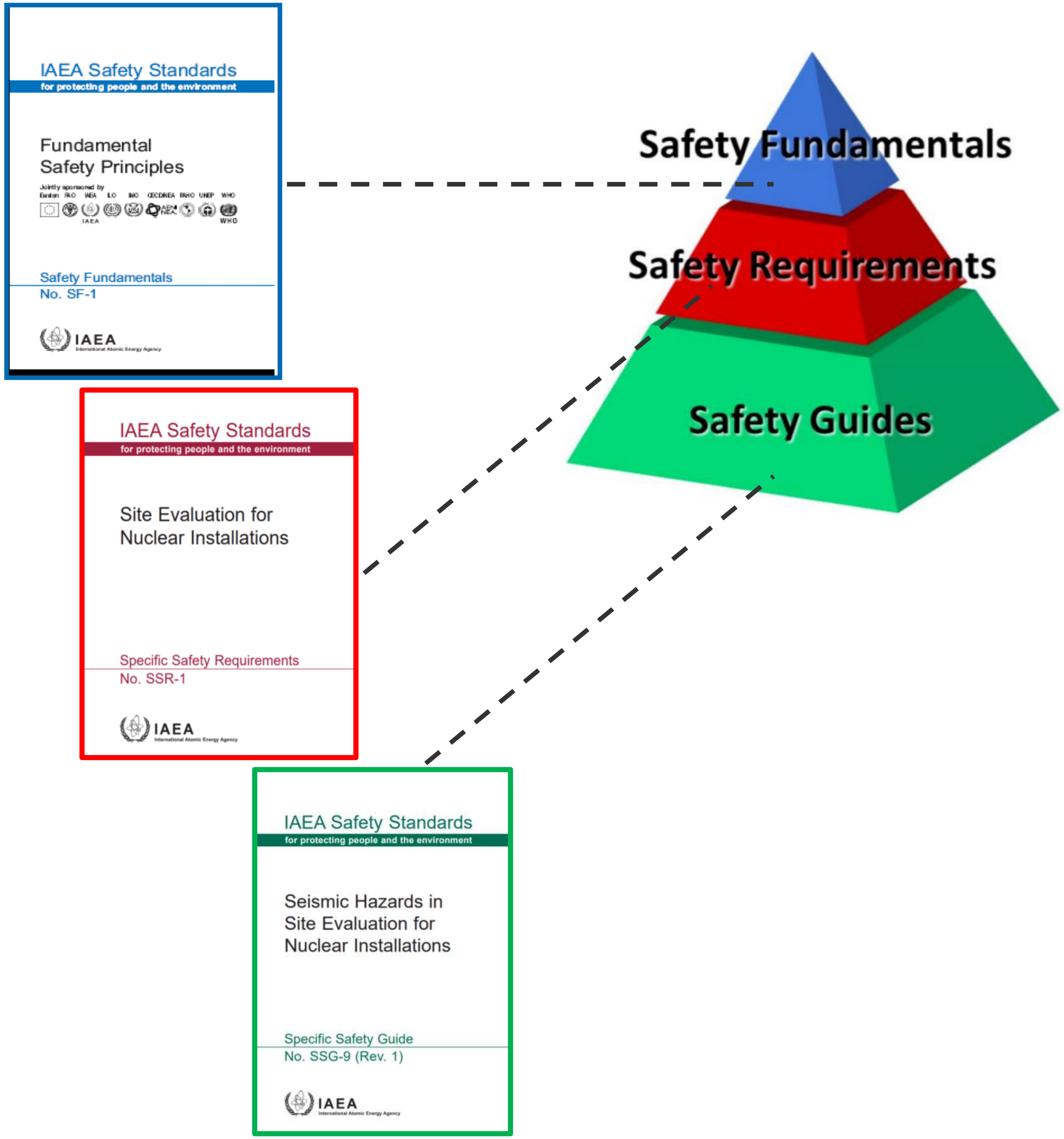
This presentation:

Summarizes the main elements of IAEA Specific Safety Guide No. SSR-9 (Rev.1) “Seismic Hazards in Site Evaluation for Nuclear Installations”.

- ✓ Rev. 1 of SSG-9 was published in 2022, superseding the 2010 version.
- ✓ Seismic hazard assessment is a speedily evolving field…
- ✓ A new review cycle is starting in 2026.





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Section	
1 and 2	Introduction and General Aspects of Seismic Hazard Assessment
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10	Application of the Management System

Where to start from, how to continue?

What to collect?
The infamous GGG-S database!
(for more details, see Slide 6)

Manage the project in a structured manner, document the results, facilitate peer review…

Where can we start?

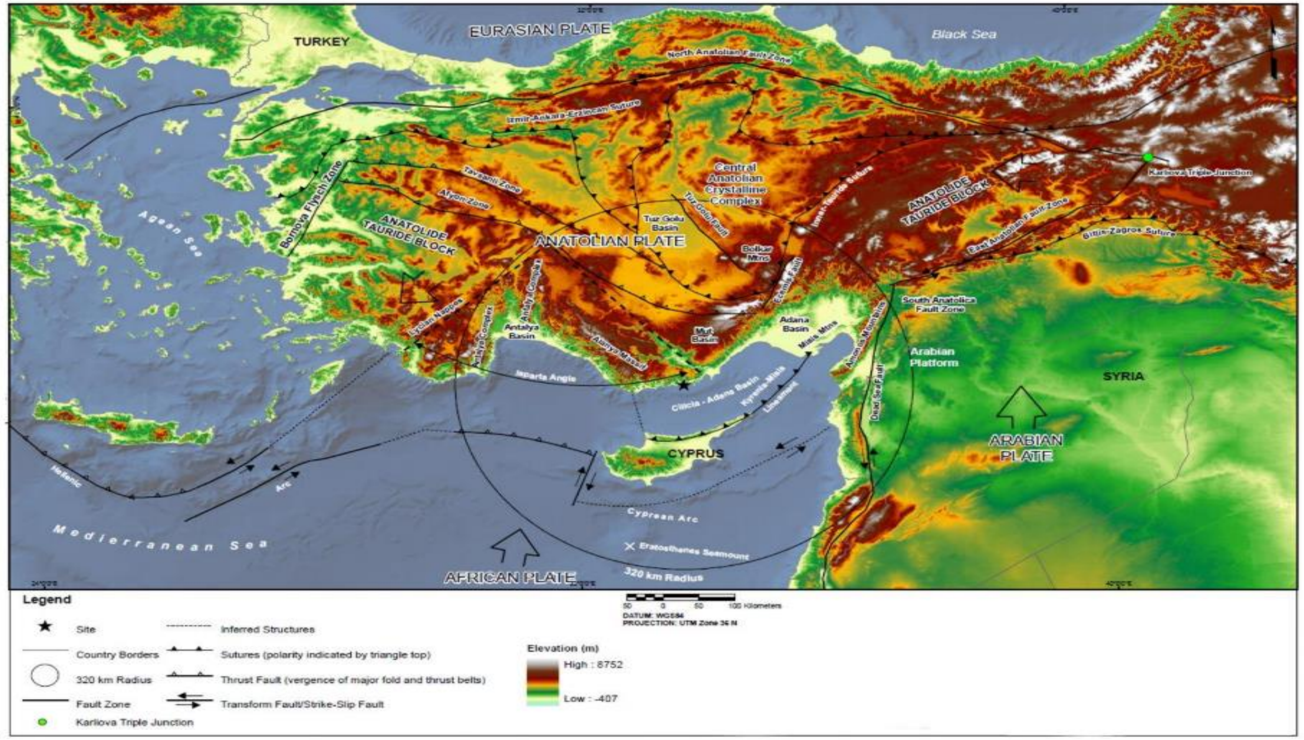
- ✓ Vibratory ground motion: **regional scale**
- ✓ Fault displacement phenomena: **near region/site vicinity**
- ✓ Geotechnical hazards: **site area/site vicinity?**

SSG-9 (Rev.1): The region should be of sufficient extent to include **all seismic sources** that could reasonably be **expected to contribute** to the seismic hazards at the site…

- Can we ignore distant seismic sources?
- Does it need to be a full circle?
- National borders?

Project – specific!

SSG-9 (Rev.1):…the geological, geophysical and seismological characteristics of the geographical region around the site and the geotechnical characteristics of the site area should be investigated…

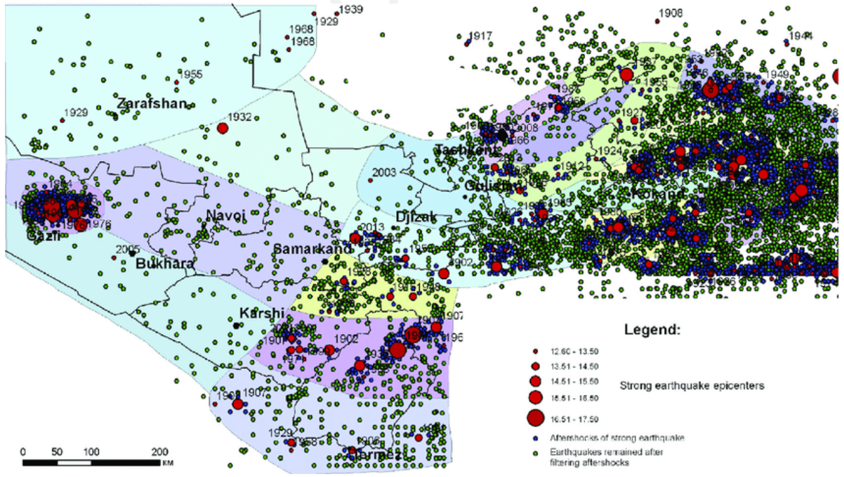


Pictures: Courtesy of Mr. Baris Guner

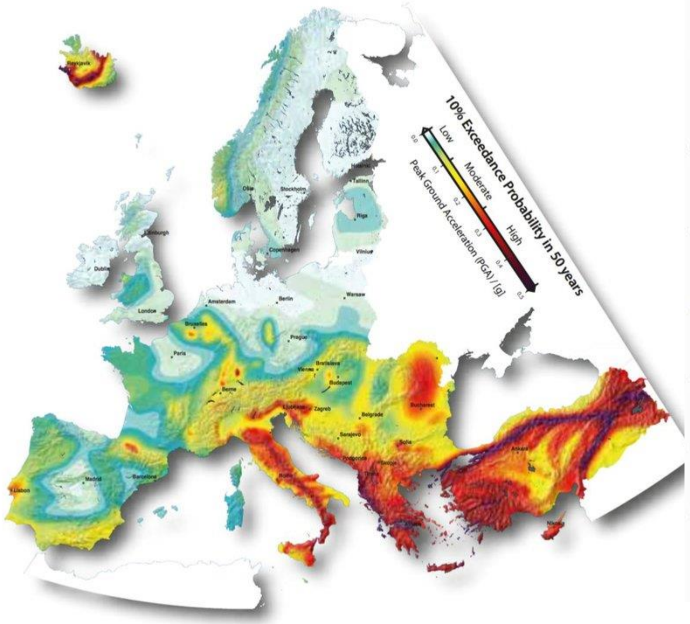
Where can we start?

SSG-9 (Rev.1):…Not all the data in the GGG-S database has to be site-specific…

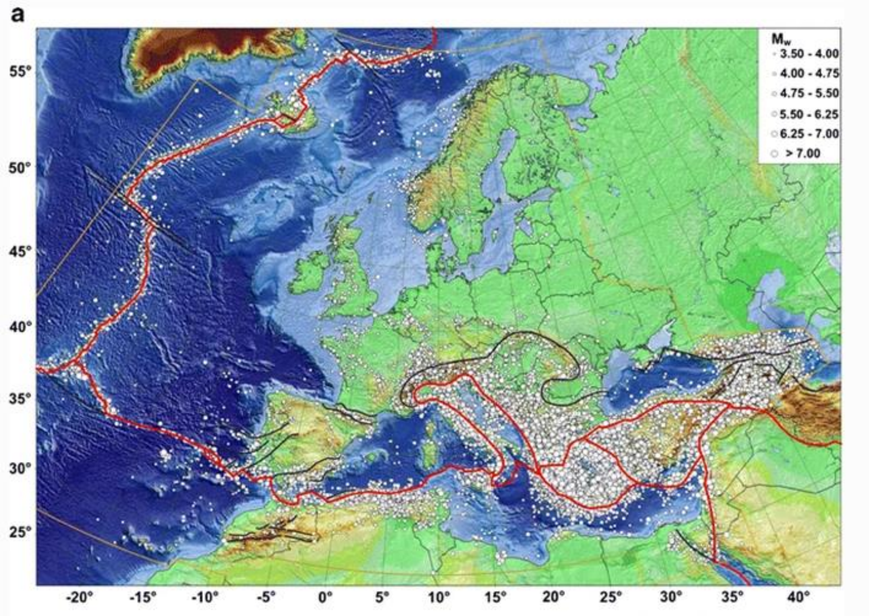
Meghraoui, M. (2016). The Seismotectonic Map of Africa. Episodes, 39



Usmanalievich, Artikov & Ibragimov, R.s & Ibragimova, Tatyana & Abdyurahimdjanovich, Mirzaev. (2020). Complex of general seismic zoning maps OSR-2017 of Uzbekistan. Geodesy and Geodynamics. 11. 10.1016/j.geog.2020.03.004.



Giardini D. et al., (2013), Seismic Hazard Harmonization in Europe (SHARE): Online Data Resource, doi: 10.12686/SED-00000001-SHARE, 2013



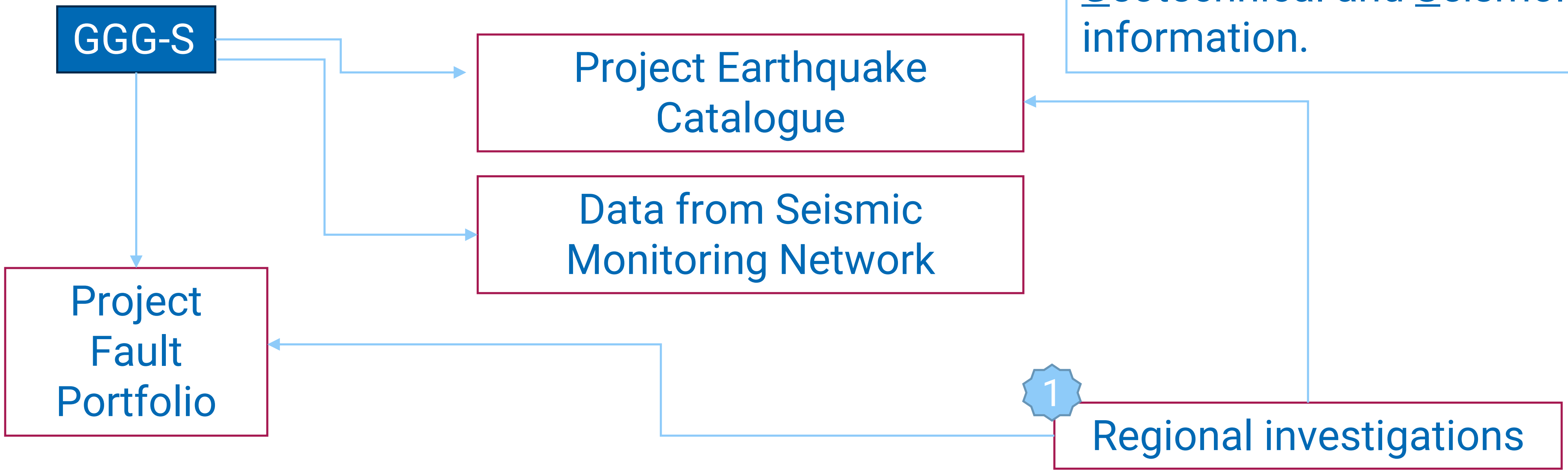
Grünthal, G., Wahlström, R. The European-Mediterranean Earthquake Catalogue (EMEC) for the last millennium. J Seismol 16, 535–570 (2012). https://doi.org/10.1007/s10950-012-9302-

Key: Collect all the available data in the first phase of the project!

- ✓ Regional geology maps
- ✓ National and global earthquake catalogues
- ✓ Strong motion datasets and national networks
- ✓ Global seismic hazard maps
- ✓ Building codes
- ✓ Global tsunami centers
- ✓ Data collected during site selection stage…

The GGG-S Database:

SSG-9 (Rev.1): GGG-S is a project-specific, comprehensive and integrated database that includes ***G***eological, ***G***eophysical, ***G***eotechnical and ***S***eismological information.



Key: The GGG-S is scale dependent (progressively more detailed from region to site area)!

Geological and geophysical data to characterize the general seismo-tectonics:

- ✓ Existing geological, geophysical, and remote sensing data (including aerial photos) – check at the field if necessary, identify gaps
- ✓ Further investigations for the gaps – proper resolution and techniques.
- ✓ Organize the data in project-specific GIS system

The GGG-S Database:

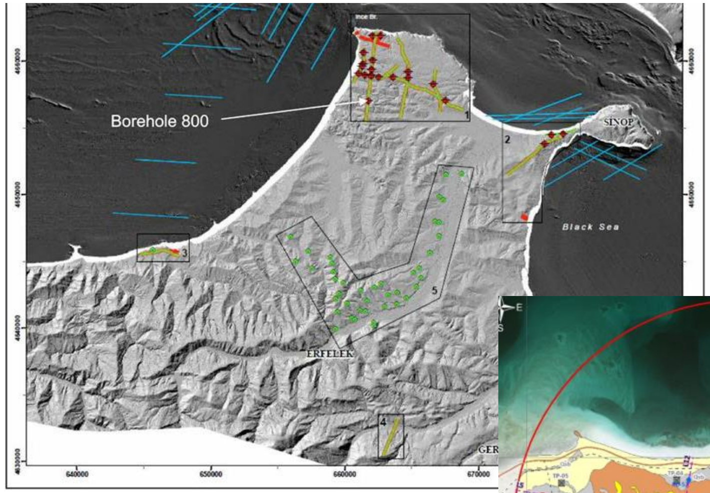
SSG-9 (Rev.1): For new sites, if reliable evidence is collected, demonstrating the existence of a capable fault within the site vicinity, and its effects cannot be compensated for by proven design or engineering protective measures, this issue should be treated as an exclusionary attribute.

2

Near - regional Investigations

More detailed investigations than region:

- ✓ Seismo-tectonic characteristics of near region, rate of activity, segmentation.
- ✓ Recent movements in seismogenic structures/fault capability issues.
- ✓ Stratigraphy, structural geology, tectonic history
- ✓ Field geological mapping, borehole and geophysical data, GPS, trenching, etc.

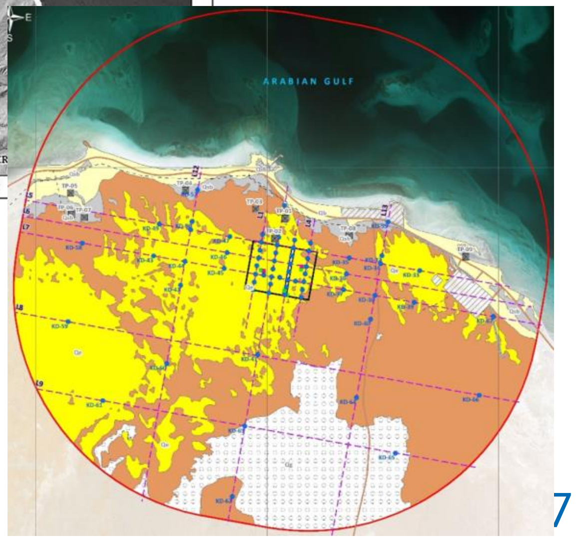


3

Site Vicinity

More detailed investigations than near-region:

- ✓ Potential for fault-capability
- ✓ Potential for geological and geotechnical instabilities
- ✓ GGG – enough number and depth of boreholes



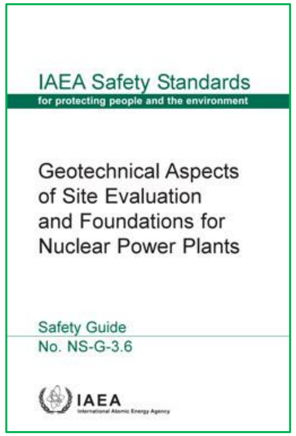
Pictures: Courtesy of Mr. Christophe Martin and Mr. Arda A. Ozacar

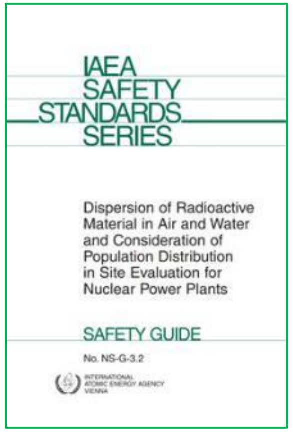
The GGG-S Database:

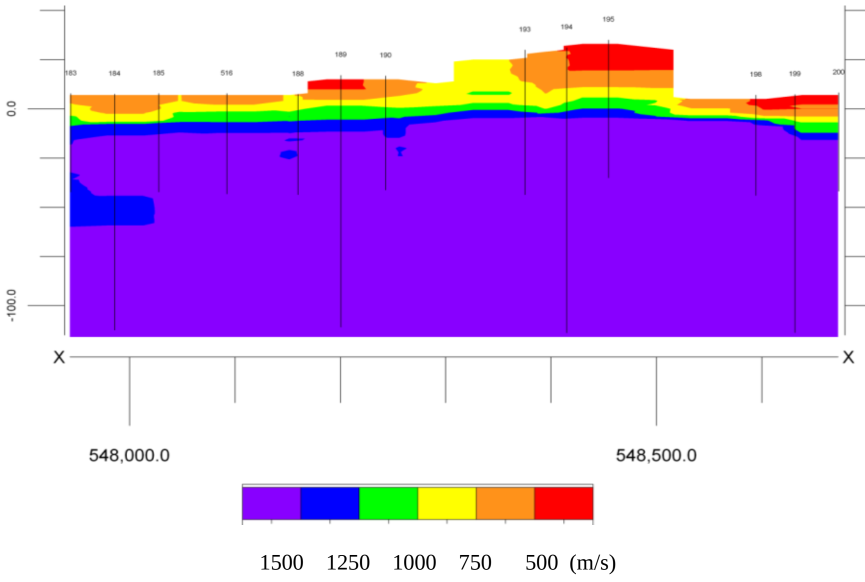
4 Site Area

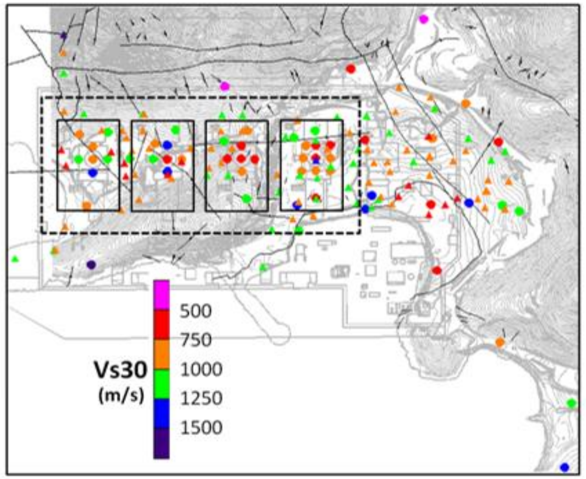
More detailed investigations than site-vicinity:
- ✓ Potential for ground displacement
- ✓ Static and dynamic properties of soil layers
- ✓ Layout known/unknown?
- ✓ Hydrogeological investigations
- ✓ Fault capability

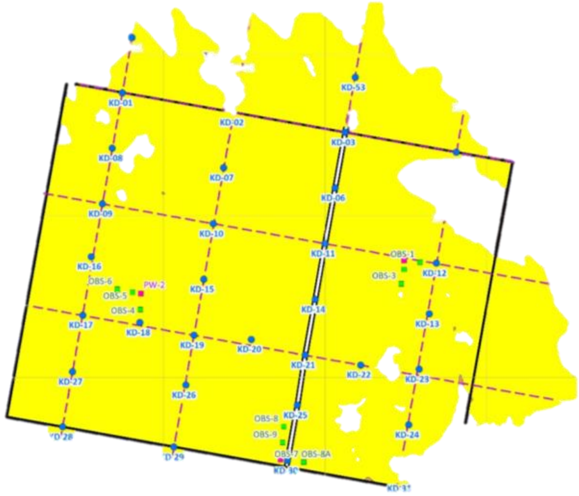
Design of site investigation program







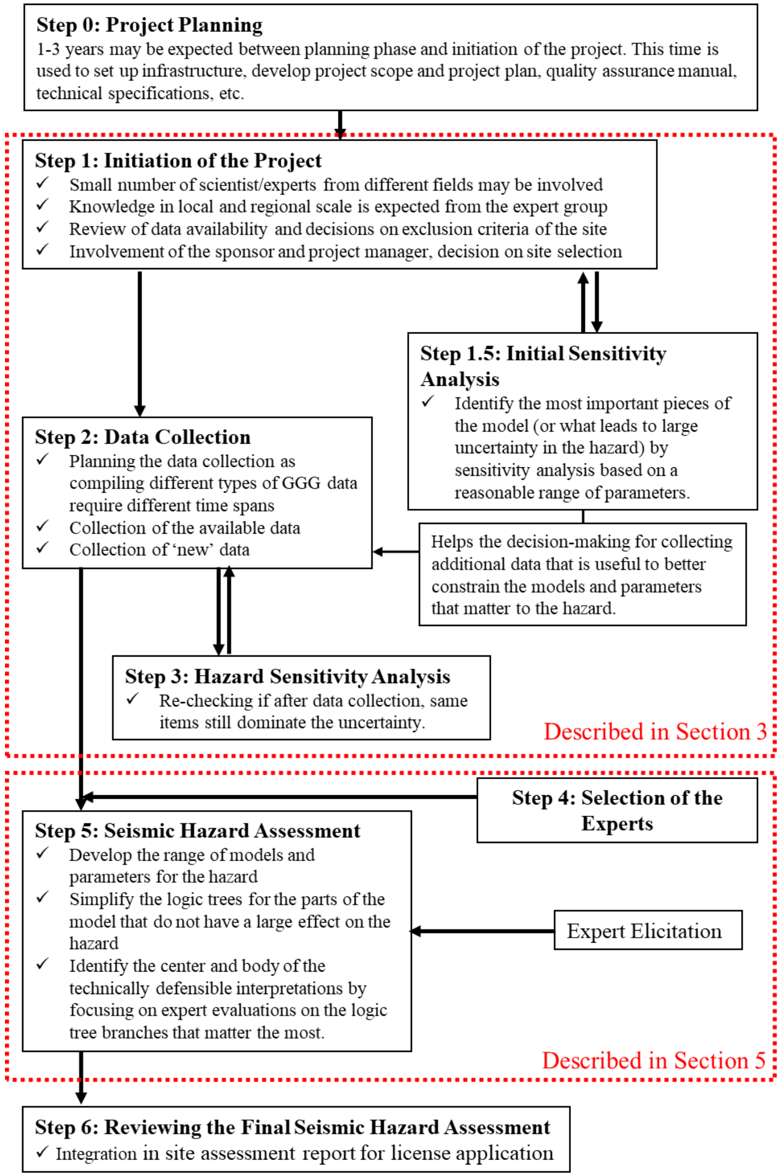




Pictures: Courtesy of Mr. Berke Sayin and Mr. Arda A. Ozacar

New Safety Report: Evaluation of Epistemic Uncertainty in Seismic Hazard Assessment for Nuclear Installations

- ✓ The new safety report will support Sections 2, 3 and 10 of SSG-9 (Rev. 1);
- ✓ This publication describes the **main components of seismic hazard assessment projects** including the **evaluation relevant datasets and information**, selection of the experts, and development of the logic tree structure;
- ✓ Presents the main sources of epistemic uncertainties in seismic hazard assessment and how to account for these uncertainties;
- ✓ Provides a structured framework to elicit multiple expert opinions in objective manner, so that the epistemic uncertainty evaluation will be able to **provide results in a transparent, scientifically rigorous, well-documented and rational way**.



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Sections 4-6 describe the main components and conduct of a seismic hazard assessment project.

- Select the approach for seismic hazard assessment (DSHA or PSHA)
- Characterize the seismic sources
- Choose the ground motion prediction equations or conduct simulations
- Conduct Seismic Hazard Analysis

Seismic Hazard Assessment: Probabilistic or Deterministic?

✓ **The current practice of seismic hazard analysis varies tremendously from poor to very good**.

✓ **The large variability in practice is not simply a reflection of project budgets.**

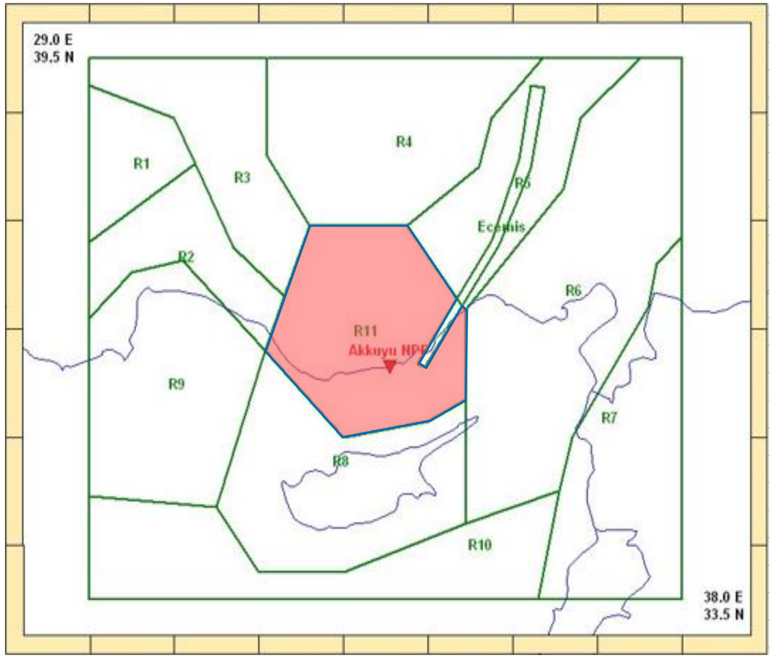
✓ **Basic methodologies used in seismic hazard analysis are generally not well understood by practicioners.**

✓ In the past, Deterministic Seismic Hazard Assessment (DSHA) was used for licensing existing NPPs:

- Design earthquake negotiated and agreed with the regulator
- Maximum Credible Earthquake for known faults and distant zones
- Smaller earthquakes for zone containing the site (Host zone)

✓ **Probabilistic Seismic Hazard Assessment (PSHA) was developed for nuclear industry to address difficulty of selecting design earthquake for the host zone.**

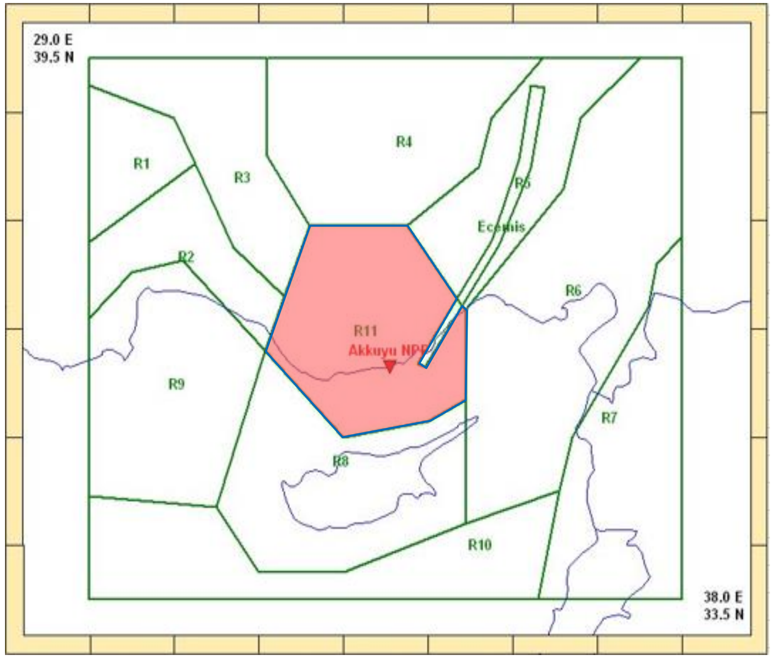
✓ **PSHA is also used for existing NPPs in order to develop input for probabilistic risk analysis.**



Picture: Courtesy of Mr. Berke Sayin

The “Host Zone”: Probabilistic or Deterministic?

- ✓ **Deterministic approach is more complicated when there is no “fault”**
- ✓ **The Mmax value assigned to the host zone is a very important parameter.**
- ✓ It can be taken as 6.5 or lower (Cao et al. 1996; DePolo 1994; Horino 2014; Petersen et al. 2008).
- ✓ In Western United States, Mmax of the host zone usually ranges from 6.0 to 6.5.
- ✓ For the inland crustal earthquakes, although it does not cause any surface faulting, it is assumed that there may be a magnitude of 6.5 or smaller earthquakes can happen anywhere in Japan (Nuclear Regulation Authority of Japan, 2013).



Picture: Courtesy of Mr. Berke Sayin

Difficulties in selecting a “reasonable” background earthquake is what led to the development of the probabilistic approach.

Option 1:Treat them the same as faults:

Largest magnitude at closest location

- M = 6.5, Distance = 0
- Not “reasonable”

Option 2: Pick some less severe earthquake

- M = 5.5, distance = 5 km?
- M = 6.0, distance = 10 km?
- M = 6.25, distance = 17 km?
- What is reasonable? - Depends on seismic activity
- Typically, this scenario has been negotiated with regulators

Selection of the seismic source type:

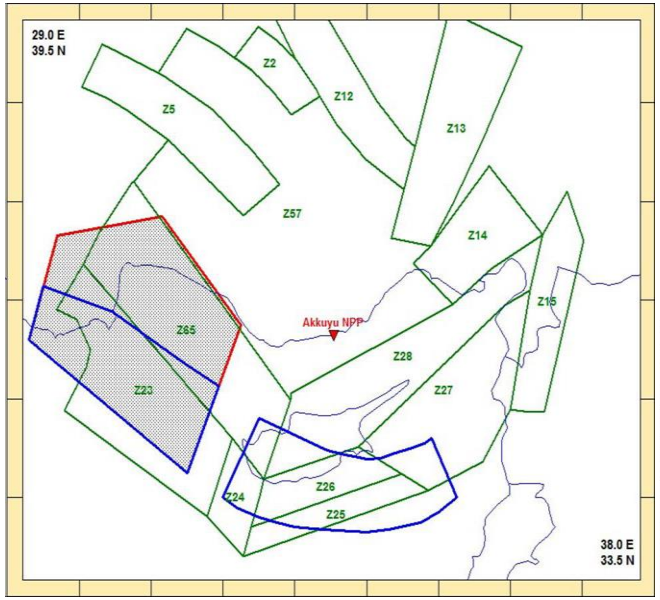
SSG-9 (Rev. 1) Para. 4.1-4.8

SSG-9 (Rev. 1) defines two types of seismic sources as:

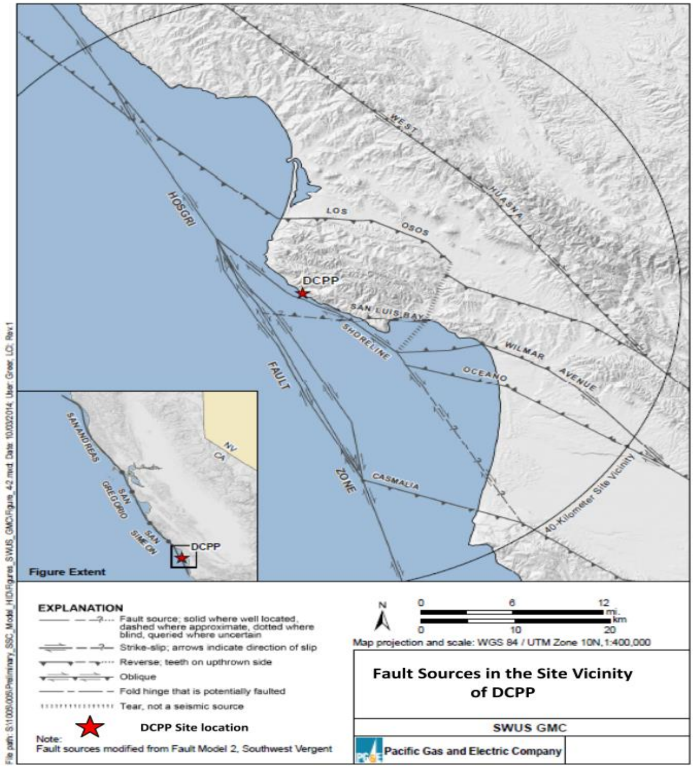
Zones of diffuse seismicity (areal sources)

Seismogenic structures (capable faults)

SSG-9 (Rev. 1): Location and the earthquake potential of seismogenic structures could contribute to both seismic hazard and fault displacement hazard.



Pictures: Courtesy of Mr. Berke Sayin and Mr. N. A. Abrahamson



- ✓ Areal source zones are used to model the spatial distribution of seismicity in regions with unknown fault zones.
- ✓ In the 1970s and 1980s, the seismic source characterization was typically based on historical seismicity data areal sources. This statement is valid for most of the NPPs that were built in 1970s and 1980s.
- ✓ In many parts of the world, particularly those without known faults, this is still the standard of practice.

Earthquake Catalogues:

Earthquake catalogue is a tabulated documentation of the earthquakes including the date, the origin time, epicentral coordinates and focal depth of the events.

DATE			TIME	EPICENTRE		DEPTH
Year	Month	Day	(UTC)	N°	E°	(km)
1982	I	09	01:55:11.9 ± 0.64	13.11 ± 0.080	-88.53 ± 0.089	89 ± 7.2
1982	I	12	05:48:19 ± 1.2	13.15 ± 0.031	-87.56 ± 0.028	10 ± 7.9
1982	VI	19	06:21:57.9 ± 0.21	13.29 ± 0.016	-89.39 ± 0.016	83 ± 1.9
1982	VI	23	08:51:39.5 ± 0.59	13.95 ± 0.076	-88.60 ± 0.072	33


Courtesy of Prof. Bommer


Courtesy of Prof. Bommer

Pictures: Courtesy of Mr. J. Bommer

SSG-9 (Rev. 1): The seismological database should recognize two different types of data – historical and archeological/geological or pre-historical:

- **Historical stage**, i.e. the period for which there are documented records of earthquake events. This period is further subdivided as follows:
  - ✓ **Pre-instrumental (or non-instrumental) period**;
  - ✓ **Instrumental period**, i.e. the period from the development and use of instruments to record earthquake parameters.
- **Pre-historical stage,** i.e. the period for which there are no documented records of earthquake events.

San Salvador, El Salvador, 1854

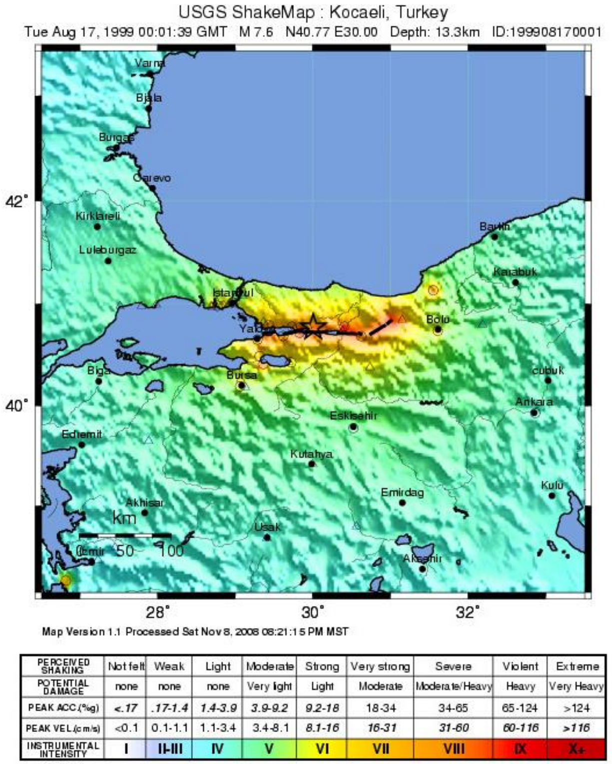

Courtesy of Prof. Bommer

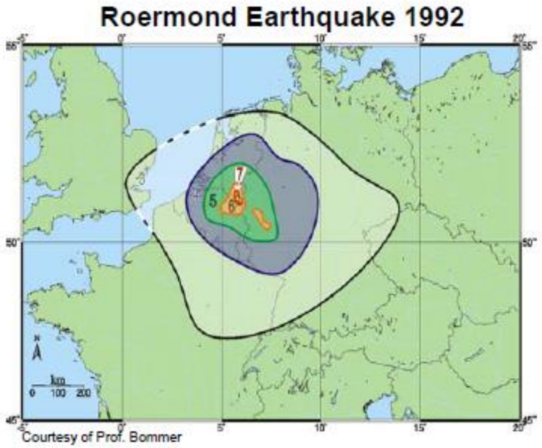
SSG-9 (Rev. 1) Para. 3.36-3.53

Historical Earthquake Catalogue:

Historical catalogues are available for almost every region, including most of the time, some sort of information on the time and intensity of the event.

How about location?





The epicentral location, or at least the general source region, can be estimated from the center of the iso-seismals.

Table of historical events from the territory of Poland and its vicinity; up to 1999, according to Guterch (2009), since 2000 according to Annual Bulletins of PLSN

No.	Date	Intensity I^o	Magnitude M	No.	Date	Intensity I^o	Magnitude M
1	1483	5.0	3.6	18	06 Aug. 1841	5.5	4.0
2	23 Jul. 1496	5.0	3.6	19	25 Nov. 1877	5.0	3.6
3	10 Feb. 1562	7.0	4.9	20	11 Jun. 1895	6.5	4.5
4	09 Jan. 1572	7.0	4.9	21	11 Feb. 1909	6.5	4.3
5	1606	6.0	4.3	22	20 Nov. 1926	6.0	4.2
6	13 Feb. 1615	5.0	3.6	23	11 Jun. 1928	5.0	3.6
7	1716	5.0	3.7	24	Feb. 1932	6.0-6.5	4.2-4.5
8	11 Mar. 1717	5.0	3.7	25	23 Mar. 1935	7.0	4.4
9	31 Jul. 1751	6.5	4.6	26	17 Mar. 1966	5.0	3.3
10	26 Jan. 1774	7.0	4.9	27	29 Jun. 1992	5.5	3.6
11	22 Aug. 1785	6.5	4.8	28	01 Mar. 1993	7.0	4.4
12	27 Feb. 1786	7.0	4.4	29	01 Jun. 1994	6.0	4.3
13	03 Dec. 1786	7.5	5.6	30	11 Sep. 1995	6.0	3.7
14	08 Jan. 1803	6.0	4.3	31	13 Oct. 1995	4.5	2.9
15	02 Jun. 1829	6.0	4.3	32	30 Nov. 2004	7.0	4.5
16	06 Feb. 1837	6.0	4.3	33	25 Jun. 2006	4	3
17	08 Feb. 1837	5.5	4.0	34	25 Sep. 2007	4	2.4

Taken from: Lizurek, G., Plesiewicz, B., Wiejacz, P., Wiszniowski, J., & Trojanowski, J. (2013). Seismic event near Jarocin (Poland). Acta Geophysica, 61(1), 26-36.

Project Earthquake Catalogue:

It is clearly stated in SSG-9 (Rev.1) that a specific '**Project Earthquake Catalogue**' should be developed. For this catalogue, all available instrumental earthquake data should be collected.

SSG-9 (Rev. 1): The magnitude scale selected for the catalogue should be consistent with the magnitude scale used in the GMPEs. This is consistent with the use of moment magnitude (M_w) becoming a worldwide standard, owing to its increased use in seismology and the development of GMPEs.

What if the local seismic network does not provide Mw?

Conversion between magnitude scales is possible by using magnitude conversion equations.

SSG-9 (Rev.1) states that specific attention should be paid to the selection of empirical magnitude conversion relations.

Pre-historical and pre-instrumental historical earthquake data

3.38. All pre-historical and pre-instrumental data on earthquakes should be collected, extending as far back in time as possible. Palaeoseismic and archaeo-seismological information on historical and prehistoric earthquakes should also be collected for such purposes.

3.39. To the extent possible, for each earthquake within these temporal scales, the database should include information on the following:

(a) The date, time and duration of the event;
(b) The location of the macroseismic epicentre of the event;
(c) The estimated focal depth of the event;
(d) The estimated magnitude of the event, including the type of magnitude (e.g. moment magnitude, surface wave magnitude, body wave magnitude, local magnitude, duration magnitude), documentation of the methods used to estimate the magnitude from the macroseismic intensity, and the estimated uncertainty in the magnitude estimate;
(e) The maximum intensity and, if different, the intensity at the macroseismic epicentre, with a description of local conditions and observed damage;
(f) The isoseismal contours of the event;
(g) The intensity of the earthquake at the nuclear installation site, together with any available details of effects on the soil and the landscape;
(h) Estimates of uncertainty for all the parameters mentioned in (a)–(g) above;
(i) An assessment of the quality and quantity of data on the basis of which such parameters have been estimated;
(j) Felt foreshocks and aftershocks;
(k) The causative fault.

Project Earthquake Catalogue: Magnitude conversion equations

When M_w had to be obtained using the empirical relationships between the local and other magnitude scales:

- ✓ Care should be taken because global empirical equations may not apply to each local network.
- ✓ The standard deviations associated with these models are significant.

Table 3 Empirical relationships between moment magnitude M_W and local magnitude M_L

Agency	Regression equation $M_W = b_0 + b_1 M_L$	Number of events	Determination coefficient, R^2	SD of regression, s_e
Tirana	$M_w = 1.22 + 0.813 M_L$ [a] (0.25) (0.056) (7)	96	0.715	0.256
Podgorica	$M_w = -0.01 + 1.028 M_L$ [a] (0.16) (0.033) (8)	75	0.930	0.184
Zagreb	$M_w = -0.11 + 1.011 M_L$ [a] (0.38) (0.080) (9)	31	0.852	0.229
Belgrade	$M_w = 0.70 + 0.858 M_L$ [a] (0.21) (0.049) (10)	50	0.953	0.182
Skopje	$M_w = 0.56 + 0.913 M_L$ [a] (0.48) (0.101) (11)	28	0.773	0.267

[a] In the second rows, in parenthesis are given the standard errors of regression coefficients

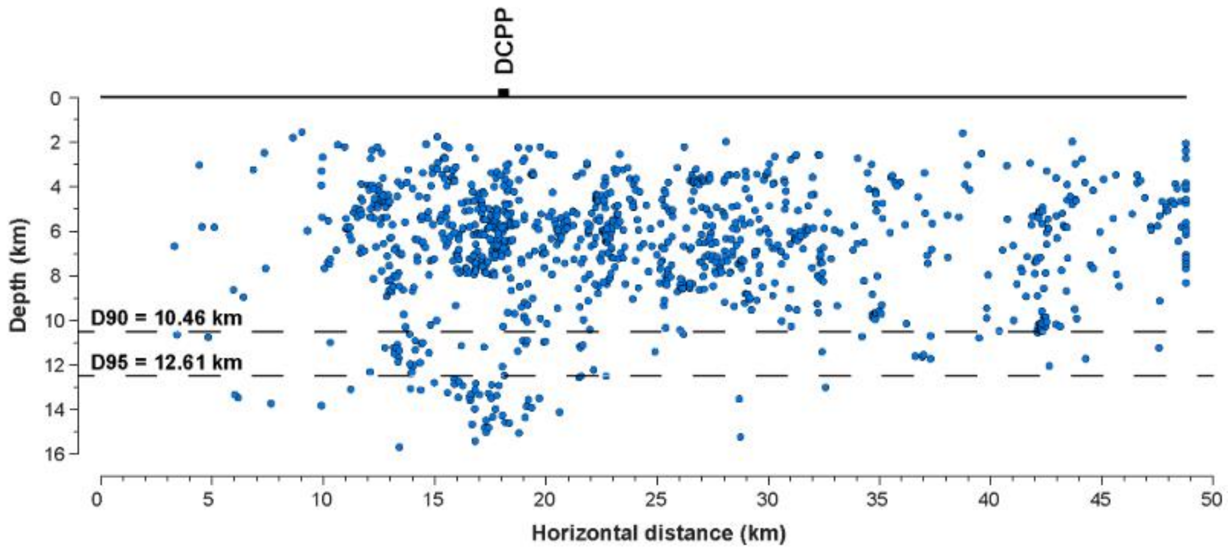
Taken from: Markušić, S., Gülerce, Z., Kuka, N., Duni, L., Ivančić, I., Radovanović, S., Glavatović, B., Milutinović, Z., Akkar, S., Kovačević, S., Mihaljević, J. and Šalić, R., 2016. An Updated and Unified Earthquake Catalogue for the Western Balkan Region, Bulletin of Earthquake Engineering 14, p.321-343. DOI 10.1007/s10518-015-9833-z

Selection of the seismic source type – If the PSHA will only utilize areal sources:

- ✓ The depth (third dimension) needs to be properly characterized.
- ✓ Most important input of the SSC model will be the project earthquake catalogue.

SSG-9 (Rev. 1): The depth distribution of the diffuse seismicity zones should be incorporated.

Thickness of the seismogenic crust or the down-dip width of the seismic sources is typically defined by calculating D90 or D95 (the depth in which 90 or 95% of the earthquakes in the area are located).



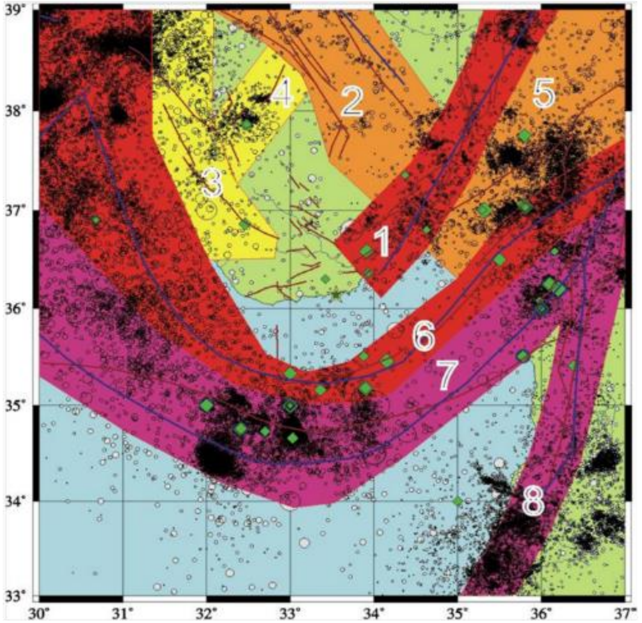
An example cross-section for depth distribution, D90 and D95 values (taken from Diablo Canyon NPP, Lettis et al. 2015)

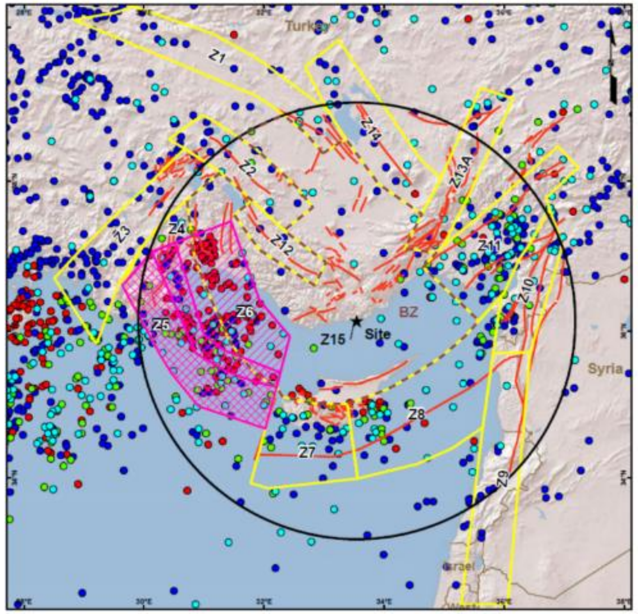
SSG-9 (Rev. 1) Para. 4.21-4.30

Selection of the seismic source type – If the PSHA will only utilize areal sources:

- ✓ Geometry of the source zone(s) should be carefully selected and the sensitivity of the hazard outcome to the source zone geometry should be tested.
- ✓ Considering the epistemic (modelling) uncertainty, alternative zonation models should be developed.
- ✓ Magnitude probability density function and its parameters, depth distribution will depend on the project earthquake catalogue and expert opinion.

Areal sources could be large, following the main tectonic features as shown in this example…





Areal sources could be small, including the details of local tectonic features as shown in this example…

SSG-9 (Rev. 1) Para. 4.21-4.30

Maximum magnitude - M_{max}:

M_{max} is the upper magnitude cutoff value of the magnitude–frequency distribution curve and it is one of the most important parameters of both probabilistic and deterministic seismic hazard assessment. IAEA/SRS No.89 (2016) underlined that the selection of M_{max} value will most probably have a significant impact on the hazard results.

There are three key approaches to estimate and assign the M_{max} value to a seismic source:

- Using the historical and instrumental catalogue for maximum observed magnitude and adding 0.5 or 1 magnitude units to this value.
- Using the statistical parameter estimation techniques that considers the maximum observed magnitude and takes into account the global analogues such as EPRI-Bayesian estimation.
- Using the empirical magnitude-rupture area equations to derive the M_{max} value from controlling and/or significant faults within the source zone.

SSG-9 (Rev. 1) Para. 4.21-4.30

Maximum magnitude - M_{max}:

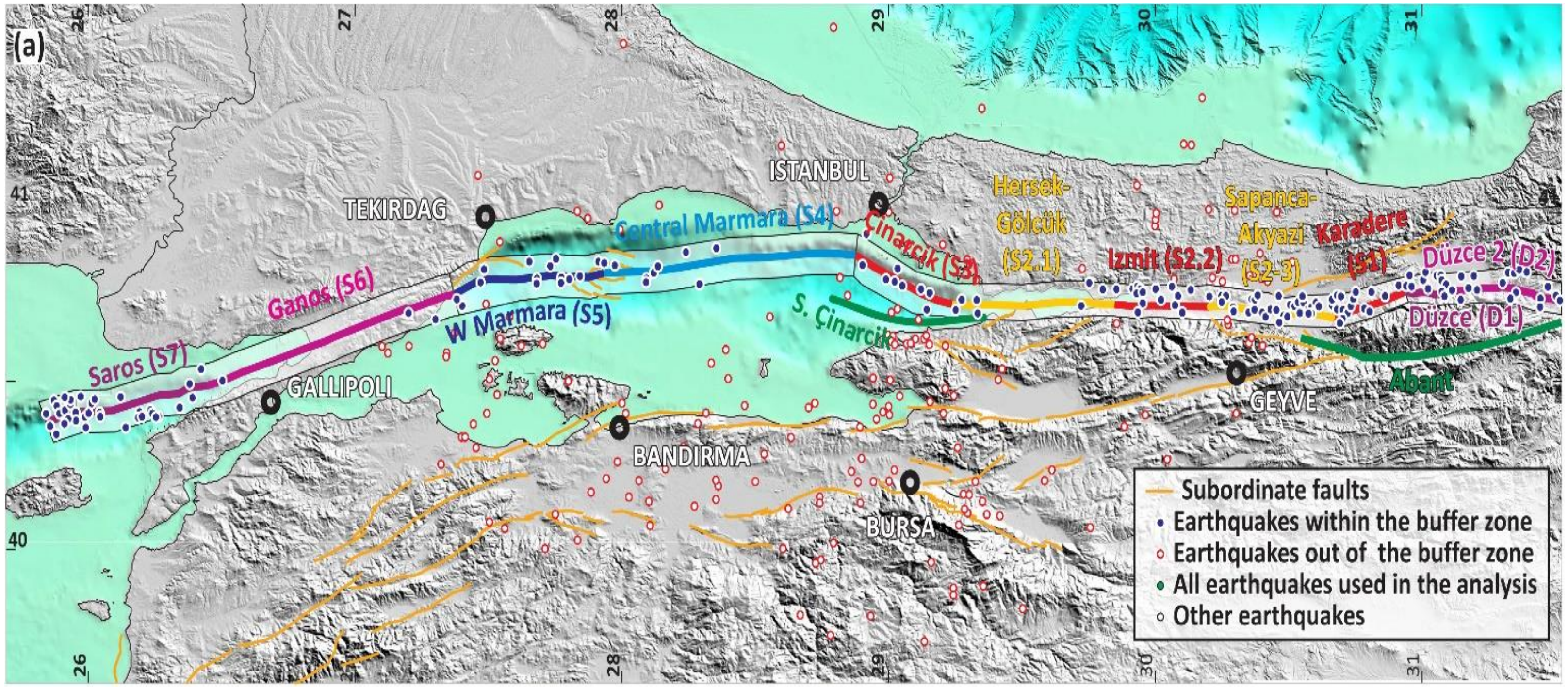
SSG-9 (Rev. 1): The largest observed earthquake is a poor and unconservative estimate of M_{max}, especially for intraplate regions.

Source Zone	M_{max} Distribution		Largest Observed Earthquake	
	M_W	Weight	M_W	Year
	7.4	0.24		
5 – Cyprus Arc Interface	8	0.62	6.3	530
	8.6	0.14		
	6.3	0.2		
6 – Cyprus Arc Intraslab	6.6	0.6	6	1979
	6.9	0.2		
	7.3	0.2		
7 – Cyprean Arc-Trodos Mountain	7.6	0.6	7	342
	7.9	0.2		
	7.4	0.2		
8 – Cyprus Arc Transform	7.7	0.6	7.1	1752
	8	0.2		
	7.4	0.2		
10 – Hatay-Northern Dead Sea Fault	7.7	0.6	7.9	526
	8	0.2		
	7.2	0.2		
11 – Kozan-Savran-Sürgü Fault Zone	7.5	0.6	6.8	713
	7.8	0.2		
12 – Bey°ehir Fault	6.9	0.2	5	1962
	7.2	0.6		
	7.4	0.2		
	7	0.2		
13A – Ecemiş Fault I	7.3	0.6	6.5	1205
	7.6	0.2		
	7.2	0.2		
13B - Ecemiş Fault II	7.5	0.6	6.5	1205
	7.8	0.2		
	5.9	0.2		
15 – 5km Site Vicinity	6.2	0.6	None in Catalog	None in Catalog
	6.5	0.2		
	6.9	0.2		
16 – Namrun Fault	7.2	0.6	3.8	1996
	7.5	0.2		
	6.6	0.2		
Background	6.9	0.6	6.3	1190
	7.2	0.2		

SSG-9 (Rev. 1) Para. 4.21-4.30

Fault Sources/ Seismogenic Structures:

- ✓ Fault sources are multi-planar features that the earthquake ruptures are distributed over the fault plane.
- ✓ To use fault sources, many important parameters of the fault (orientation, length, width, slip rate, segmentation, previous earthquakes, etc. should be investigated.
- ✓ **Important aspects:** M_{max} potential, multi-segment ruptures…



Taken from: Gülerce, Z., Buğra Soyman, K., Güner, B., & Kaymakci, N. (2017). Planar seismic source characterization models developed for probabilistic seismic hazard assessment of Istanbul. Natural Hazards and Earth System Sciences, 17(12), 2365-2381.

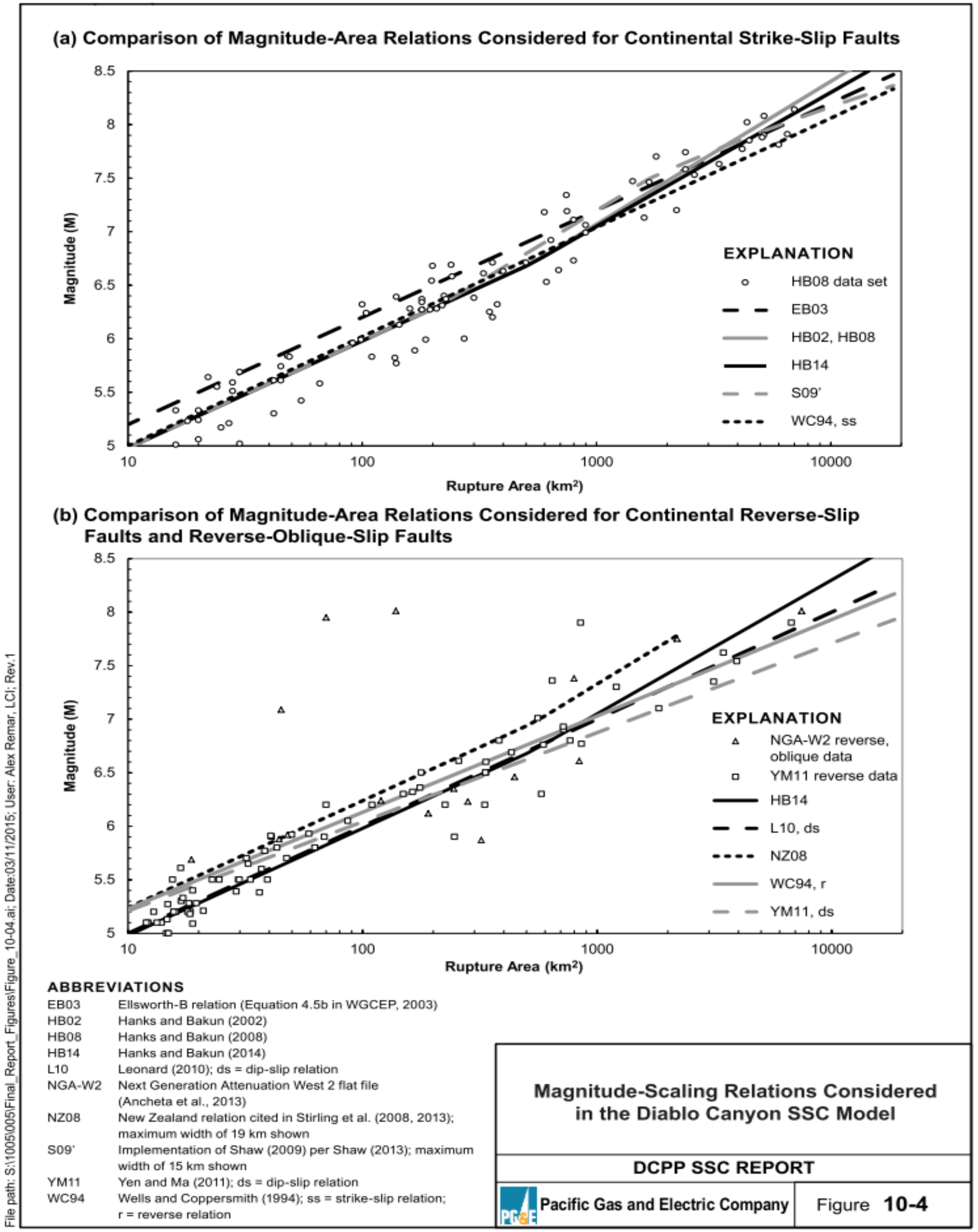
SSG-9 (Rev. 1) Para. 4.9-4.20

Maximum magnitude for fault sources:

When sufficient information about the fault or seismogenic structure (such as segmentation, fault length and width, average stress drop etc.) is available, this information is used to evaluate the maximum potential magnitude by empirical relationships.

IAEA TECDOC-1767 (2015) had grouped the empirical rupture area-magnitude relations by their applicability in different tectonic regimes and fault mechanism (slip types).

It is a good idea to calculate and compare the values based on different relations.



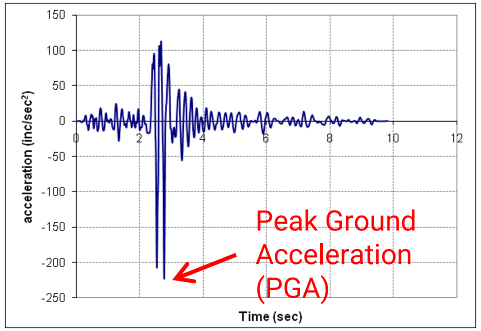
SSG-9 (Rev. 1)
Para. 4.9-4.20

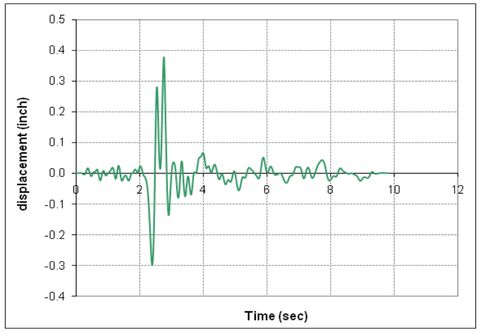
Estimation of vibratory ground motions:

SSG-9 (Rev. 1)
Para. 5.1-5.5

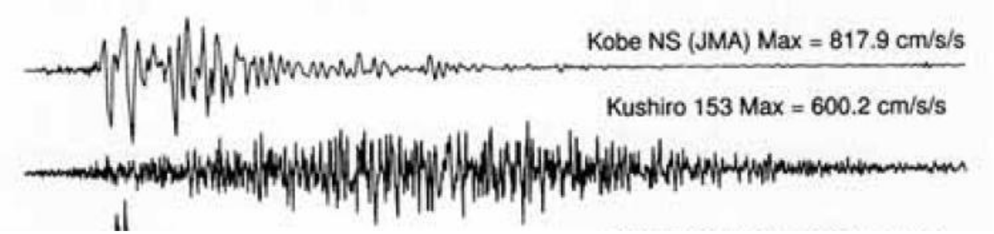
SSG-9 (Rev. 1): The definition of the vibratory **ground motion intensity measure** used in the ground motion characterization should be **consistent with the intended use** in subsequent engineering design and probabilistic safety analyses for structures, systems, and components of the nuclear installation and for the assessment of ground failures such as slope failures and liquefaction.

Amplitude



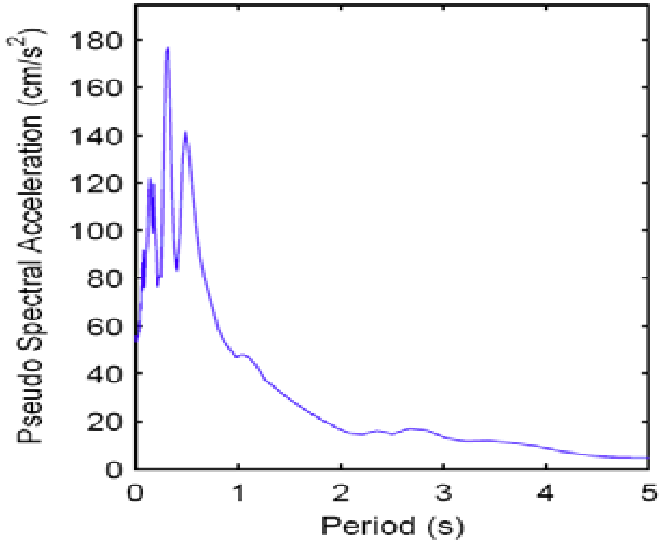


Duration



Frequency content

Frequency content describes how the amplitude of ground motions is distributed among different frequencies.



Duration of strong ground motion can have a strong influence on earthquake damage because many physical processes such as stiffness and strength degradation of structures, build up of pore water pressures in sands etc. are sensitive to the number of loading cycles.

Estimation of vibratory ground motions:

- ✓ Usually, the earthquake source, wave propagation and site response effects are modelled in attenuation relations. These effects are parametrized by magnitude, distance, style of faulting and site classification.

- ✓ A typical attenuation relationship has a form of:

$$\ln Y = f_1(M,R) + f_2(F) + f_3(S) + \sigma$$

Ground motion parameter

Magnitude
and distance
effects

Style of faulting
Strike-slip...

Site effects
rock, soil

Standard deviation

SSG-9 (Rev. 1): Currently available methods for estimating ground motions include ground motion prediction equations, which are primarily empirical, and direct simulation methods, which are physics-based scaling to interpolate a smaller range of data.

Ground Motion Prediction Equations:

SSG-9 (Rev. 1)
Para. 5.6-5.16

More than 500 published attenuation models are avaliable around the world!

a) **According to the tectonic regime:** Many published studies found significant differences in attenuation between various tectonic regions and also for various geological conditions. We may group the attenuation relations in three main headings:

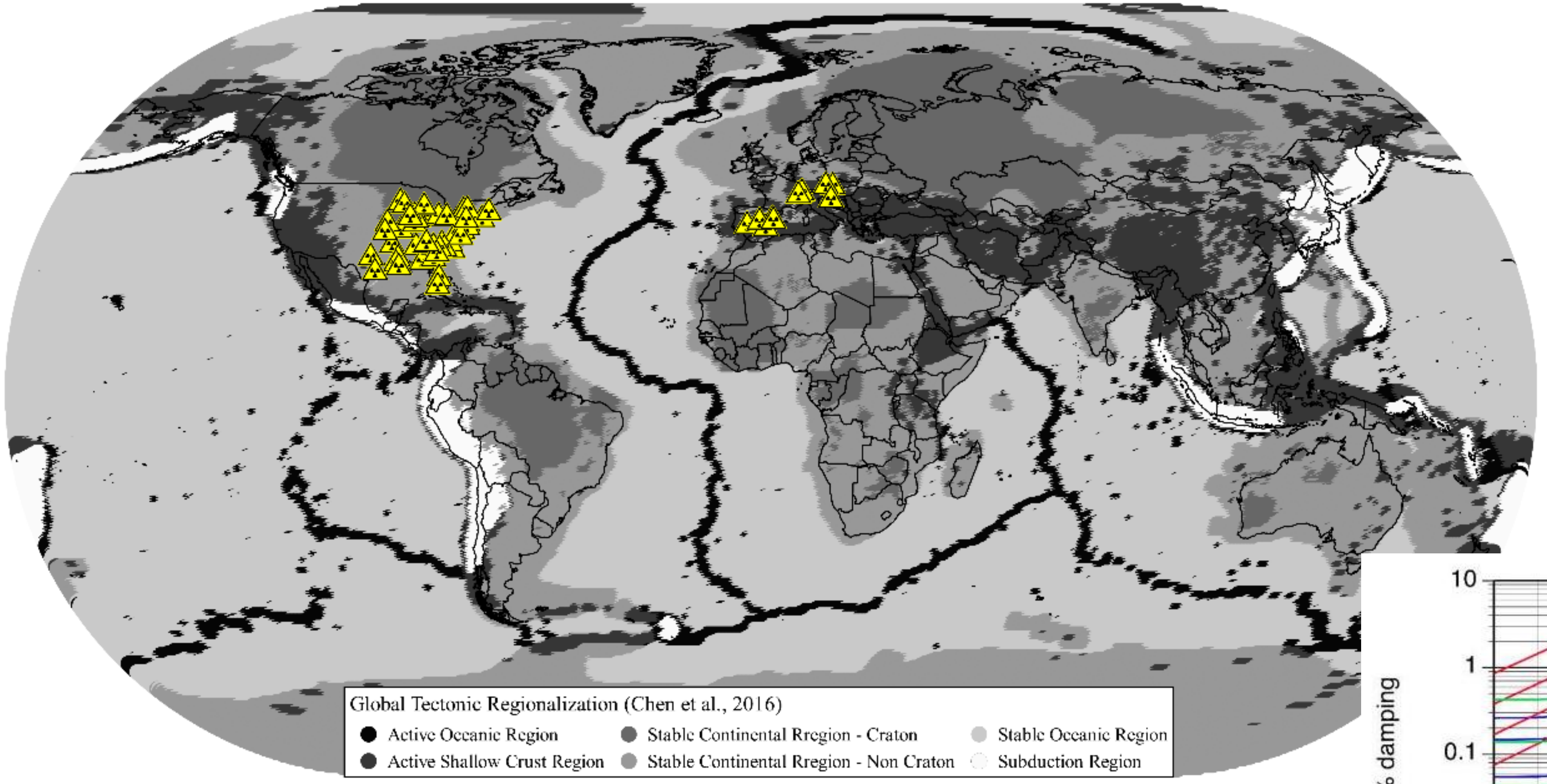
- Shallow crustal earthquakes in active tectonic regions (e.g. Turkiye, Italy, California...)
- Shallow crustal earthquakes in stable continental regions (e.g. Eastern US, Europe)
- Subduction zone earthquakes (e.g. Japan, Chile...)

b) **According to the parameter:** There are various relationships for peak acceleration, velocity, spectral accelerations, Fourier amplitude spectrum, duration, Arias Intensity...etc. You may use one of them according to the parameter you are interested in.

c) **According to the region:** Regional attenuation relations are developed for regions with enough data (Japan is a good example). You may use the regional models in additional to the global models.

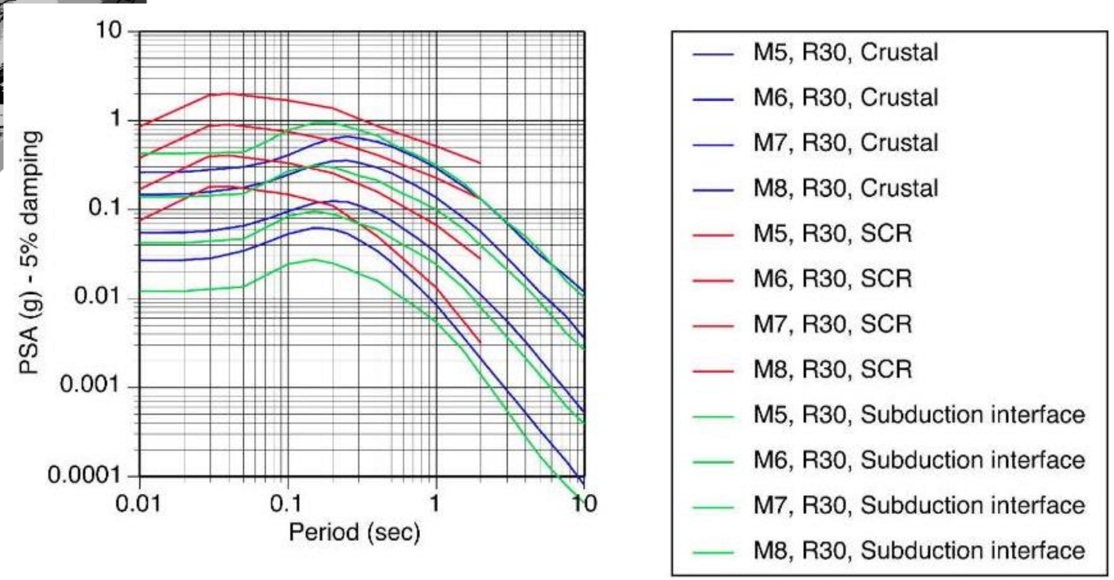
Ground Motion Prediction Equations:

SSG-9 (Rev. 1)
Para. 5.6-5.16



Pictures: Courtesy of Mr. A. Arda Ozacar and N. A. Abrahamson.

- ✓ Shallow Crustal in Active Regions
  - Primarily empirically-based models
- ✓ Shallow Crustal in Stable Continental Regions
  - Seismological simulations due to the lack of recordings
- ✓ Subduction
  - Primarily empirically-based models
  - Some simulations for very large magnitudes (M9)

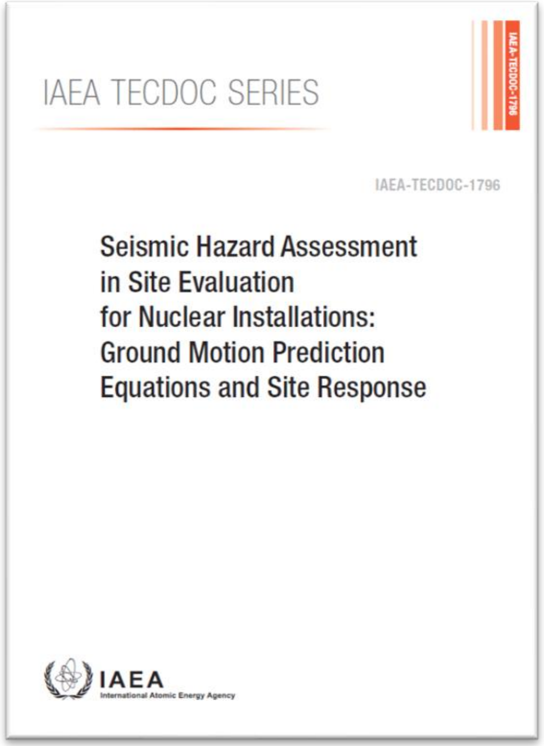


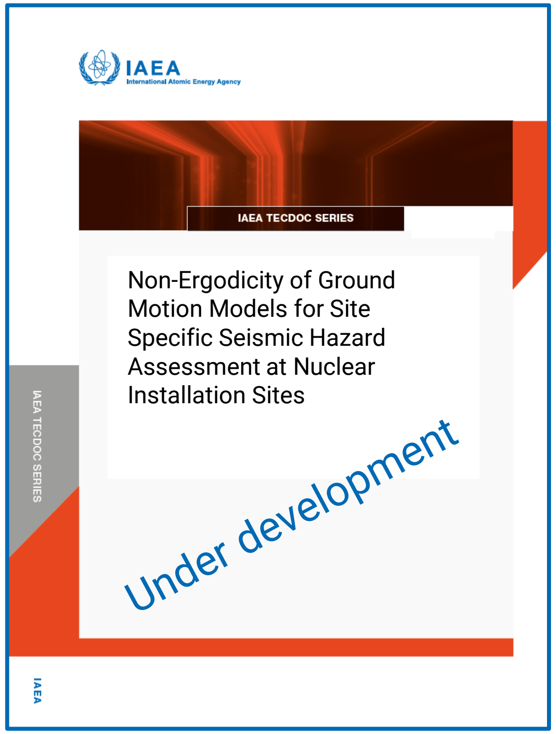
Ground Motion Prediction Equations:

SSG-9 (Rev. 1)
Para. 5.6-5.16

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.



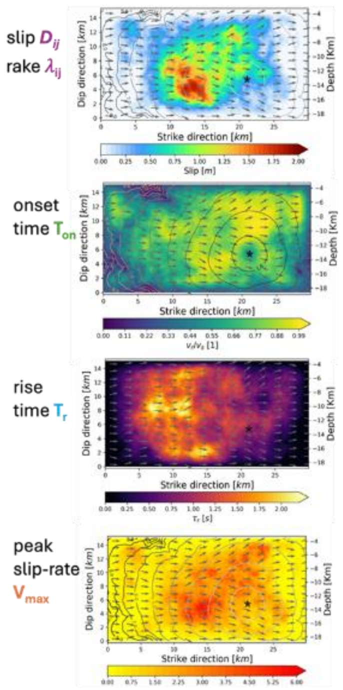


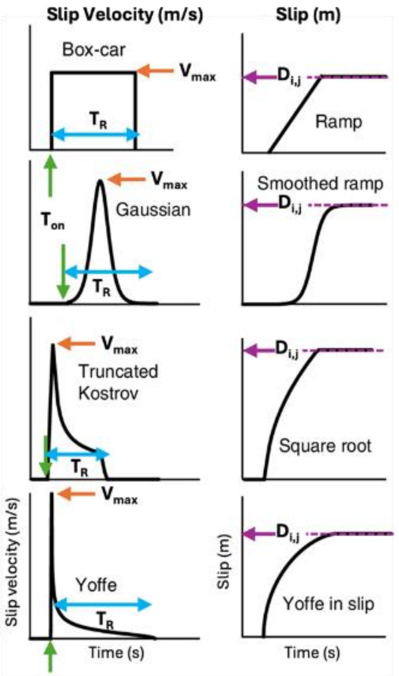
Ground motion simulations:

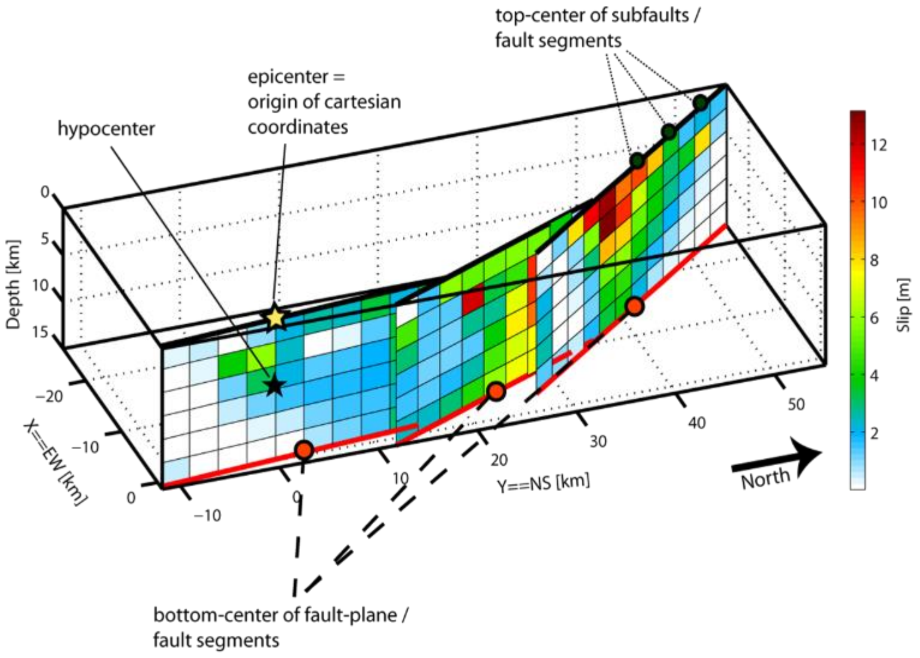
SSG-9 (Rev. 1)
Para. 5.17-5.23

PSHA studies may be supported by finite-fault ground motion simulations to either augment existing databases of recorded ground motions (in magnitude and distance ranges of limited or missing data) or to generate ground motion time series for scenarios of interest and importance.

SSG-9 (Rev. 1): Several simulation methods exist. Any simulation approach used should be carefully validated and calibrated against available recorded data from the region of interest.





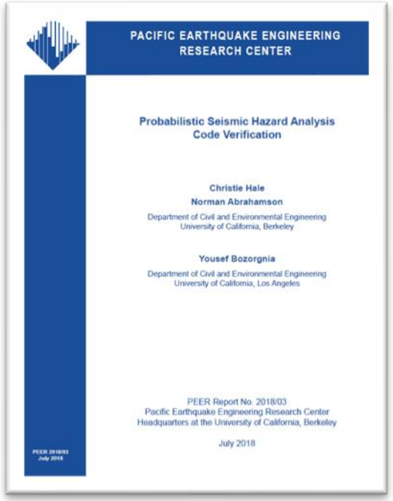


Pictures: Courtesy of Mr. M.Mai

Seismic hazard assessment report:

SSG-9 (Rev. 1)
Section 6

Verification of the hazard code


PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

Probabilistic Seismic Hazard Analysis Code Verification

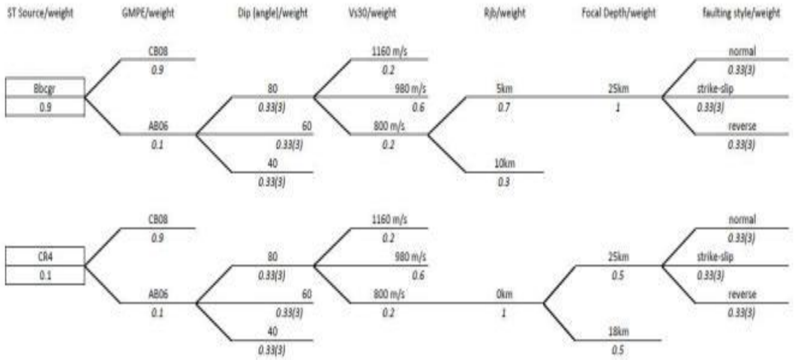
Christie Hale
Norman Abrahamson
Department of Civil and Environmental Engineering
University of California, Berkeley

Yousef Bozorgnia
Department of Civil and Environmental Engineering
University of California, Los Angeles

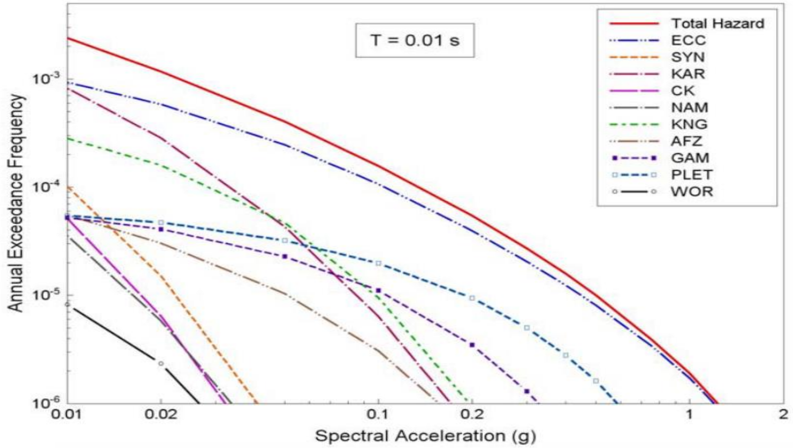
PEER Report No. 2018/03
Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley

July 2018

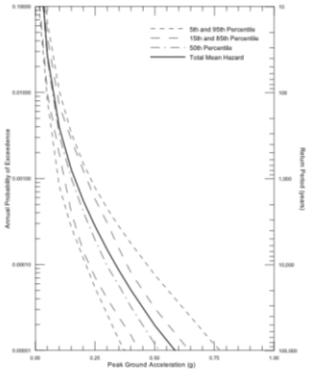
Proper documentation of the logic tree (in tables, not with pictures for QA) - HID



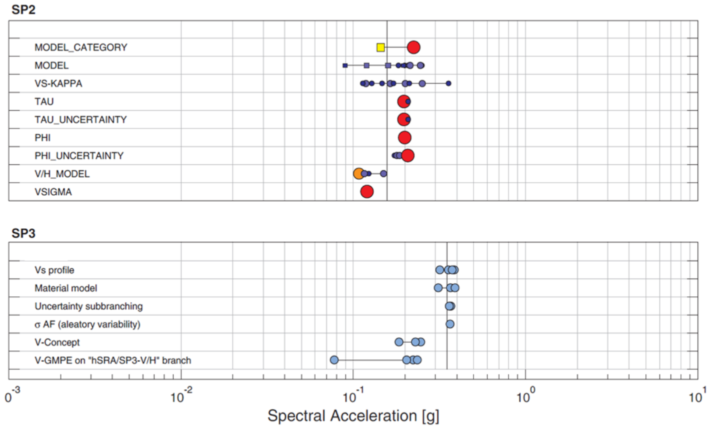
Contribution of each seismic source to the total hazard.



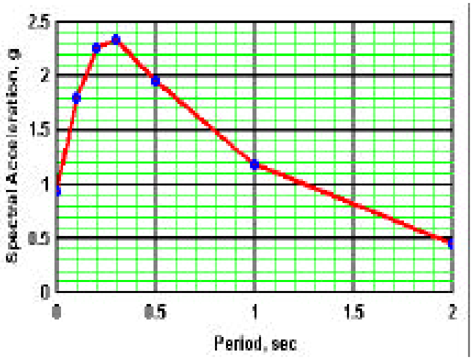
Mean hazard curve and fractiles



Sensitivity plots – different formats are available.



Uniform Hazard Spectrum for each design level for horizontal and vertical ground motions.



Contents of SSG-9 (Rev.1)

Section	
1 and 2	Introduction and General Aspects of Seismic Hazard Assessment
3	Database of Information and Investigations
4	Development of Seismic Source Models
5	Methods for Estimating Vibratory Ground Motion
6	Vibratory Ground Motion Hazard Analysis
7	Evaluation of the Potential for Fault Displacement at the Site
8	Parameters Relating to Vibratory Ground Motion Hazards, Fault Displacement Hazards and Other Hazards Associated with Earthquakes
9	Evaluation of Seismic Hazards for Nuclear Installations Other Than Nuclear Power Plants
10	Application of the Management System

Fault capability and fault displacement – updated in (Rev.1)

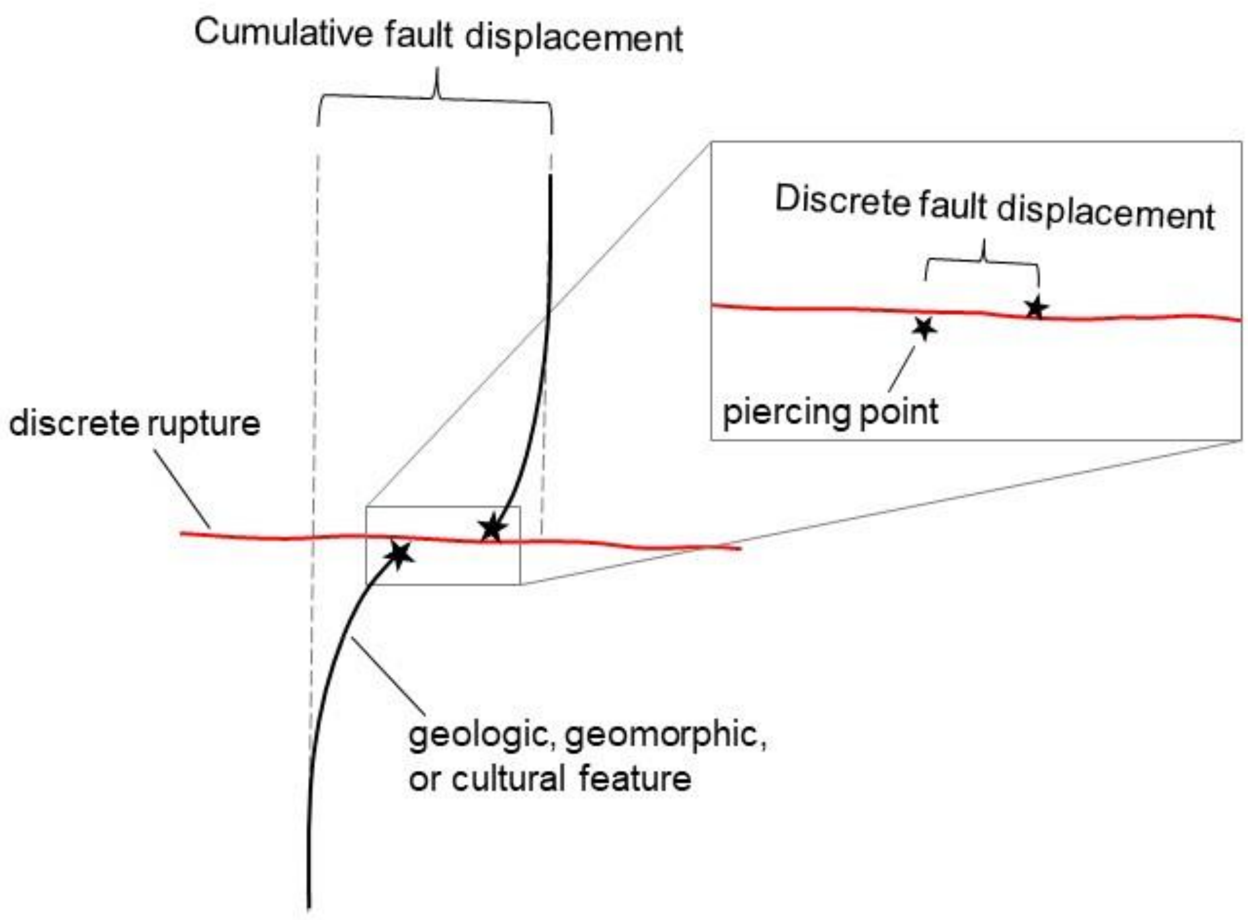
A hot topic, considering the new reactor designs!

Fault capability – issues for new and existing sites

In the site selection and characterization stages of site evaluations for new nuclear installation sites, **sufficient geological, geophysical, geotechnical, and seismological data** are obtained to demonstrate the **existence of fault capability at or near the site**.

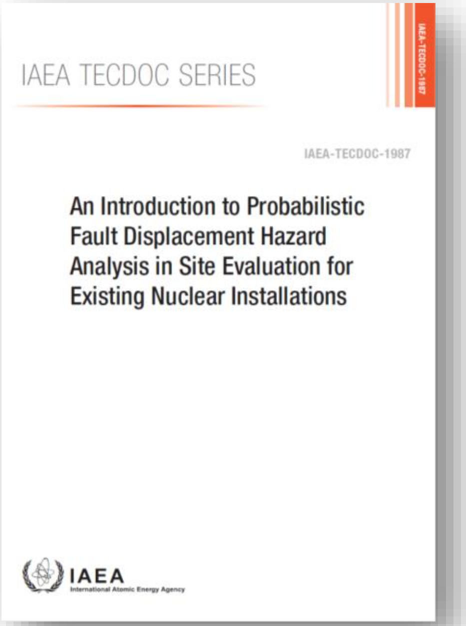
Although the capable fault issues are expected to be addressed at these stages of site evaluation, subsequent studies may reveal the information that there is potentially a capable fault in the site vicinity of existing nuclear installations.

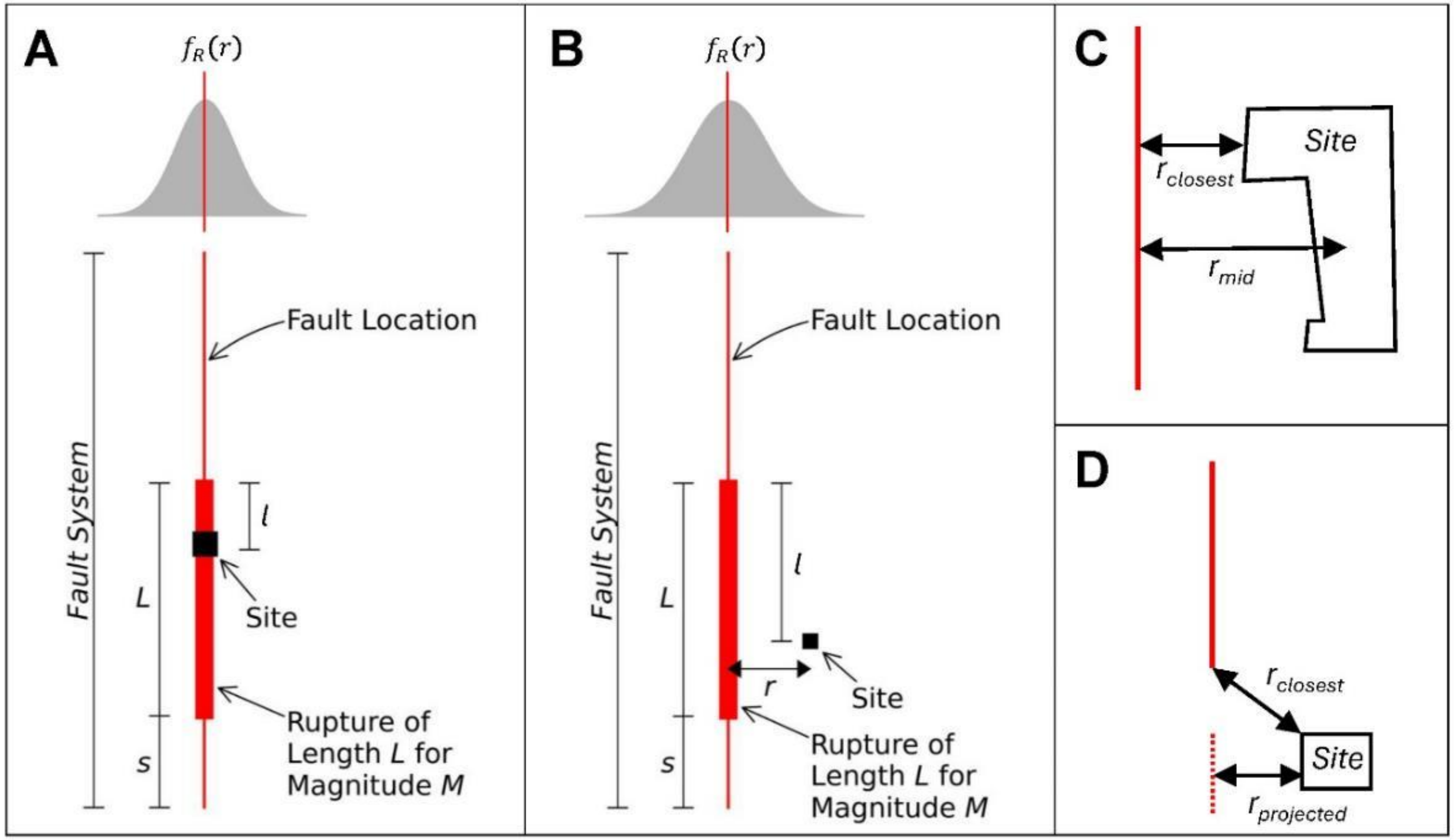
For this case, SSG-9 (Rev.1) recommends the assessment of the potential for fault displacement using probabilistic methods.



Fault displacement – use of probabilistic methods

- ✓ Probabilistic approach for estimating the fault displacement is quite new.
- ✓ The method itself is as complicated as the problem.
- ✓ IAEA published a TECDOC in 2021.

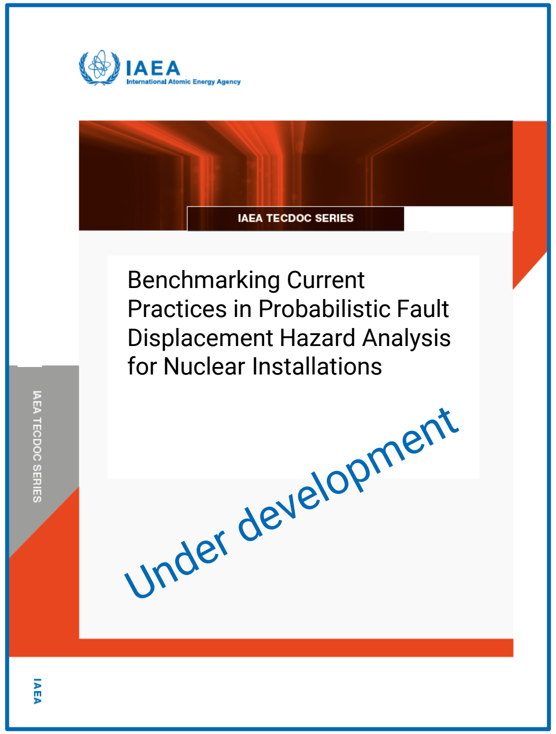


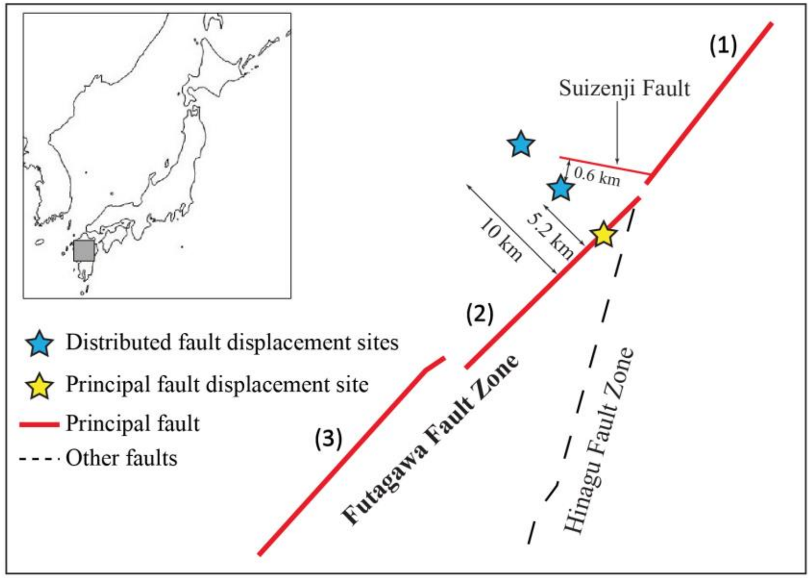


$$\lambda(D > D_0) = \alpha(M_{min}) \int_{m,s} f_{M,S}(m,s) \times P[sr \neq 0|m]$$

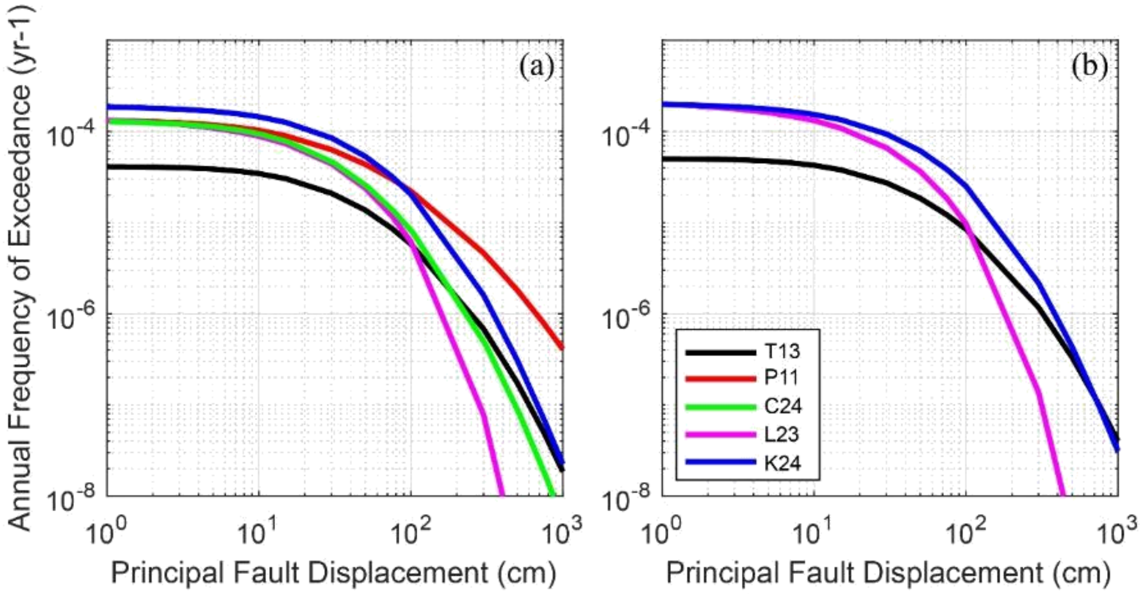
$$\times \int_{r} f_R(r) \times P[D \neq 0|z, r, sr \neq 0] \times P[D > D_0|l^*, m, D \neq 0] \times dr\, dm\, ds$$

Fault displacement – use of probabilistic methods



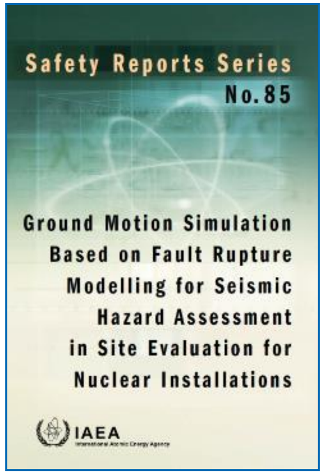


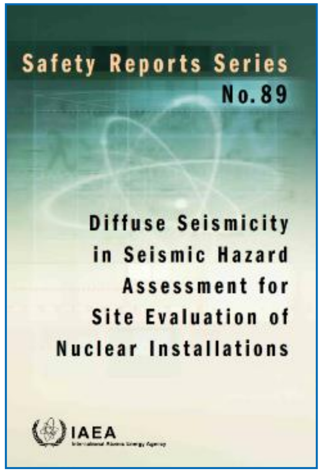
- ✓ Terminology: definitions used in fault displacement hazard assessment such as total, aggregate, net, primary, distributed…
- ✓ Several fault displacement prediction models are available. They are used in combination with surface rupture models.
- ✓ The user needs to understand the effect of the models on the hazard curve.

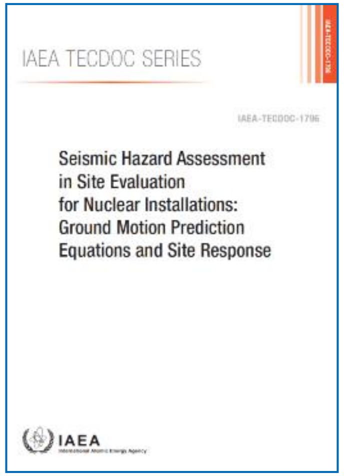


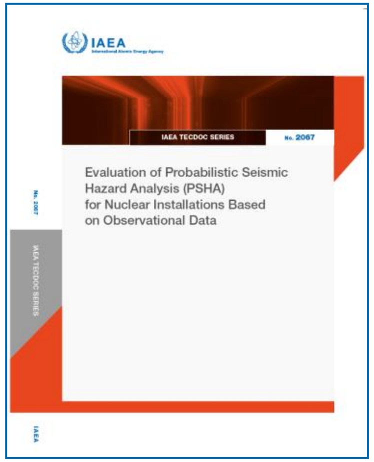
Concluding Remarks:

- ✓ IAEA Safety Standard: SSG-9 Seismic Hazards in Site Evaluation for Nuclear Installations was published in 2010.
- ✓ Fukushima Daiichi accident (March 11, 2011)
- ✓ Many supporting documents of IAEA safety standards, expert and review missions by IAEA since 2011, reflecting good practices and lessons learned…
- ✓ SSG-9 (Rev. 1) was published in 2022.









Thank you!

Safety-Standards.Contact-Point@iaea.org