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Hazard sensitivity tests and their importance

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This lecture will discuss the importance in PSHA of tests which explore the sensitivity of the resulting hazard estimates to some of the expert judgements that have to be made in the face of uncertainty.

Sensitivity tests provide an important input to seismic hazard assessments on two levels:

> (a) without an adequate general understanding of how the decisions that are being made are likely to impact on the hazard results, it is hard to see how expert judgement can properly be exercised in the first place, and
>
> (b) it is necessary to use sensitivity tests to explore and, eventually, to demonstrate (to regulatory authorities, etc.) the effects in detail of those decisions in the particular circumstances under consideration.

In this latter context, it is important that the sensitivity tests present a systematic and thorough exploration of the impact that the various expert judgements made in constructing the hazard model will have had on estimated hazard levels. They should not merely be a set of analyses in which arbitrary adjustments are made to model parameter values but they should be scientifically rational and grounded in physical reality.

Ideally, the material that is available to inform initial modelling decisions should include a substantial number of tests which demonstrate the sensitivity of hazard results to typical variations in the parameter values and attenuation relations that are used. At this stage, the preoccupation can be just with the ground motion which has 10^{-4} p.a. probability of exceedance.

A full suite of such tests might be expected to cover variations in all of the following input parameters:

- magnitude completeness thresholds
- activity rates
- b-values
- minimum magnitude
- maximum magnitude
- focal depth distribution
- strong motion attenuation sigma value
- strong motion attenuation relation
- zonation
- the presence of faults in the seismic source model

When the initial modelling decisions have been made for any site-specific study, a customised set of sensitivity tests should be carried out to understand in detail the import of those decisions in that particular context. Depending on the consensus view, there may, at this stage be a need for iterative changes to be made to the model itself.

Finally, decisions should be made on the systematic suite of sensitivity tests that will be presented in the final report on the hazard assessment. Where appropriate (for example, in assessing the impact of the weighted distribution assigned to maximum magnitude values), these last tests should explore the effects on various frequencies of ground motion hazard and not just on the *pga* hazard.

Typically, such published tests should explore the implications for the estimated site-specific hazard exposure levels of:

- changes in the location of significant zone boundaries;
- changes in the activity rate assigned to significant zones (for example, through removing or adding *ad hoc* conservatisms or testing the effects of using alternative magnitude completeness thresholds);
- changes in the other seismological parameters (b-value, maximum magnitude, and focal depth) assigned to significant zones;
- changes in the seismicity assigned to background zones;
- changes in the active-status of any fault sources;
- changes in the seismological parameters assigned to any fault sources;
- in cases where the primary model allows for multiple alternative zonations, the hazard results that would be calculated for each individual zonation, and
- using other attenuation relations.

As well as all these published sensitivity tests, which make adjustments to the conventional source model, in the more recent studies carried out in the UK, advantage has been taken of the availability of the 'kernel function' modelling technique to provide a hazard estimate which is based on that entirely different approach.

Having presented examples from a typical series of conventional sensitivity tests, the lecture will go on to examine first the effects of including a fault source within a simplified seismic source model and then consider some more complex issues. These will include the significance of magnitude completeness thresholds and, using case histories, the variations in estimated hazard levels caused by changing the boundaries of the principal seismic zones.

There now follow a few sheets which give an indication of the material that will be presented and discussed in the lecture.

EXAMPLES OF ROUTINE SENSITIVITY TESTS

These tests concentrate mainly, but not exclusively, on the expected *pga* hazard at 10^{-4} p.a. probability of exceedance and explore the impact on that hazard of varying the parameter values from those that are assigned to the usual benchmark model representing average British conditions.

This `base model' has the following properties:

Activity rate	=	0.0055 events of $4M_S$ or greater per year 10,000km^2	(weight 1.0)
b- value	=	1.28	(weight 1.0)
Minimum magnitude	=	$4.0M_S$	
Maximum magnitude	=	$6.5M_S$	(weight 1.0)
Focal depth	=	10km	
Area of zone	=	500 x 500km	

For the *pga* hazard sensitivity studies, use is made of the standard Principia Mechanica Ltd. (1982) peak acceleration attenuation relation, with the following weighted distribution of attenuation σ values:

0.5 (weight 0.2)
0.553 (weight 0.5)
0.6 (weight 0.3)

Where appropriate, for response spectral velocity studies, use is made of the Principia Mechanica Ltd. (1988) URS attenuation hard and soft ground relations at 1Hz. To supplement the empirical σ value obtained from spectral attenuation regression analysis, allowance for variability is made by assigning weights of 0.2, 0.5 and 0.3 respectively to the empirical value adjusted by the following amounts: -0.05; + 0, and +0.05. That is to say, the following distributions are used in the base model:

Hard site:

0.7 (weight 0.2)
0.75 (weight 0.5)

0.8 (weight 0.3)

Soft site:

0.66 (weight 0.2)
0.71 (weight 0.5)
0.76 (weight 0.3)

Sensitivity to attenuation σ value

	Attenuation σ value for *pga* (weight)	**10^{-4} p.a. *pga* [%g]** *(50%) EXPECTED (90%)*	**10^{-4} p.a. 1Hz PSV HARD [cm/sec]** *(50%) EXPECTED (90%)*	**10^{-4} p.a. 1Hz PSV SOFT [cm/sec]** *(50%) EXPECTED (90%)*
BASE MODEL	0.5 0.533 0.6 (0.2) (0.5) (0.3)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	0.6 (1)	17.86 17.86 17.86	6.62 6.62 6.62	13.68 13.68 13.68
(ii)	0.65 (1)	19.39 19.39 19.39	7.3 7.3 7.3	14.94 14.94 14.94
(iii)	0.5 (1)	15.36 15.36 15.36	5.54 5.54 5.54	11.65 11.65 11.65
(iv)	0.5 0.533 0.6 (0.2) (0.5) (0.3) Truncated at 3 σ	16.62 16.69 17.76	5.98 6.01 6.46	12.54 12.59 13.46
(v)	0.5 0.533 0.6 (0.2) (0.5) (0.3) Truncated at 2 σ	15.92 15.98 16.88	5.42 5.44 5.76	11.61 11.64 12.29

Sensitivity to b-value

	b-value **(weight)**	**10^{-4} p.a. *pga* [%g]** ***(50%)*** *EXPECTED* ***(90%)***	**10^{-4} p.a. 1Hz PSV HARD [cm/sec]** ***(50%)*** ***EXPECTED*** ***(90%)***	**10^{-4} p.a. 1Hz PSV SOFT [cm/sec]** ***(50%)*** ***EXPECTED*** ***(90%)***
BASE MODEL	1.28 (1)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	1.2 (1)	16.99 17.06 18.19	6.61 6.65 7.17	13.61 13.66 14.64
(ii)	1.0 (1)	17.95 18.02 19.23	8.34 8.39 9.07	16.74 16.80 18.02
(iii)	0.9 (1)	18.58 18.66 19.89	9.50 9.55 10.31	18.87 18.94 20.30
(iv)	1.4 (1)	16.34 16.40 17.47	5.47 5.50 5.93	11.60 11.65 12.48

Sensitivity to maximum magnitude

	Maximum Magnitude Ms **(weight)**	**10^{-4} p.a. *pga* [%g]** ***(50%)*** ***EXPECTED*** ***(90%)***	**10^{-4} p.a. 1Hz PSV HARD [cm/sec]** ***(50%)*** ***EXPECTED*** ***(90%)***	**10^{-4} p.a. 1Hz PSV SOFT [cm/sec]** ***(50%)*** ***EXPECTED*** ***(90%)***
BASE MODEL	6.5 (1)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	7.0 (1)	16.75 16.82 17.92	6.49 6.52 7.01	13.22 13.27 14.21
(ii)	7.5 (1)	16.77 16.84 17.94	6.70 6.73 7.23	13.52 13.57 14.51
(iii)	6.0 (1)	16.59 16.65 17.74	5.53 5.57 6.02	11.90 11.95 12.81

Sensitivity to focal depth

	Focal depth (weight)	10^{-4} p.a. *pga* [%g] *(50%)* ***EXPECTED*** *(90%)*	10^{-4} p.a. 1Hz PSV HARD [cm/sec] *(50%)* ***EXPECTED*** *(90%)*	10^{-4} p.a. 1Hz PSV SOFT [cm/sec] *(50%)* ***EXPECTED*** *(90%)*
BASE MODEL	10.0 (1)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	5.0 (1)	19.56 19.61 20.75	6.45 6.49 6.99	14.45 14.49 15.47
(ii)	15.0 (1)	14.37 14.45 15.52	5.83 5.86 6.33	11.55 11.60 12.46
(iii)	20.0 (1)	12.66 12.74 13.68	5.62 5.65 6.10	10.72 10.77 11.58

Sensitivity to activity rate

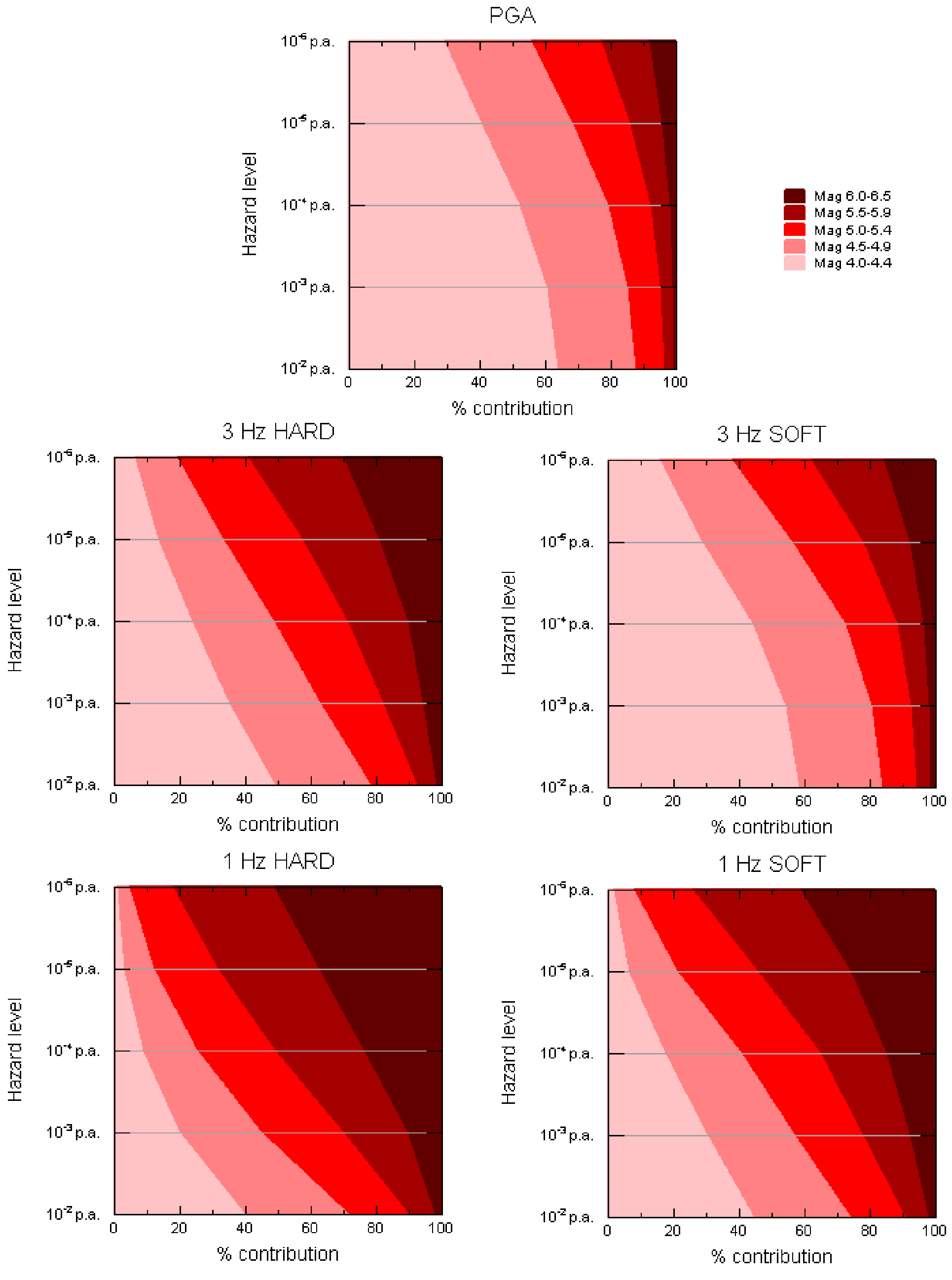
	Activity rate* per 10,000 sq km **(weight)**	**10^{-4} p.a. *pga* [%g]** ***(50%) EXPECTED (90%)***	**10^{-4} p.a. 1Hz PSV HARD [cm/sec]** ***(50%) EXPECTED (90%)***	**10^{-4} p.a. 1Hz PSV SOFT [cm/sec]** ***(50%) EXPECTED (90%)***
BASE MODEL	0.0055 (1)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	0.0055 x 1.25 (1)	17.88 17.96 19.22	6.63 6.66 7.20	13.89 13.95 14.98
(ii)	0.0055 x 1.50 (1)	18.91 19.00 20.33	7.10 7.14 7.73	14.95 15.01 16.15
(iii)	0.0055 x 2.00 (1)	20.54 20.66 22.20	7.91 7.95 8.64	16.78 16.86 18.18
(iv)	0.0055 x 0.75 (1)	15.18 15.24 16.26	5.47 5.50 5.92	11.31 11.35 12.13

* events per year with magnitude greater than or equal to $4.0M_S$

Sensitivity to minimum magnitude

	Minimum Magnitude Ms **(weight)**	**10^{-4} p.a. *pga* [%g]** ***(50%)*** ***EXPECTED*** ***(90%)***	**10^{-4} p.a. 1Hz PSV HARD [cm/sec]** ***(50%)*** ***EXPECTED*** ***(90%)***	**10^{-4} p.a. 1Hz PSV SOFT [cm/sec]** ***(50%)*** ***EXPECTED*** ***(90%)***
BASE MODEL	4.0 (1)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	4.5 (1)	12.74 12.77 13.42	5.88 5.91 6.35	11.71 11.75 12.50
(ii)	5.0 (1)	8.54 8.55 8.92	5.42 5.44 5.79	10.02 10.04 10.60
(iii)	5.5 (1)	5.08 5.09 5.29	4.51 4.52 4.88	6.95 6.97 7.47
(iv)	3.5 (1)	19.86 20.00 21.59	6.17 6.20 6.70	13.12 13.18 14.19

<u>Hazard sensitivities revealed by disaggregation</u>



Sensitivity to activity rate distribution

Apart from the multiple weighted attenuation σ value, the preceding sensitivity studies have all been made on a hazard model with single value parameters.

A single set of examples is now presented which allows for variations in the activity rate distribution. As before, the results examined are those for the mean, 50% and 90% confidence *pga* and 1Hz values at 10^{-4} annual exceedance probability.

In this case, the weighted distributions for the other parameter values are as follows:

b-value:	1.28	(weight 0.5)
	1.19	(weight 0.5)
Minimum magnitude	4.0	
Maximum magnitude:	6.2	(weight 0.2)
	6.5	(weight 0.6)
	6.8	(weight 0.2)
Focal depth:	5km	(weight 0.3)
	10km	(weight 0.5)
	15km	(weight 0.1)
	20km	(weight 0.1)
Attenuation σ value:	0.5	(weight 0.2)
	0.533	(weight 0.5)
	0.6	(weight 0.3)

Sensitivity to activity rate distribution

	Activity rate* per 10,000 sq km (weight)	**10^{-4} p.a. *pga* [%g] *(50%) EXPECTED (90%)***	**10^{-4} p.a. 1Hz PSV HARD [cm/sec] *(50%) EXPECTED (90%)***	**10^{-4} p.a. 1Hz PSV SOFT [cm/sec] *(50%) EXPECTED (90%)***
BASE MODEL	0.0055 (1)	16.70 16.77 17.87	6.10 6.13 6.61	12.70 12.75 13.66
(i)	0.0055 x 0.5 0.0055 x 0.5 0.0055 x 1.0 0.0055 x 1.25 0.0055 x 1.5 (0.2) each	16.53 17.22 20.60	6.24 6.45 7.71	12.96 13.48 16.49
(ii)	0.0992 0.1132 0.1221 0.1295 0.1364 0.1433 0.1507 0.1593 0.1704 0.1903 (0.1) each	16.90 17.37 20.34	6.40 6.52 7.48	13.33 13.63 16.00
(iii)	10 point discretization of Gamma distribution with 0.0055 as its mean (0.1) each	16.74 16.85 18.22	6.11 6.16 6.77	12.74 12.83 14.05

The effects on hazard levels of:
(i) introducing a nearby fault source, and
(ii) varying the parameters assigned to that fault

MODEL	Active-status of fault	Earthquake on fault ?	Expected 10^{-4} p.a. *pga* (%g)
No fault	0	0	20.3
With fault	**0.8**	**0.5**	**26.2**
With fault	0.8 0.8 0.8	0.75 0.25 0.1	28.8 23.4 21.5
With fault	1 0.5 0.2 0.1	0.5 0.5 0.5 0.5	27.5 24.1 21.8 21.1

Examples of the effects on hazard levels of the inclusion in a source model of a nearby fault

SITE	10-4 p.a. pga Without fault	10-4 p.a. pga with fault
V	0.203g	0.262g
IV Model A	0.208g	0.239g
IV Model B	0.255g	0.277g

Example indicating hazard sensitivity to zonation

SITE	**MODEL**	**WEIGHT**	**Individual 10^{-4} p.a. *pga***	**Overall 10^{-4} p.a. *pga***
I	1 2 3	0.4 0.4 0.2	0.212g 0.223g 0.193g	0.213g
II	A B C	0.4 0.4 0.2	0.196g 0.114g 0.217g	0.179g
III	A B C	0.37 0.41 0.22	0.258g 0.234g 0.183g	0.236g
IV	A B	0.57 0.43	0.239g 0.277g	0.257g

(It may be noted that both of the alternative zonations for Site IV allowed for the same fault source.)

Addressing a possible systematic source of conservatism

A simple preliminary examination of the potential impact of introducing magnitude-depth dependency capping using the fixed values 'standard model' for a source zone which experiences average UK seismicity.

As previous sensitivity studies have shown:

when all seismicity is assumed to occur at 10km, the expected 10^{-4} p.a. probability of exceedance *pga* hazard is about 16.77%g

when all the seismicity is taken to occur at 5km depth, the corresponding hazard level is about 19.61%g

when it all occurs at 15km depth, the result is about 14.45%g.

If the hazard model is reconfigured as follows:

the average UK seismicity budget is redistributed into three sources at:
5km, 10km and 15km,

the proportional activity rates taken to be 25%, 50% and 25 % of the total respectively

the b-values are adjusted to maintain the same aggregate activity at all magnitudes

the modelled magnitude ranges (M_{min} to M_{max}) corresponding to these sources are assigned so as to allow for some arbitrary measure of depth-dependency, as follows:

5km depth:	4.0 – 5.0M_S
10km depth:	4.0 – 6.0M_S
15km depth:	4.0 – 6.5M_S

then, a 10^{-4} p.a. *pga* hazard of about 17%g is obtained.

The attached tables (Tables 4.1, 4.2, 4.4 and 4.5) present an analysis of hazard sensitivity to magnitude completeness thresholds, activity rates and b-values

Table 4.1 Effects on hazard level of variations in magnitude completeness thresholds, b-value and source area

Scenario	Magnitude Completeness Thresholds	No. of quakes	b-value	Source area (radius)	Equiv. M4 years	M4 activity rate	Activity rate density per 10^4 km^2	Expected 10^{-3} p.a. *pga* (%g)	Expected 10^{-4} p.a. *pga* (%g)	Expected 10^{-5} p.a. *pga* (%g)
0-A	5Ms 1000-1800 4Ms 1800-2000	0	1.28	100km	242	0.00399	0.00127	2.9	9.6	21.7
0-Ai	ditto	0	1.58	100km	221	0.00437	0.00139	2.7	9.0	20.4
0-Aii	ditto	0	1.19	100km	251	0.00385	0.00125	2.9	9.6	21.9
0-Aiii	ditto	0	1.02	100km	274	0.00352	0.00112	3.0	10.0	22.9
0-Aiv	ditto	0	1.28	150km	242	0.00399	0.00057	1.5	6.7	16.7
0-Av	ditto	0	1.28	50km	242	0.00399	0.00509	6.3	16.1	32.1
0-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	0	1.28	100km	679	0.00142	0.00046	1.1	6.0	15.5
0-Bi	ditto	0	1.58	100km	819	0.00118	0.00038	0.7	5.2	13.8
0-Bii	ditto	0	1.19	100km	648	0.00149	0.00047	1.2	6.2	16.1
0-Biii	ditto	0	1.02	100km	603	0.00160	0.00051	1.3	6.7	17.2

Table 4.2 Effects on hazard level of variations in magnitude completeness thresholds, b-value and number of earthquakes in complete dataset

Scenario	Magnitude Completeness Thresholds	No. of quakes	b-value	Source area (radius)	Equiv. M4 years	M4 activity rate	Activity rate density per 10^4 km^2	Expected 10^{-3} p.a. *pga* (%g)	Expected 10^{-4} p.a. *pga* (%g)	Expected 10^{-5} p.a. *pga* (%g)
0-A	5Ms 1000-1800 4Ms 1800-2000	0	1.28	100km	242	0.00399	0.00127	2.9	9.6	21.7
0-Ai	ditto	0	1.58	100km	221	0.00437	0.00139	2.7	9.0	20.4
0-Aii	ditto	0	1.19	100km	251	0.00385	0.00125	2.9	9.6	21.9
0-Aiii	ditto	0	1.02	100km	274	0.00352	0.00112	3.0	10.0	22.9
1-A	ditto	1	1.28	100km	242	0.00813	0.00259	4.5	12.7	26.6
1-Ai	ditto	1	1.58	100km	221	0.00888	0.00283	4.5	12.5	25.9
1-Aii	ditto	1	1.19	100km	251	0.00783	0.00249	4.4	12.7	26.9
1-Aiii	ditto	1	1.02	100km	274	0.00716	0.00228	4.4	12.8	27.5
8-A	ditto	8	1.28	100km	242	0.03710	0.01181	9.3	21.2	39.5
8-Ai	ditto	8	1.58	100km	221	0.04055	0.01290	9.2	20.7	38.2
8-Aii	ditto	8	1.19	100km	251	0.03572	0.01137	9.3	21.3	40.1
8-Aiii	ditto	8	1.02	100km	274	0.03266	0.01039	9.3	21.7	41.2

Table 4.2 Effects on hazard level of variations in magnitude completeness thresholds, b-value and number of earthquakes in complete dataset, cont.

Scenario	Magnitude Completeness Thresholds	No. of quakes	b-value	Source area (radius)	Equiv. M4 years	M4 activity rate	Activity rate density per 10^4 km^2	Expected 10^{-3} p.a. *pga* (%g)	Expected 10^{-4} p.a. *pga* (%g)	Expected 10^{-5} p.a. *pga* (%g)
0-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	0	1.28	100km	679	0.00142	0.00046	1.1	6.0	15.5
0-Bi	ditto	0	1.58	100km	819	0.00118	0.00038	0.7	5.2	13.8
0-Bii	ditto	0	1.19	100km	648	0.00149	0.00047	1.2	6.2	16.1
0-Biii	ditto	0	1.02	100km	603	0.00160	0.00051	1.3	6.7	17.2
1-B	ditto	1	1.28	100km	679	0.00289	0.00092	2.3	8.3	19.6
1-Bi	ditto	1	1.58	100km	819	0.00240	0.00076	1.9	7.3	17.5
1-Bii	ditto	1	1.19	100km	648	0.00303	0.00096	2.4	8.6	20.3
1-Biii	ditto	1	1.02	100km	603	0.00326	0.00104	2.6	9.3	21.7
8-B	ditto	8	1.28	100km	679	0.01320	0.00420	5.8	15.1	30.4
8-Bi	Ditto	8	1.58	100km	819	0.01094	0.00348	5.0	13.4	27.5
8-Bii	ditto	8	1.19	100km	648	0.01383	0.00440	6.0	15.6	31.5
8-Biii	ditto	8	1.02	100km	603	0.01486	0.00473	6.5	16.7	33.7

Table 4.4 Effects on hazard level of using Set 2 magnitude completeness thresholds

Scenario	Magnitude Completeness Thresholds	No. of quakes	b-value	Source area (radius)	Equiv. M4 years	M4 activity rate	Activity rate density per 10^4 km^2	Expected 10^{-3} p.a. *pga* (%g)	Expected 10^{-4} p.a. *pga* (%g)	Expected 10^{-5} p.a. *pga* (%g)
0-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	0	1.28	100km	679	0.00142	0.00046	1.1	6.0	15.5
0-C	4.6Ms 1000-1600 4.2Ms 1600-1750 3.5Ms 1750-1850 3.2Ms 1850-2000	0	1.28	100km	2208	0.00044	0.00014	< 0.1	3.1	9.9
1-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	1	1.28	100km	679	0.00289	0.00092	2.3	8.3	19.6
1-C	4.6Ms 1000-1600 4.2Ms 1600-1750 3.5Ms 1750-1850 3.2Ms 1850-2000	1	1.28	100km	2208	0.00089	0.00028	< 0.1	4.7	13.1
8-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	8	1.28	100km	679	0.01320	0.00420	5.8	15.1	30.4
8-C	4.6Ms 1000-1600 4.2Ms 1600-1750 3.5Ms 1750-1850 3.2Ms 1850-2000	8	1.28	100km	2208	0.00406	0.00129	3.0	9.6	21.7
8-Ci	ditto	16	1.28	100km	2208	0.00768	0.00244	4.3	12.3	26.2

Table 4.5 Effects on hazard level of using instrumental magnitude completeness thresholds, with variations in b-value

Scenario	Magnitude Completeness Thresholds	No. of quakes	b-value	Source area (radius)	Equiv. M4 years	M4 activity rate	Activity rate density per 10^4 km^2	Expected 10^{-3} p.a. *pga* (%g)	Expected 10^{-4} p.a. *pga* (%g)	Expected 10^{-5} p.a. *pga* (%g)
0-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	0	1.28	100km	679	0.00142	0.00046	1.1	6.0	15.5
0-D	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-1970 3.2Ms 1970-1984 2.7Ms 1984-2000	0	1.28	100km	1467	0.00066	0.00021	< 0.1	4.0	11.7
0-Di	ditto	0	1.28 for Ms ?3.6; 1.0 for Ms <3.6	100km	990	0.00098	0.00031	< 0.1	4.9	13.5
0-Dii	ditto	0	1.28 for Ms ?3.6; 0.8 for Ms <3.6	100km	820	0.00118	0.00037	0.7	5.5	14.5
0-Diii	ditto	0	1.28 for Ms ?4.0; 1.0 for Ms <4.0	100km	879	0.00108	0.00034	< 0.1	5.2	14.1
0-Div	ditto	0	1.28 for Ms ?4.0; 0.8 for Ms <4.0	100km	661	0.00145	0.00046	1.1	6.0	15.6

Table 4.5 Effects on hazard level of using instrumental magnitude completeness thresholds, with variations in b-value, cont.

Scenario	Magnitude Completeness Thresholds	No. of quakes	b-value	Source area (radius)	Equiv. M4 years	M4 activity rate	Activity rate density per 10^4 km^2	Expected 10^{-3} p.a. *pga* (%g)	Expected 10^{-4} p.a. *pga* (%g)	Expected 10^{-5} p.a. *pga* (%g)
0-B	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-2000	0	1.28	100km	679	0.00142	0.00046	1.1	6.0	15.5
0-D	5Ms 1000-1600 4.6Ms 1600-1750 3.9Ms 1750-1850 3.6Ms 1850-1970 3.2Ms 1970-1984 2.7Ms 1984-2000	0	1.28	100km	1467	0.00066	0.00021	< 0.1	4.0	11.7
0-Di	ditto	0	1.28 for Ms ?3.6; 1.0 for Ms <3.6	100km	990	0.00098	0.00031	< 0.1	4.9	13.5
0-Dii	ditto	0	1.28 for Ms ?3.6; 0.8 for Ms <3.6	100km	820	0.00118	0.00037	0.7	5.5	14.5
0-Diii	ditto	0	1.28 for Ms ?4.0; 1.0 for Ms <4.0	100km	879	0.00108	0.00034	< 0.1	5.2	14.1
0-Div	ditto	0	1.28 for Ms ?4.0; 0.8 for Ms <4.0	100km	661	0.00145	0.00046	1.1	6.0	15.6

Other information presented in one or other of my three lectures appears in the following references:

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