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"2nd Workshop on Earthquake Engineering for Nuclear Facilities: Uncertainties in Seismic Hazard"

14 - 25 February 2005

PSHA studies in Indian NPPs site

Prabir C. Basu

Civil & Structural Engineering Division
Atomic Energy Regulatory Board
India

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

2nd Workshop on Earthquake Engineering for Nuclear Facilities
Uncertainties in Seismic Hazard Assessment
Trieste - Italy, 14 - 25 February 2005

PSHA studies in Indian NPPs site

Trieste, Italy, 14-25 February 2005
Unit 30,

Prabir C. Basu,
Atomic Energy Regulatory Board, India

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Atomic Energy Regulatory Board

&

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Nuclear Power Corporation of India Ltd.

Outline of presentation

- Introduction
- PSHA of Indian NPPs site
- Examination of uncertainties
- Lessons learnt and conclusions
- Summary
- Reference and Glossary

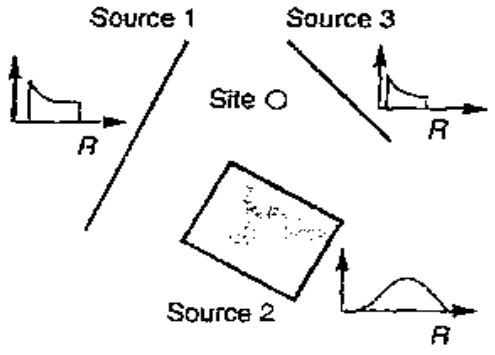
Introduction

- The goal of probabilistic seismic hazard analysis (PSHA) is to calculate the rate (or probability) of exceedence of various ground-motion levels at a site (or a map of sites) given all possible earthquakes scenarios

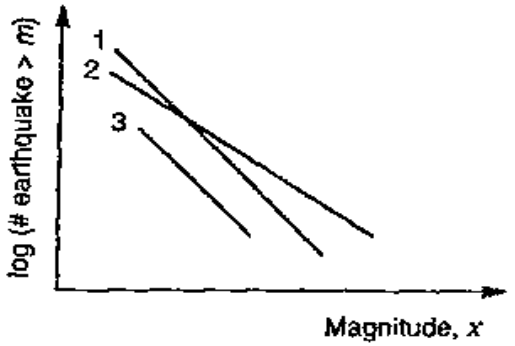
Introduction…

- In contrast to the typical deterministic analysis, which make use of discrete, single valued events to arrive at the description of seismic hazard, probabilistic analysis allows the use of multi-valued or continuous events and models.

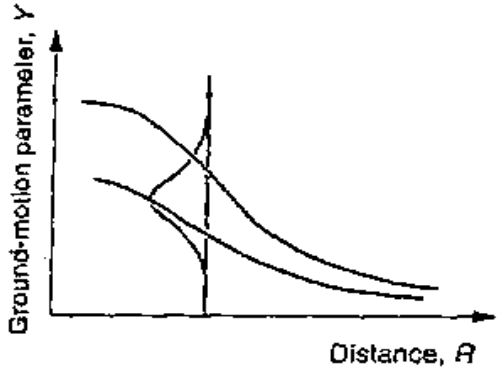
Introduction…



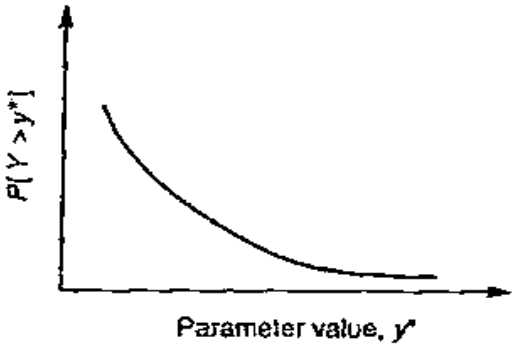
STEP 1



STEP 2



STEP 3



STEP 4

Introduction…

- Though the PSHA approach is more rational than deterministic method to evaluate ground motion parameters, the accuracy of PSHA becomes clouded with uncertainties due to inadequacy of data and lack of information.

Introduction…

- This is particularly relevant for intra-plate regions like peninsular India.

- The problem of inadequacy of data and lack of knowledge can best be addressed, within the present - state of - knowledge, by examining the effects of uncertainties.

PSHA of Indian NPP site

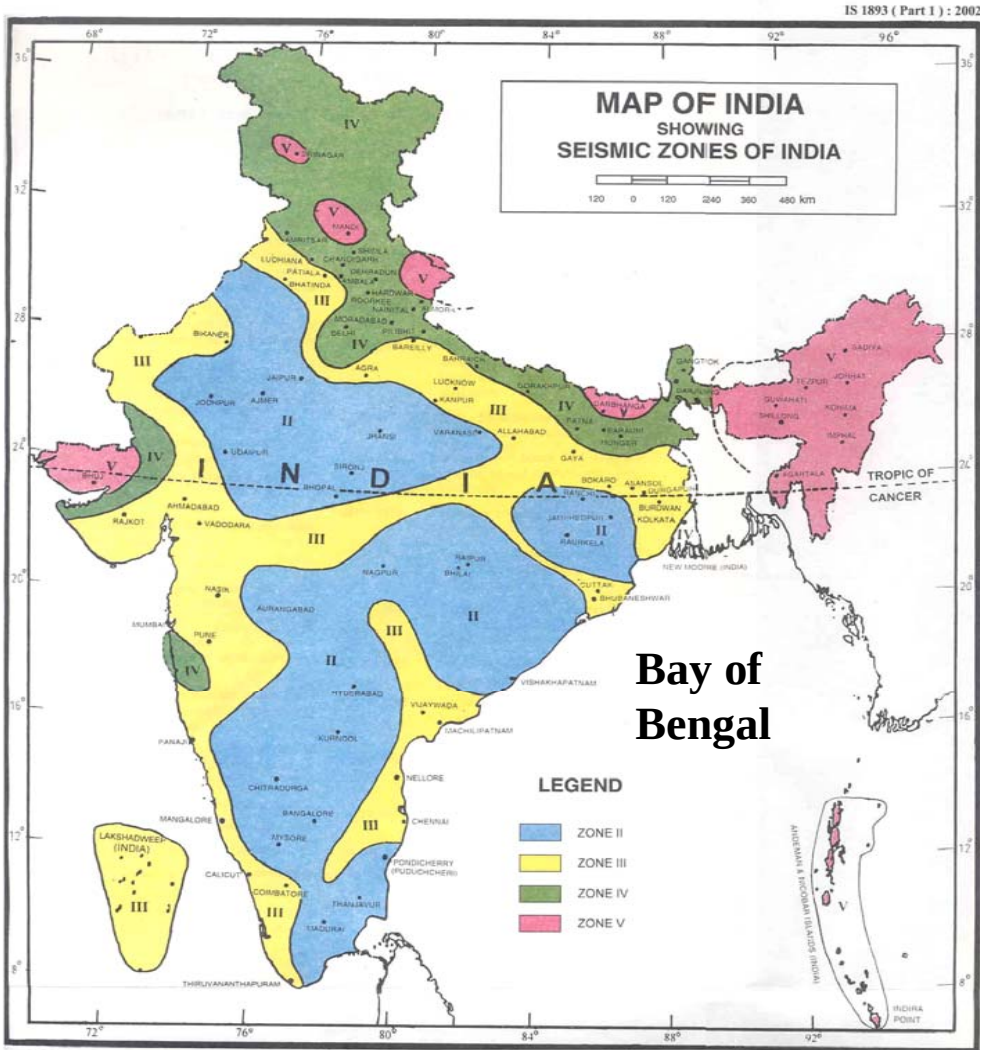
PSHA of Indian NPP Site…

- Work on PSHA of Indian NPPs site has been started in recent past. The work is in preliminary stage and would need more time for completion.
- Main emphasis is put on at present in the survey of uncertainties
- Work is presently confined to determination of PGA and not UHS
- Some of the results of PSHA (three analyses) carried out for an Indian NPP site is presented along with examination of uncertainties.
  - Analysis I : Approach
  - Analyses II & III : Examination of uncertainities

PSHA of Indian NPP Site…

- Site is located on the coast of peninsular India
- As per Indian standard IS 1893 (2002), site falls in Mesozoic formation.
- Site falls in seismic zone III of IS 1893.

PSHA of Indian NPP Site…



Seismic zone (as per IS1893)	I	II	III	IV	V
Associated Intensity (*MMI*)	V	VI	VII	VIII	IX & above
Magnitude	**4**	**5**	**5-6**	**6-7**	**7-8**

Seismic zoning map of India (IS 1893-2002).

PSHA of Indian NPP Site…

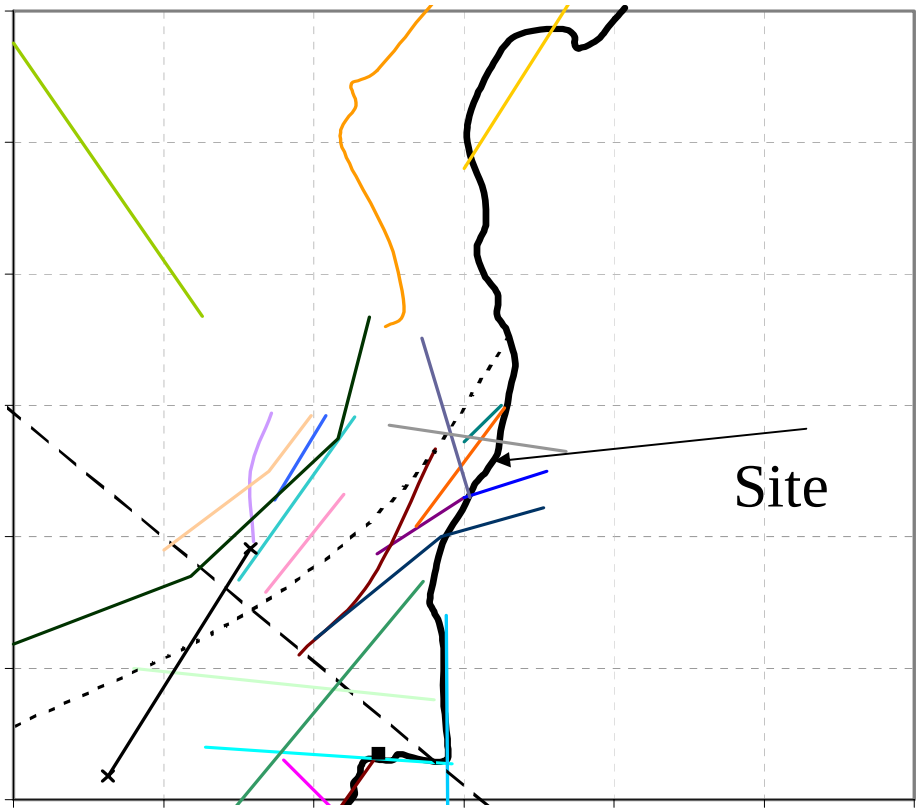
- The site investigations carried out following AERB Safety Code, AERB/SC/S; and AERB Safety Guide AERB/SG/S-11
- Amongst others, site investigations carried out in particular are:
  - Photo-geological map .
  - Field checks .
  - Collection of seismic reflection survey data.
  - Geotechnical investigations
- Seismotectonic model of the region (having 300km radius) was developed.

PSHA of Indian NPP Site…

- Geological setting
  - The bed rocks comprise of charnokolites and granite ferrous granite gniesses of Archean age intruded by dolerite dykes and covered by coastal sands.
  - The thickness of overburden (sand layer) varies between 6m to 9m, and total depth to top of fresh rock from the existing ground level varies between 10 to 15m.
- The site has been considered as rocky site as the average shear wave velocity v_s >1600m/s.

PSHA of Indian NPP Site…

Square area is 6^0
x 6^0 i.e.,
~ 660x660 km



Faults around the site

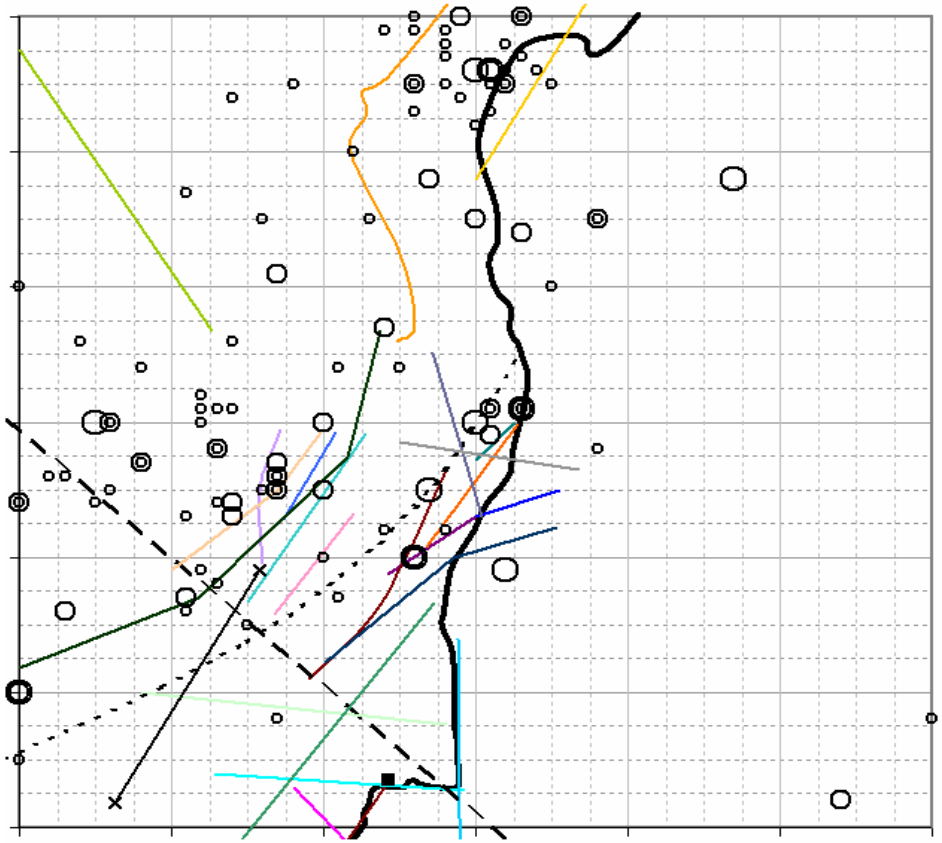
PSHA of Indian NPP Site…

- The largest earthquake to have occurred within study area of peninsular India was the Coimbatore earthquake of February 8, 1900, having a magnitude of 6.0.

PSHA of Indian NPP Site…

- Earthquake data for the site is available from 1807 to 2001.
- Approximately 100 records are available (m_o =3.0)
- For historical data, magnitudes were calculated from observed epicentral intensities.

PSHA of Indian NPP Site…



Earthquakes within 300 km radius of the site

PSHA of Indian NPP Site…

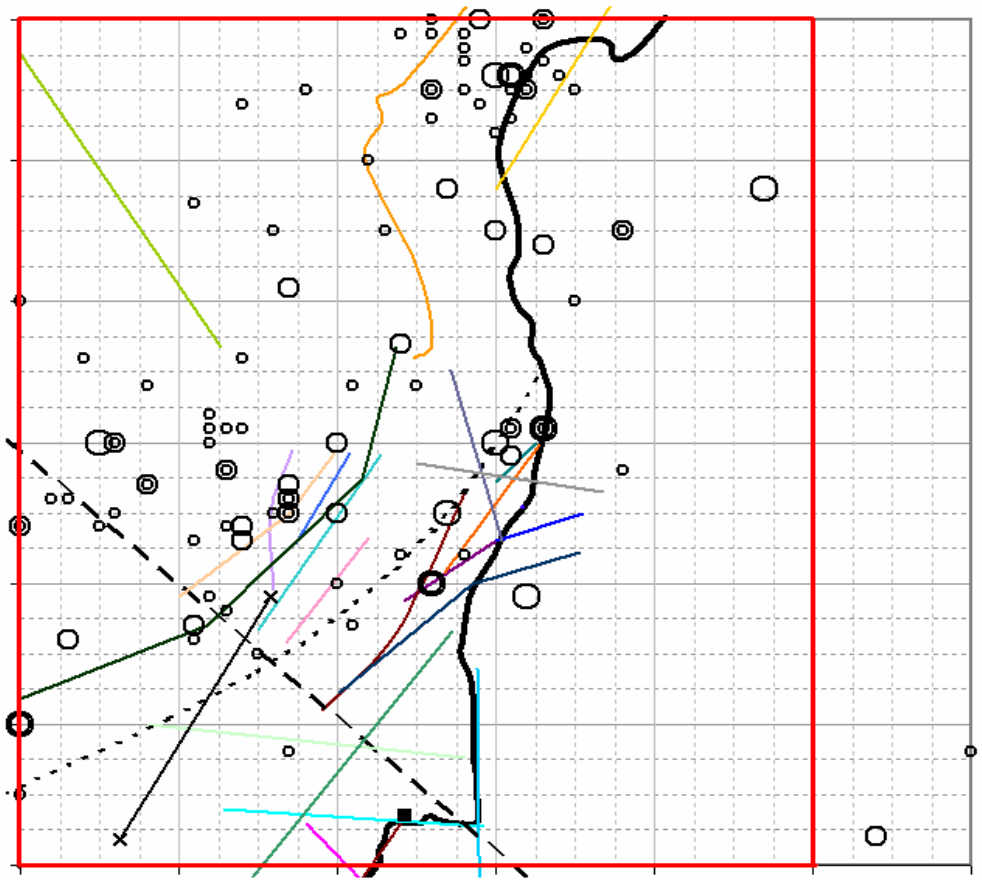
Analysis I

Step - 1

1. Definition of earthquake sources
    a) Geometry of the sources
    b) Maximum earthquake potential of the sources
    c) Calculation of the range of earthquake magnitudes and distances to be considered in the analysis

PSHA of Indian NPP Site…

Analysis I



Source model SM_1: site with a single source

PSHA of Indian NPP Site…

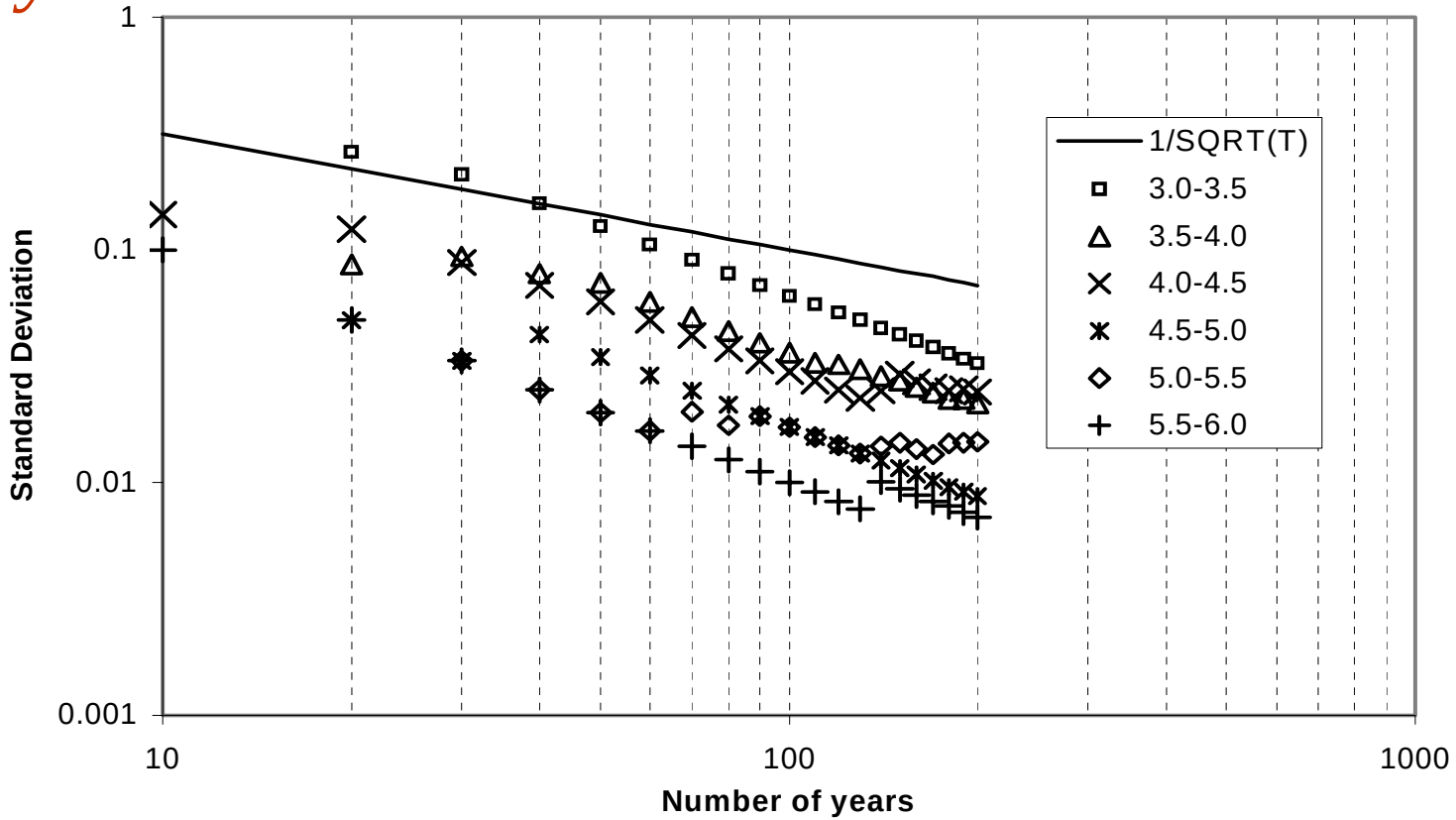
Analysis I

Step – 2

- Calculation of recurrence relationships for each source
  - Completeness checking of the earthquake catalogue (by Stepp's method)
  - Derivation of 'a' and 'b' values
    - The exceedance rates corresponding to each magnitude are plotted in semi-log scale and the parameters (a & b) corresponding to best fit straight line is derived.

PSHA of Indian NPP Site…

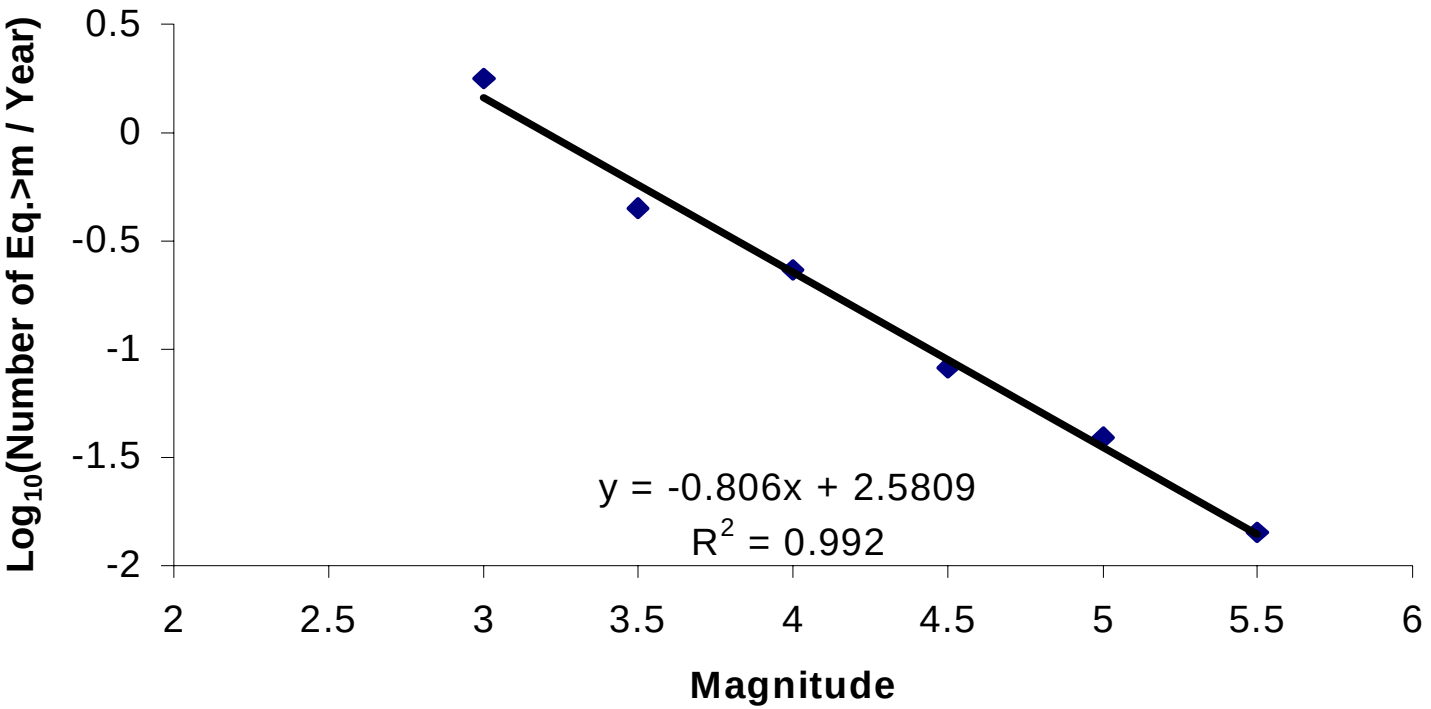
Analysis I



Checking the completeness of catalogue by Stepp's method ((10 year increment in data bins and 0.5 increase in magnitude bins)

PSHA of Indian NPP Site…

Analysis I



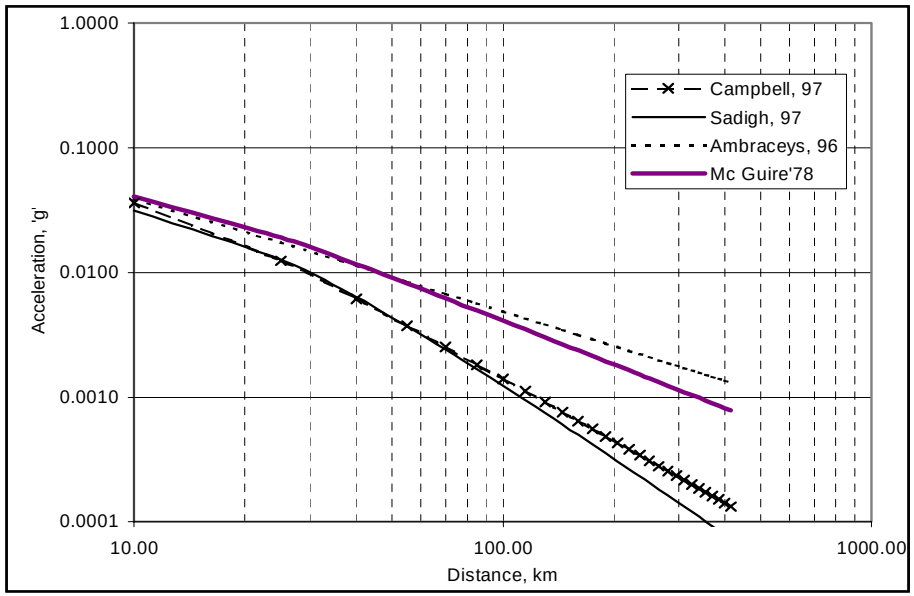
Gutenberg-Richter relationship

(Option-3: 10 year as data bins and 0.5 as magnitude bins used for completeness test)

PSHA of Indian NPP Site…

Step – 3

- Attenuation model ($ln\ y = C1 + C2m + C3\ ln\ R$) has been used.
- Particular attenuation relation adopted for the work was Mc Guire'78



Comparison of some attenuation relationships

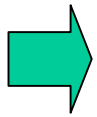
PSHA of Indian NPP Site…

Analysis I

Step – 3

- The expected value of the annual probability of exceedence of PGA, ‘z’

$$E(z) = \sum_{i=1}^{N} \alpha_i \int_{m_0}^{m_u} \int_{r=0}^{r=\infty} f_i(m)\, f_i(r) P(Z > z | m, r)\, dr\, dm$$



- Software ‘EQRISK’ was used to estimate E(z)

PSHA of Indian NPP Site…

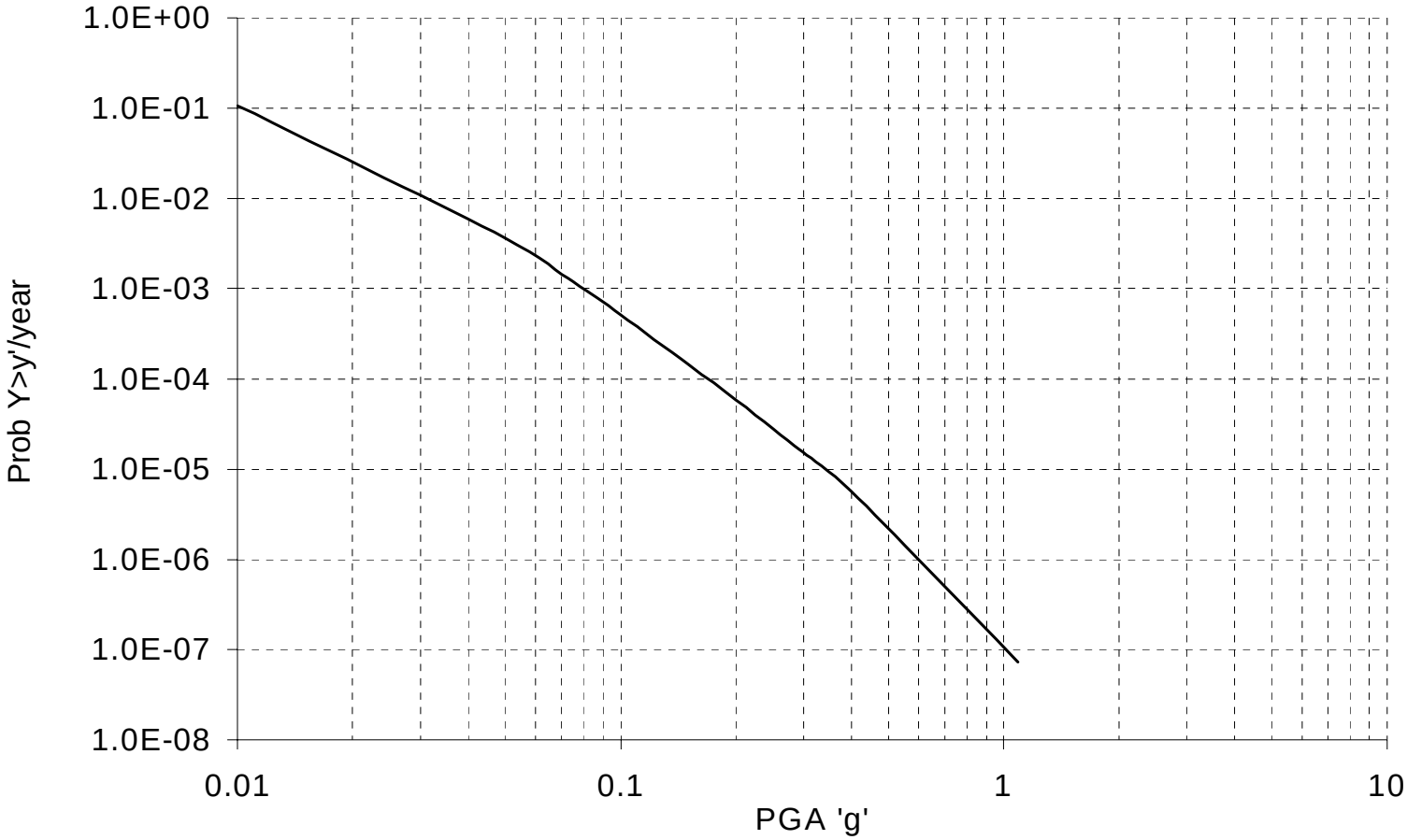
Analysis I

The following considerations are made in calculating E(z)

- Minimum magnitude, m_0 was taken as 3.0
- Upper cutoff magnitude (m_u) was decided based on the maximum observed magnitude in that source

  $m_u = m_{observed} + 0.7$ (1 intensity equivalent)
- No de-aggregation of seismic hazard has been performed.

PSHA of Indian NPP Site…



Hazard curve

Examination of Uncertainties

Examination of Uncertainties…

- Randomness in PSHA arises out of the following :
  - Aleatory variability
  - Epistemic uncertainty

- Aleatory variability is due to primary randomness of the physical system, and is taken care in the equation for hazard computation.

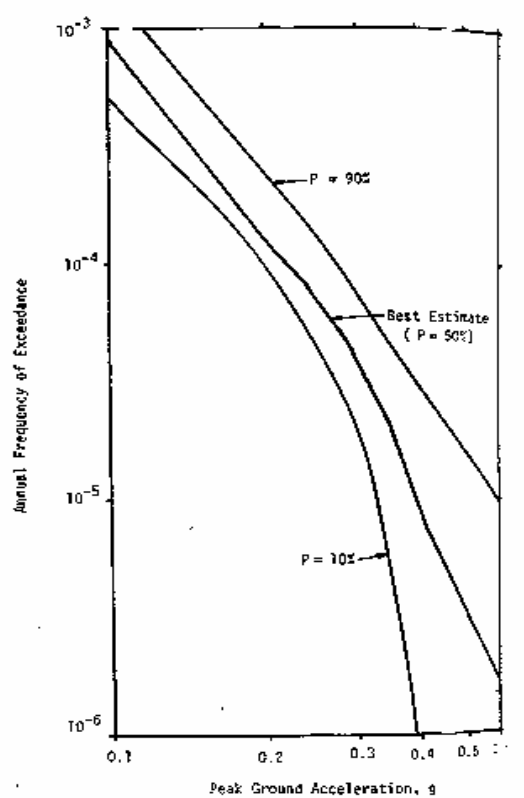
- Epistemic uncertainty is of secondary type and is due to data inadequacy, lack of information, deficiency in modeling, etc.

Examination of Uncertainties…

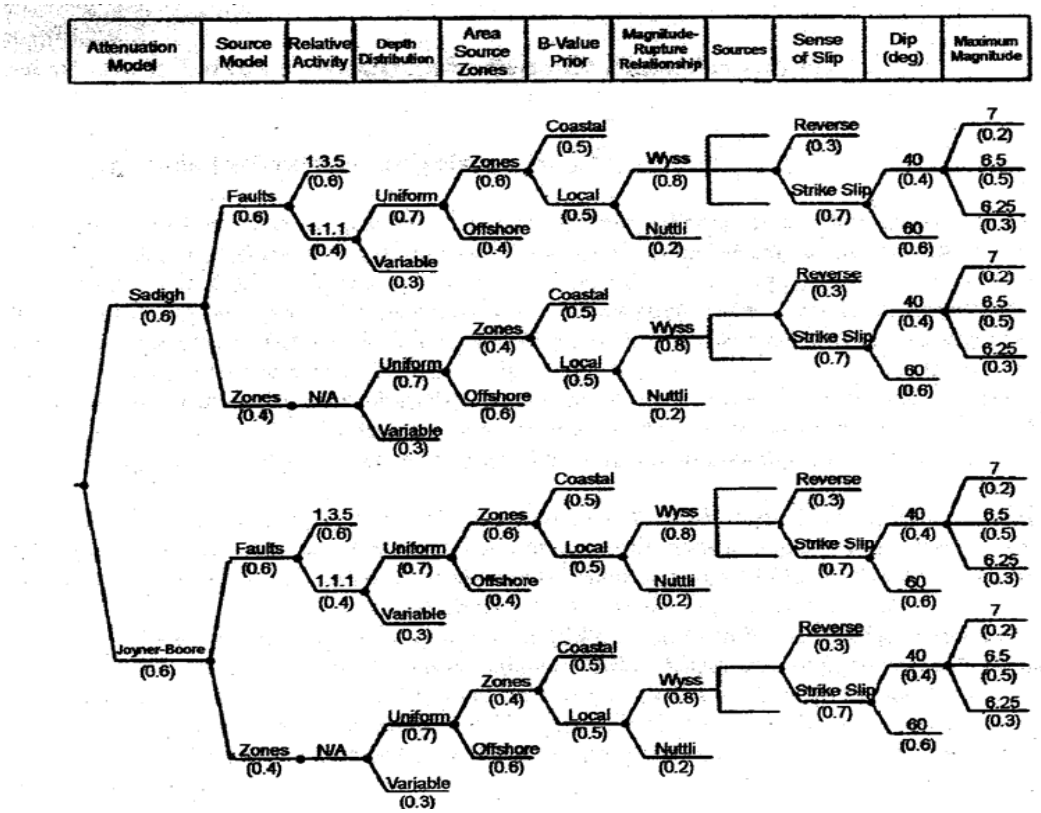
- Major contributors to the epistemic uncertainties are:
  a) model of seismic sources
  b) specification of activity of the seismic sources
  c) estimation of earthquake magnitude from records based on intensity and maximum magnitude m_u
  d) attenuation relationship
  e) proportioning of activity into different sources

Examination of Uncertainties…

Two approaches for addressing the epistemic uncertainties



Uncertainty bands



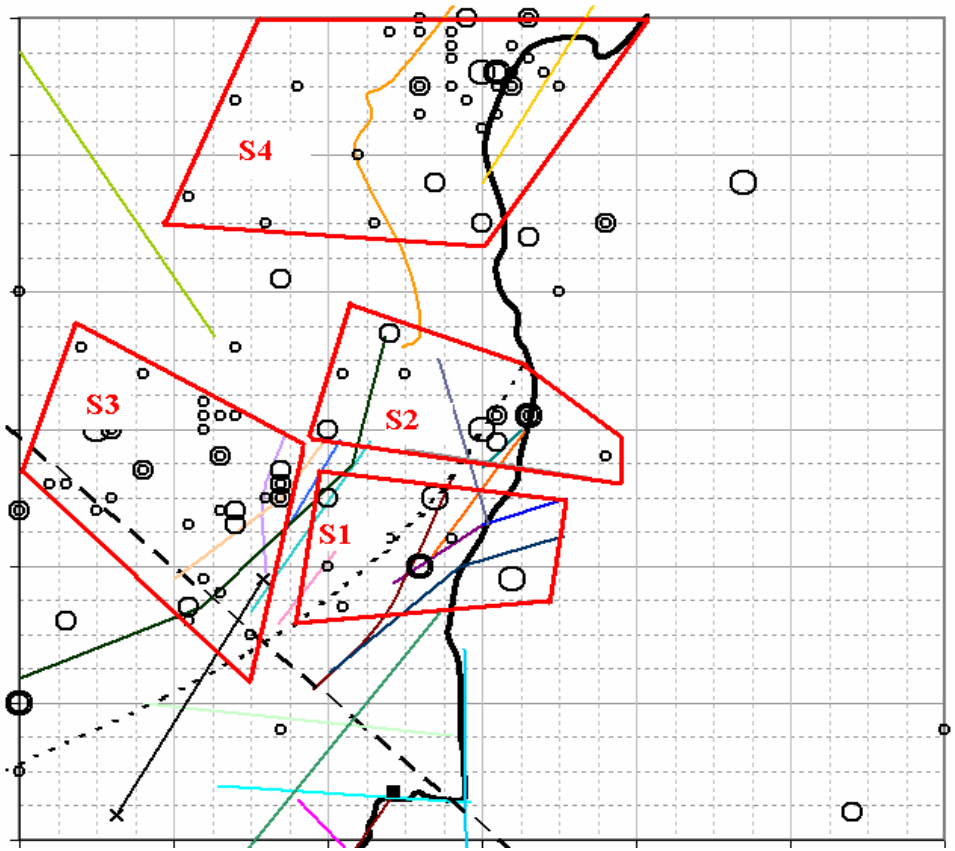
Logic trees

Examination of Uncertainties…

- Analysis II covers the examination of uncertainties conducted for the following
  - modeling of source gometry
  - ‘a’ & ‘b’ values, and
  - attenuation relationship

Examination of Uncertainties…

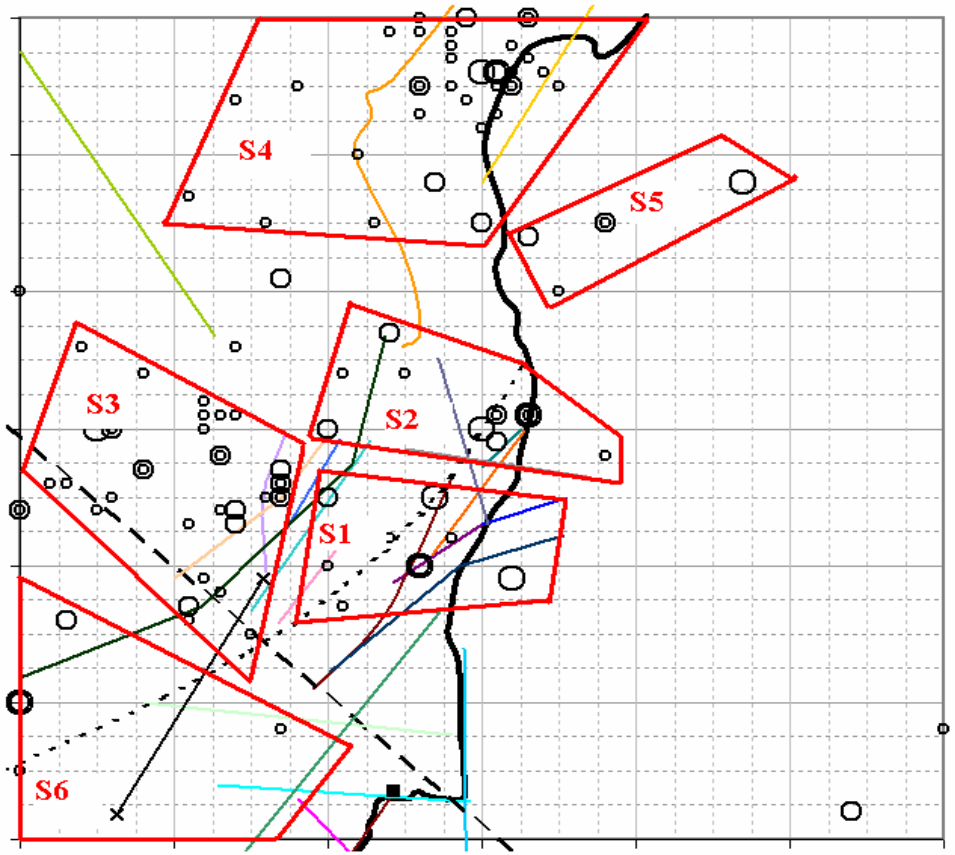
Analysis II



Source geometry model SM_2: site with four sources and remaining seismicity assigned to background activity

Examination of Uncertainties…

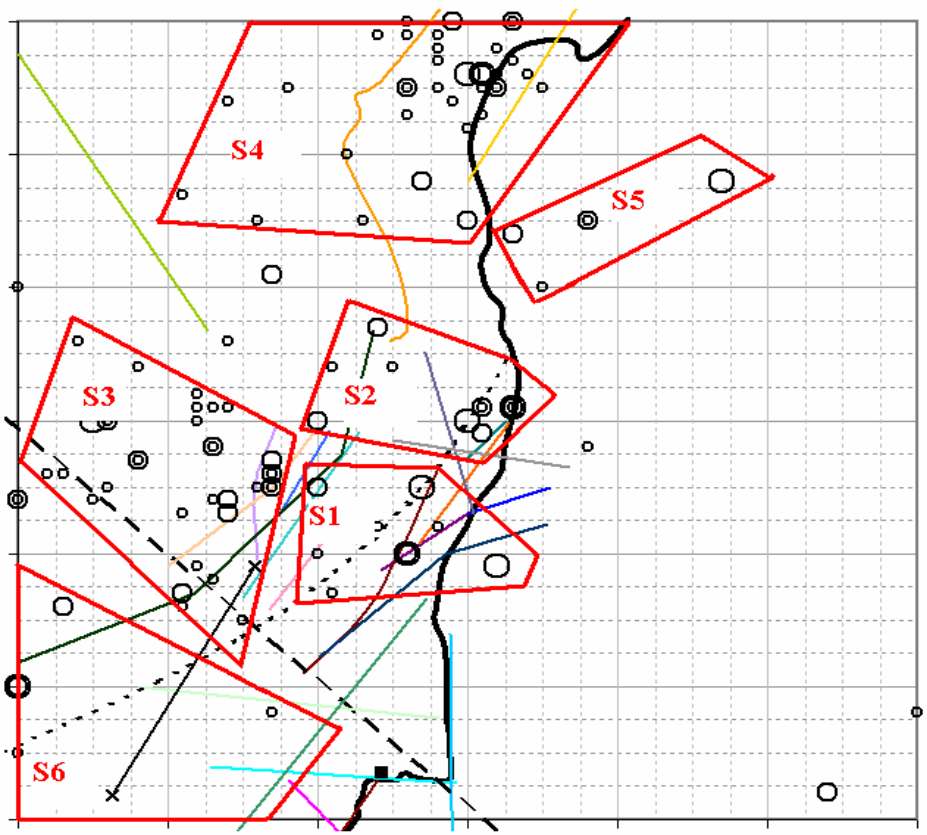
Analysis II



Source geometry model SM_3: site with six sources and remaining seismicity assigned to background activity

Examination of Uncertainties…

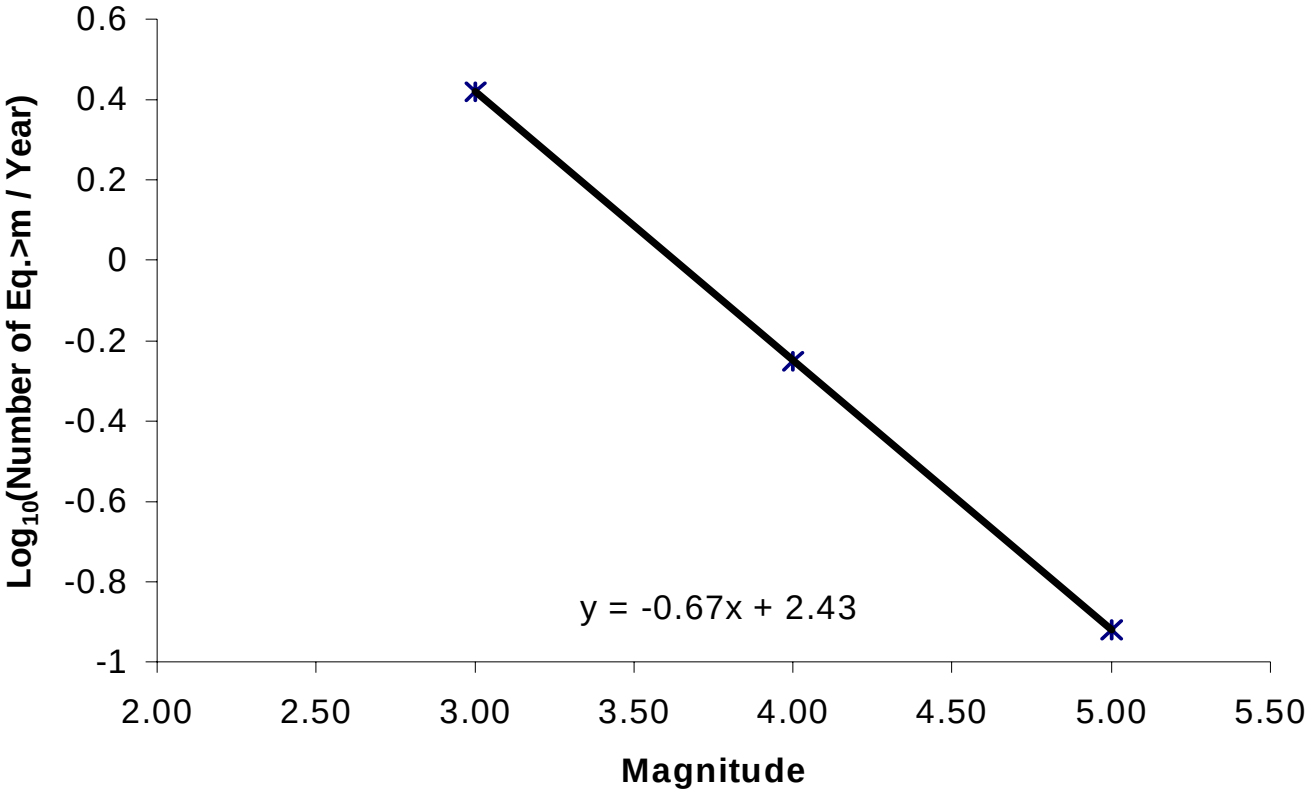
Analysis II



Source geometry model SM_4: site with a six sources (modified S1 and S2) and remaining seismicity assigned to background activity

Examination of Uncertainties…

Analysis II

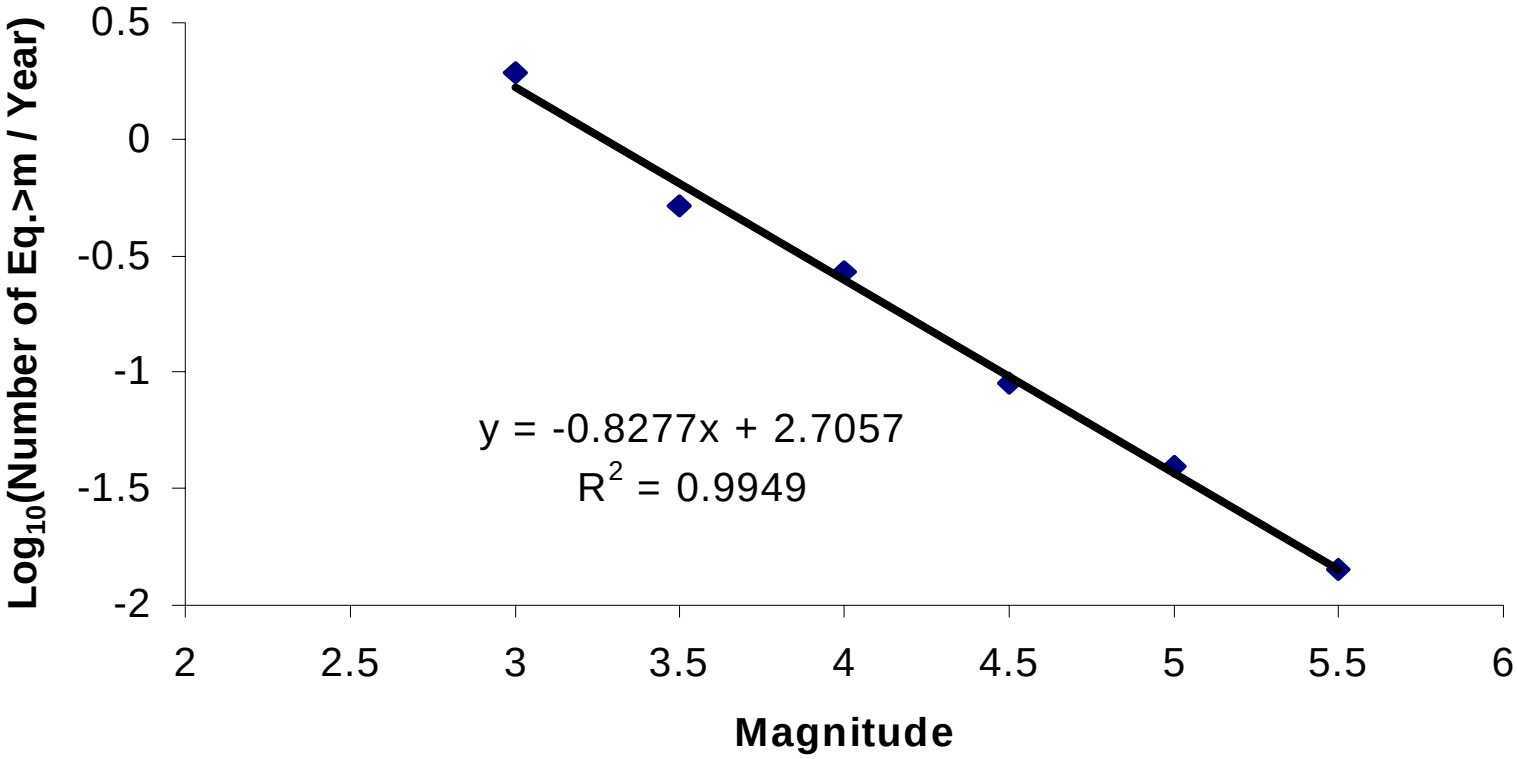


Gutenberg-Richter relationship

(Option 1: for the full data available for the site, no completeness check)

Examination of Uncertainties…

Analysis II

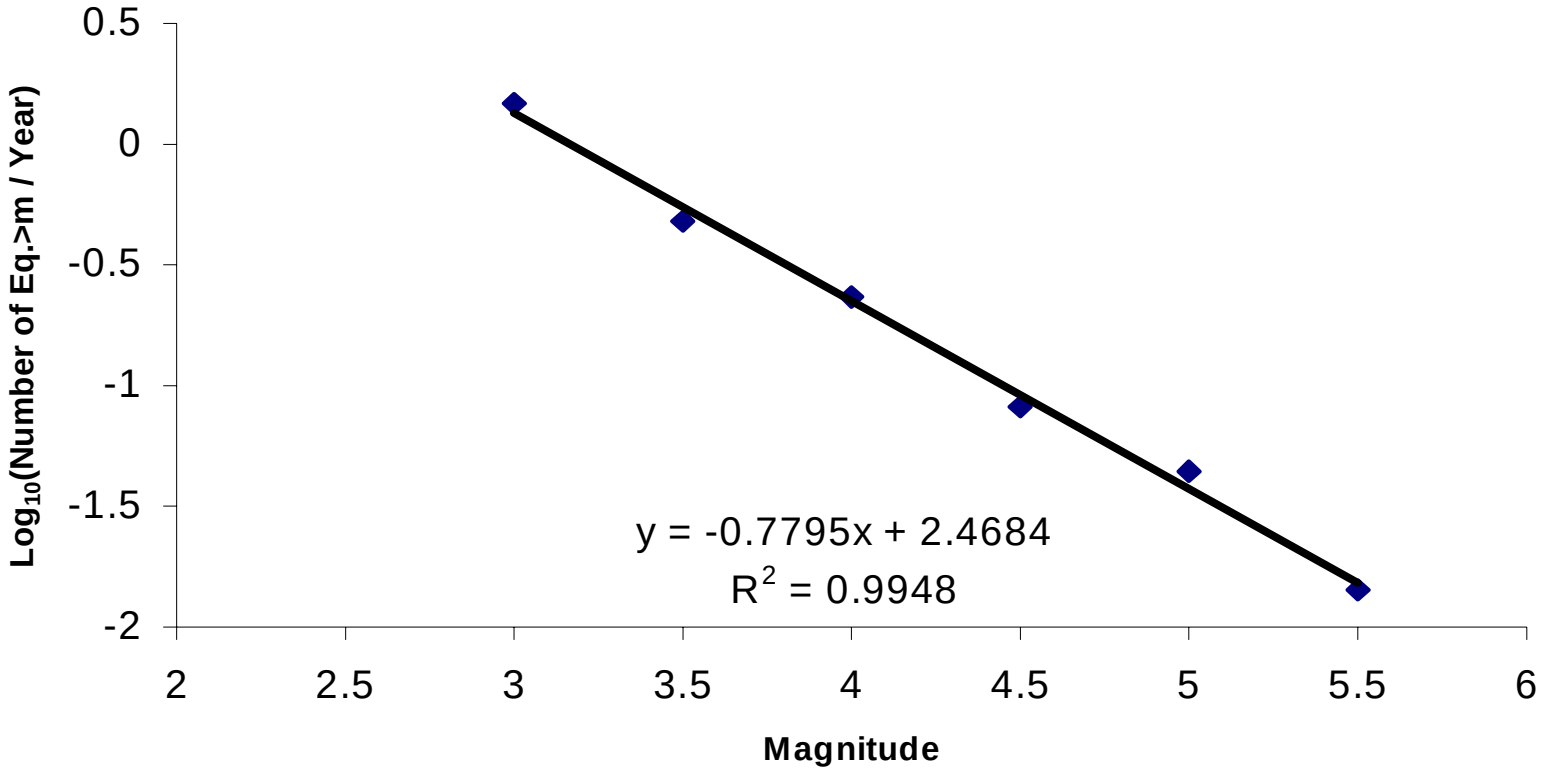


Gutenberg-Richter relationship

(Option 2: 5 year as data bins and 0.5 as magnitude bins used for completeness test)

Examination of Uncertainties…

Analysis II



Gutenberg-Richter relationship

(Option 4: 20 year as data bins and 0.5 as magnitude bins used for completeness test)

Examination of Uncertainties…

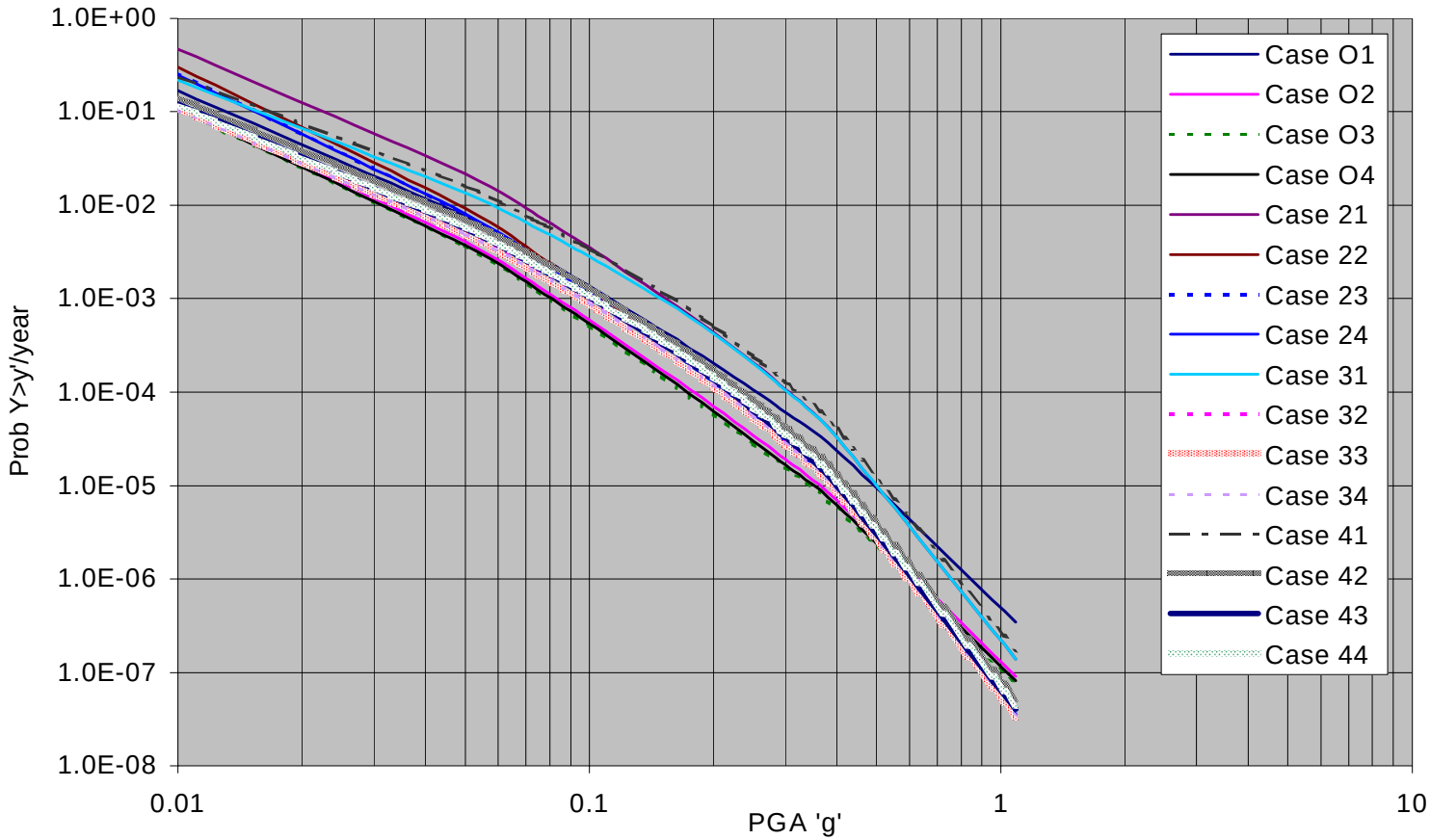
Analysis II

Different Cases

Source model	a_1= 2.43, b_1= -0.67	a_2= 2.71, b_2= -0.82	a_3= 2.58, b_3= -0.81	a_4= 2.47, b_4= -0.78
SM_1: Single Source	Case 01	Case 02	Case 03	Case 04
SM_2: Four Source	Case 21	Case 22	Case 23	Case 24
SM_3: Six Source	Case 31	Case 32	Case 33	Case 34
SM_4: Six Source (Modified)	Case 41	Case 42	Case 43	Case 44

Examination of Uncertainties…

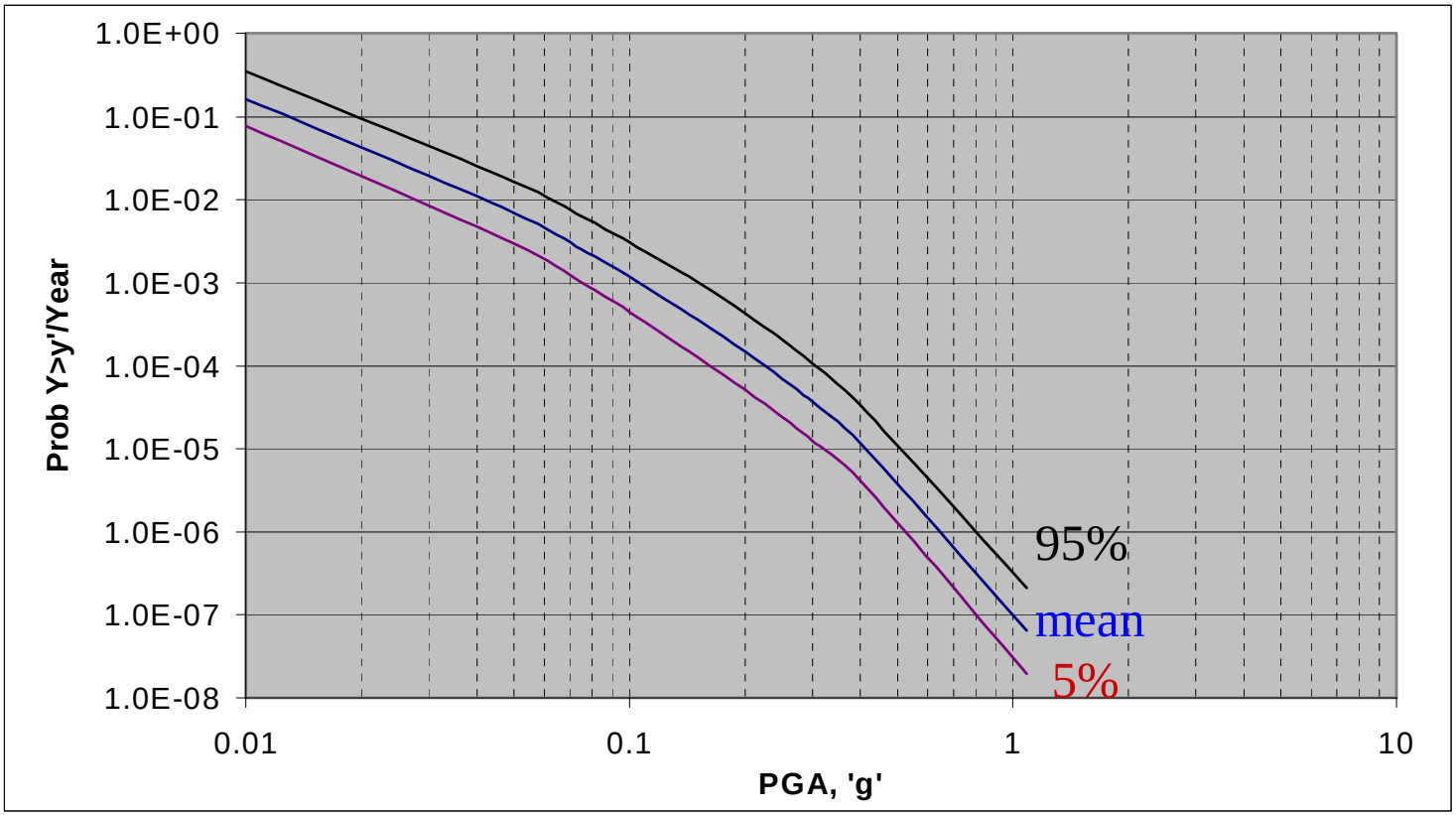
Analysis II



Hazard curves obtained for different combinations of source models and ‘a’ & ‘b’ values.

Examination of Uncertainties…

Analysis II

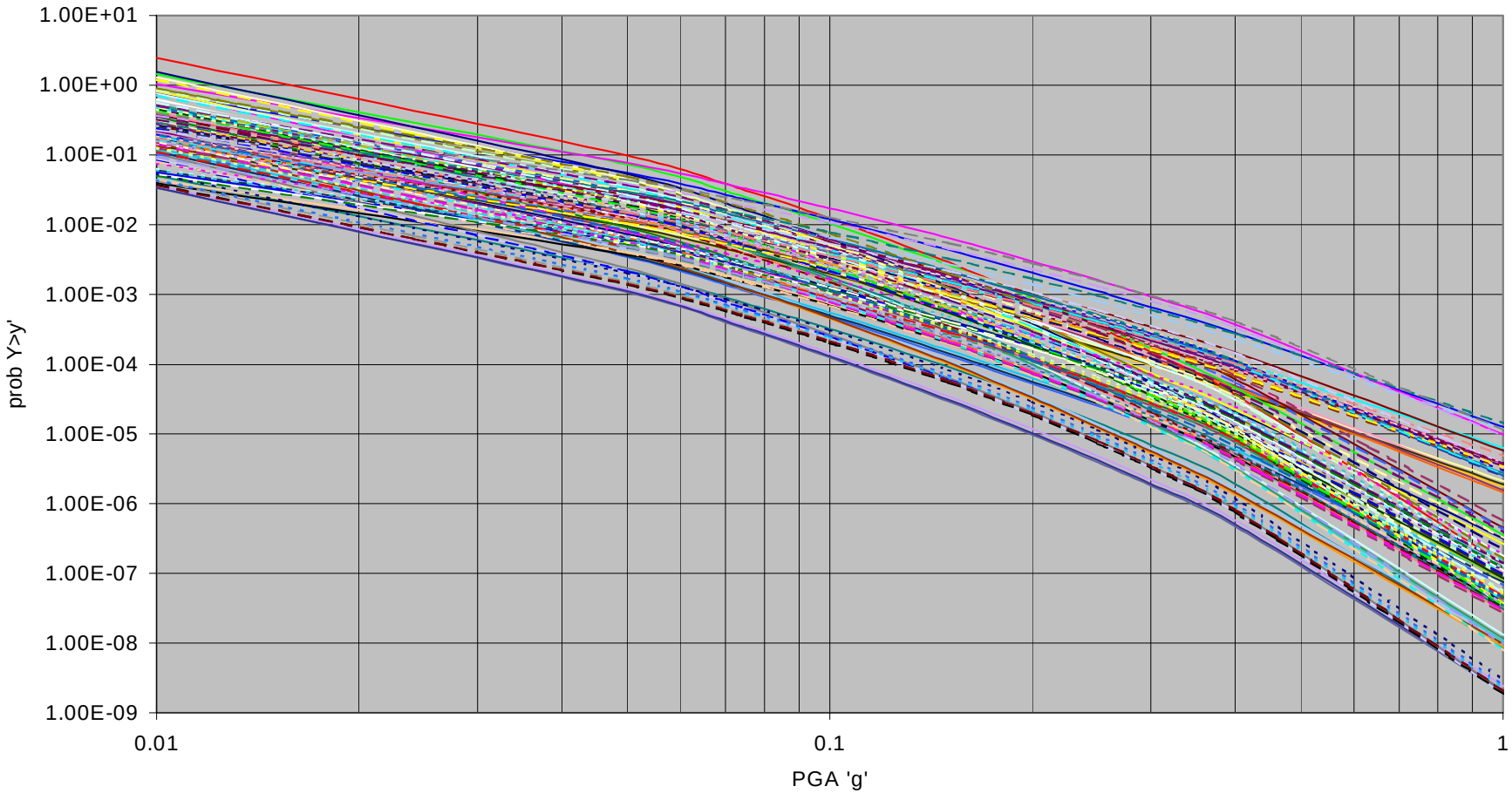


Hazard band - I (4 source geometry models SM1, SM2, SM3 & SM4 and 4 combinations of a & b values, a_1b_1, a_2b_2, a_3b_3, & a_4b_4)

Examination of Uncertainties…

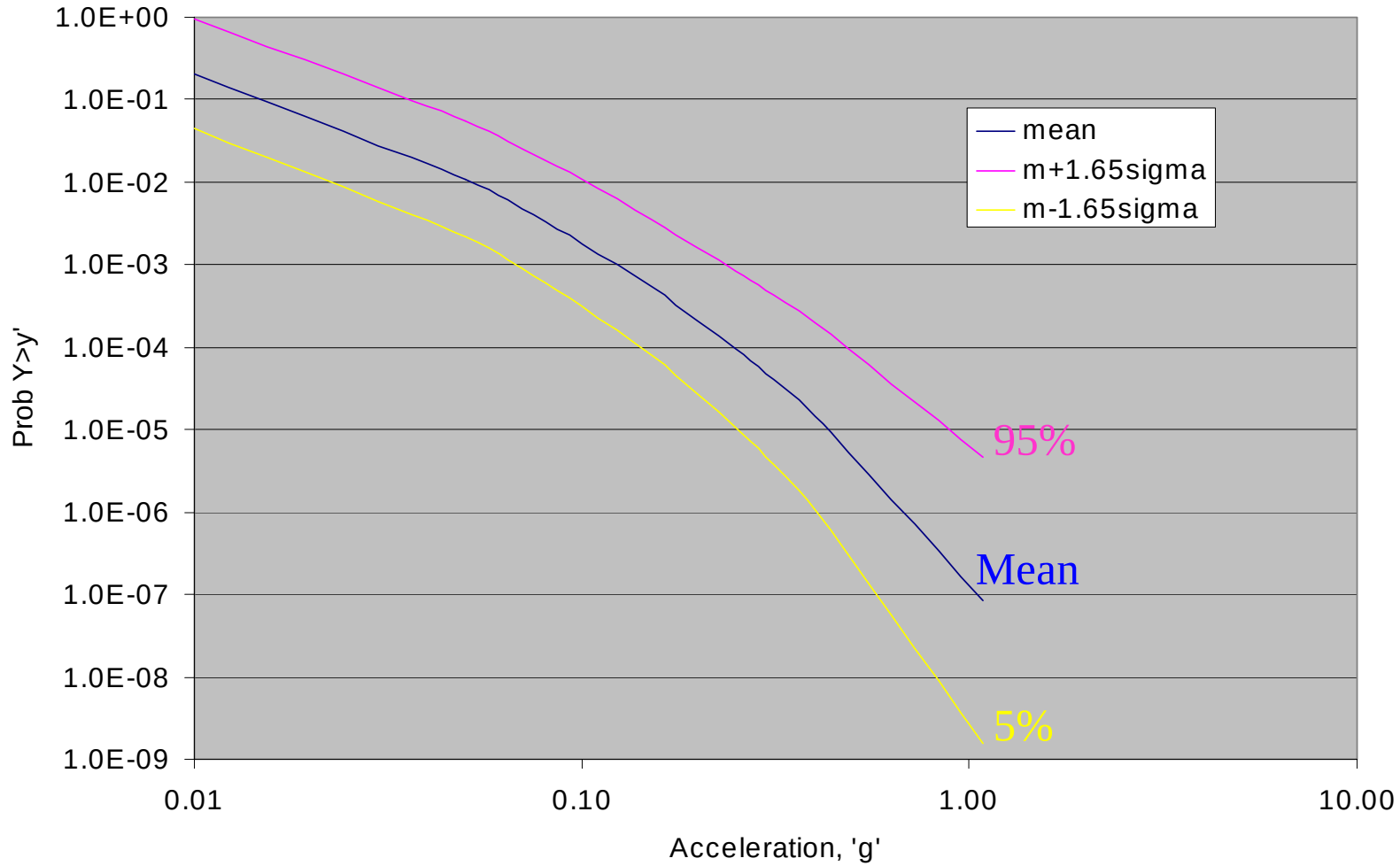
- Analysis III covers the examination of uncertainties on account of attenuation relationship was examined considering the following:
  - Mc Guire ‘78,
  - Boore’97,
  - Tento ’92,
  - Dahle’90,
  - Ambraseys’96,
  - Atkinson ’97,
  - Sadigh’97,
  - Campbell’97

Examination of Uncertainties…



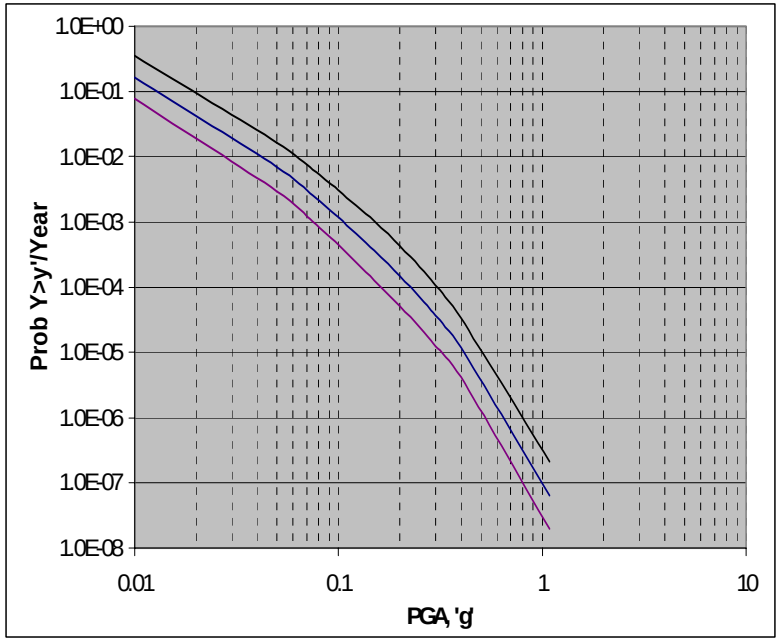
Hazard band (128 combinations 4 source geometry models, 4 combinations of a-b values and 8 attenuation relations)

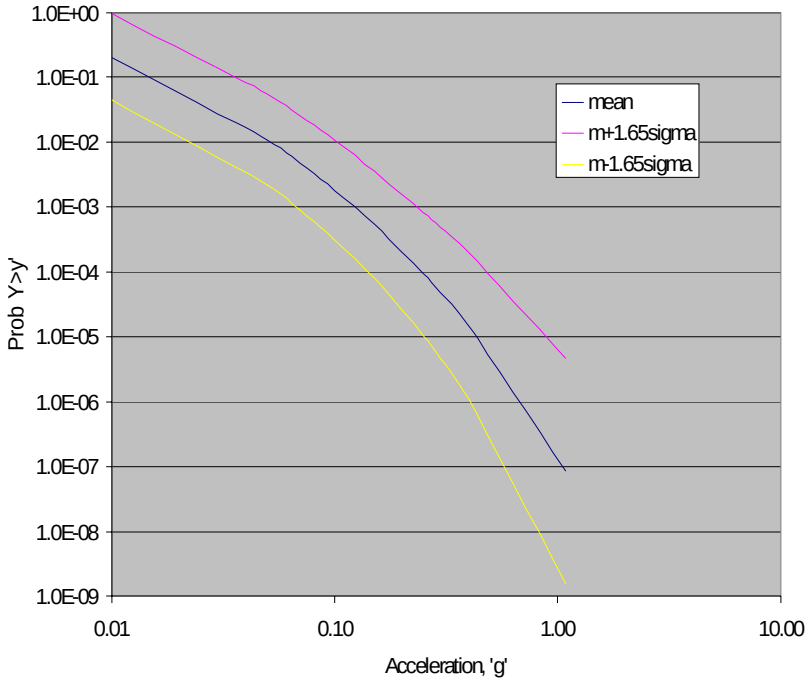
Examination of Uncertainties…Analysis II



Hazard bands II (4 source geometry models, 4 combinations of a-b values and 8 attenuation relations)

Examination of Uncertainties…Analysis II

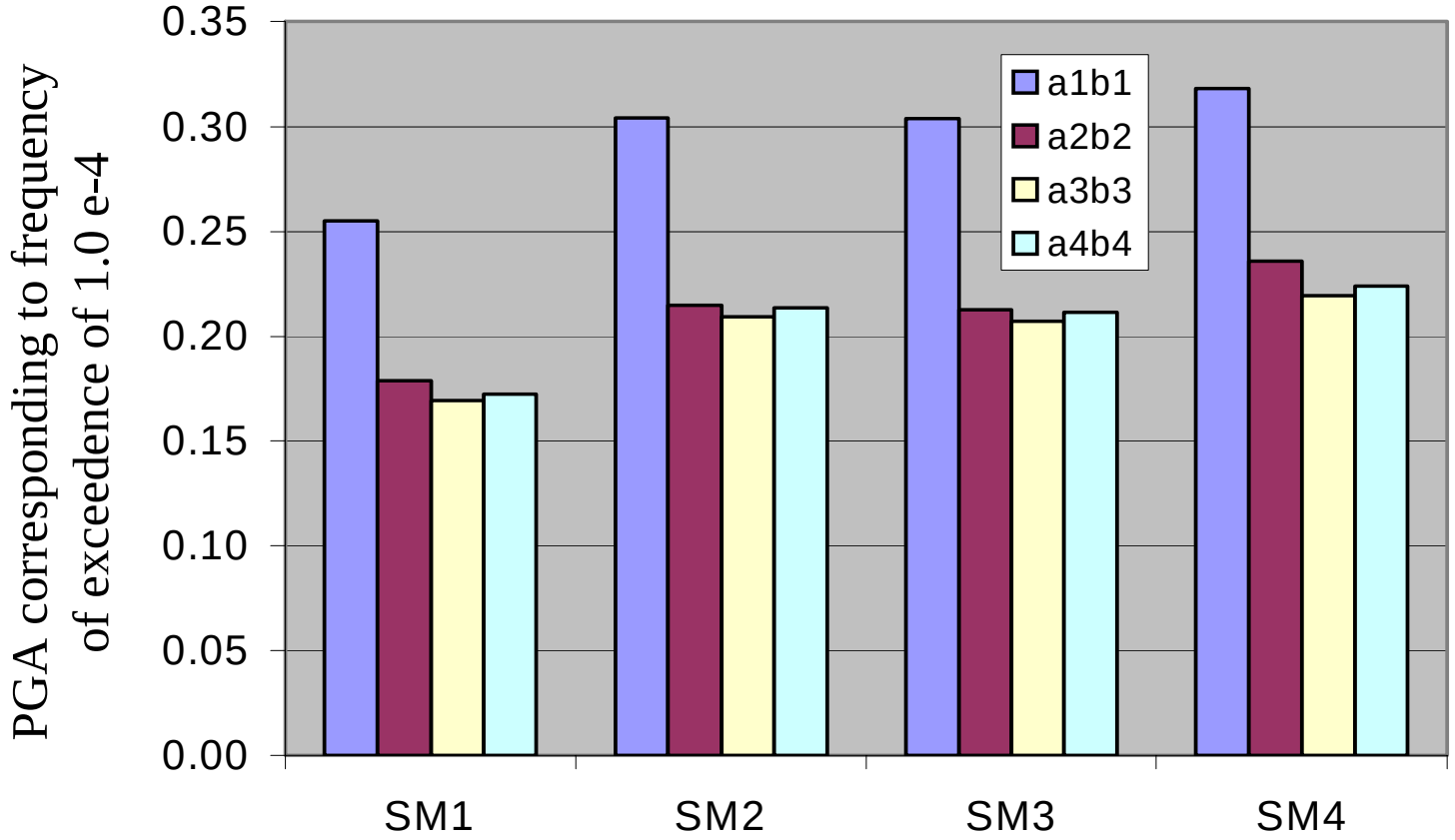




Hazard bands I & II

Examination of Uncertainties…

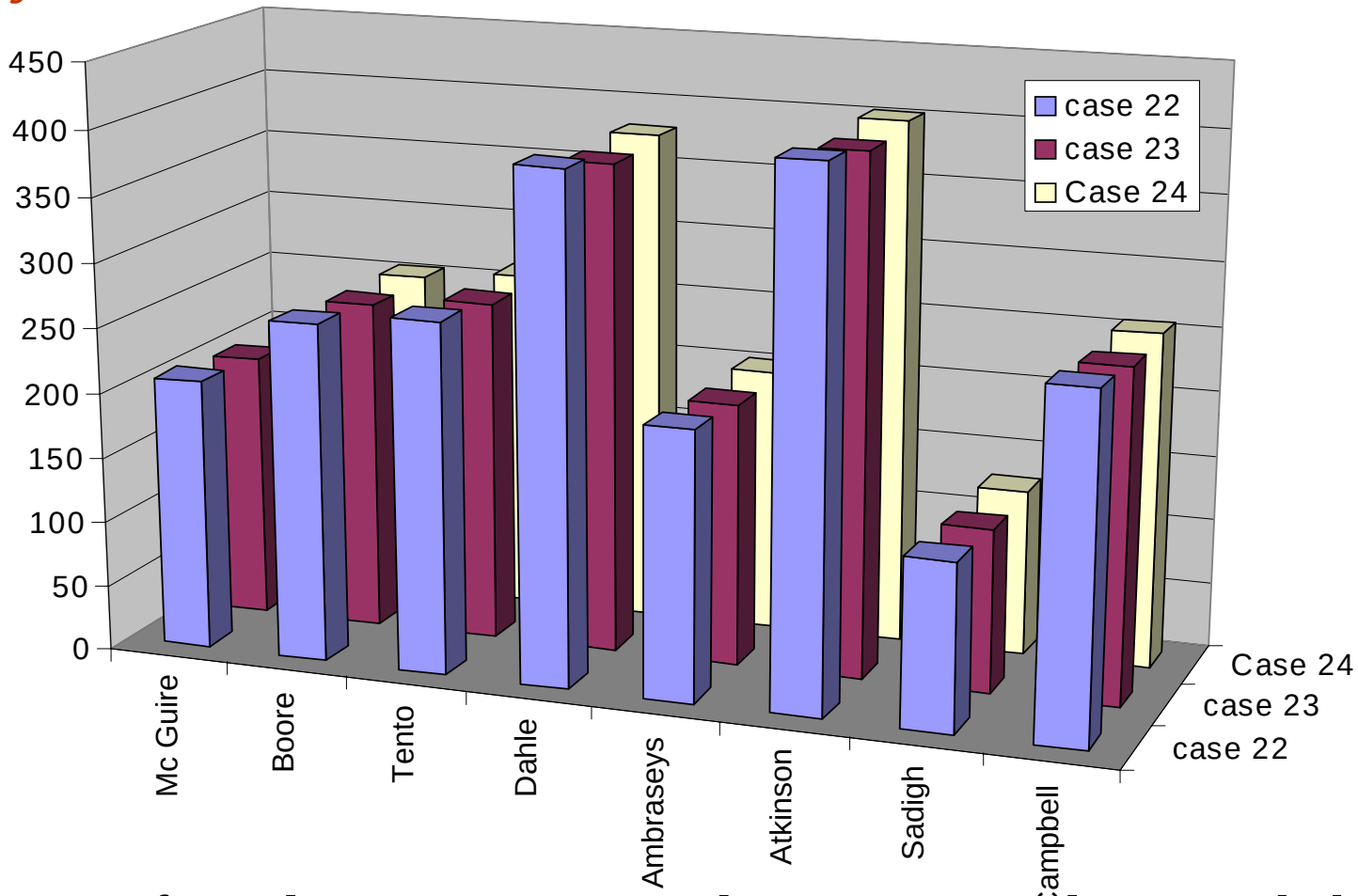
Analysis II



PGA corresponding to annual frequency of exceedence of $1x10^{-4}$ (4 sources geometry and 4- combinations of a & b values)

Examination of Uncertainties…

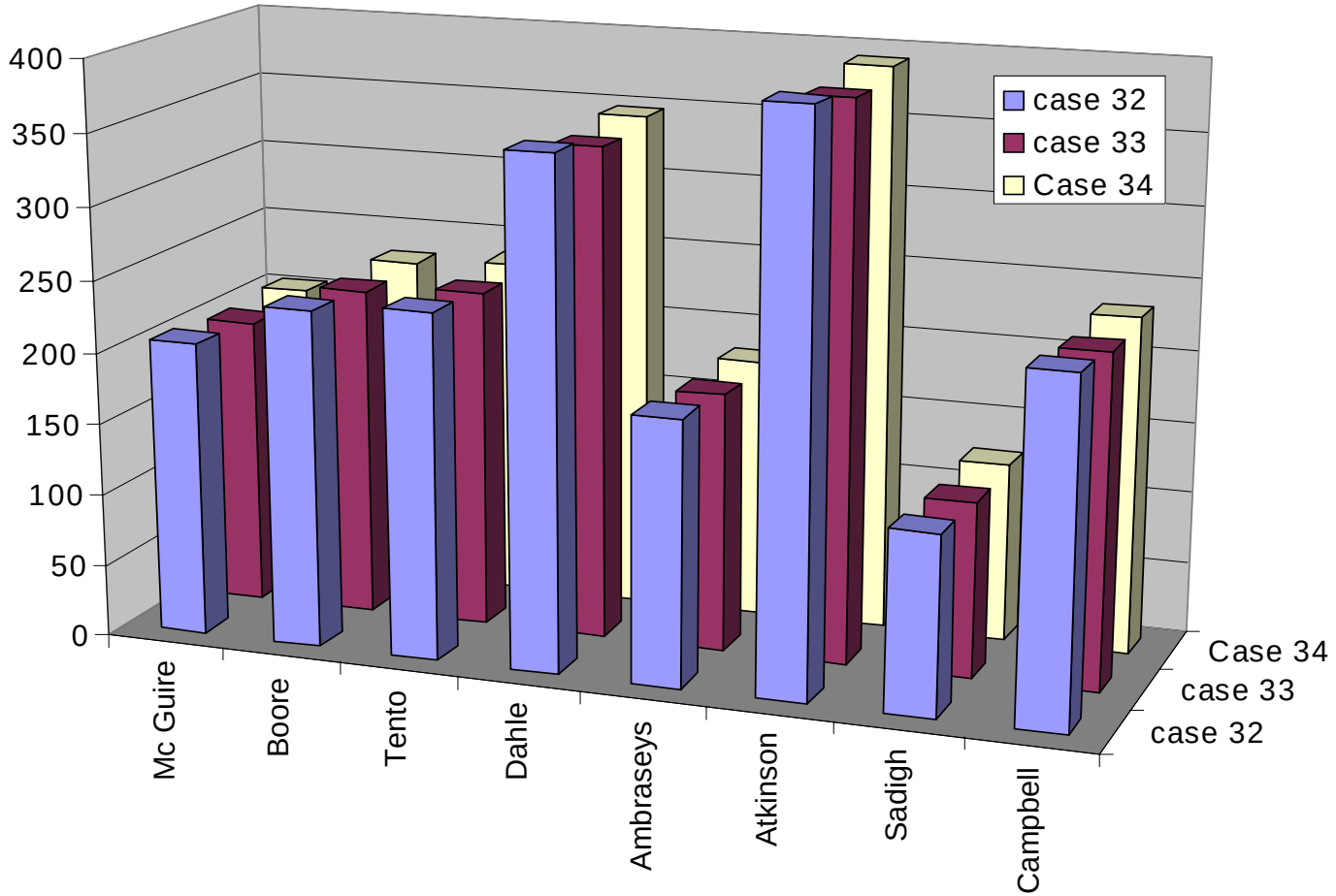
Analysis III…



Variation of acceleration corresponding to a exceedence probability of $1x10^{-4}$, source type SM2

Examination of Uncertainties…

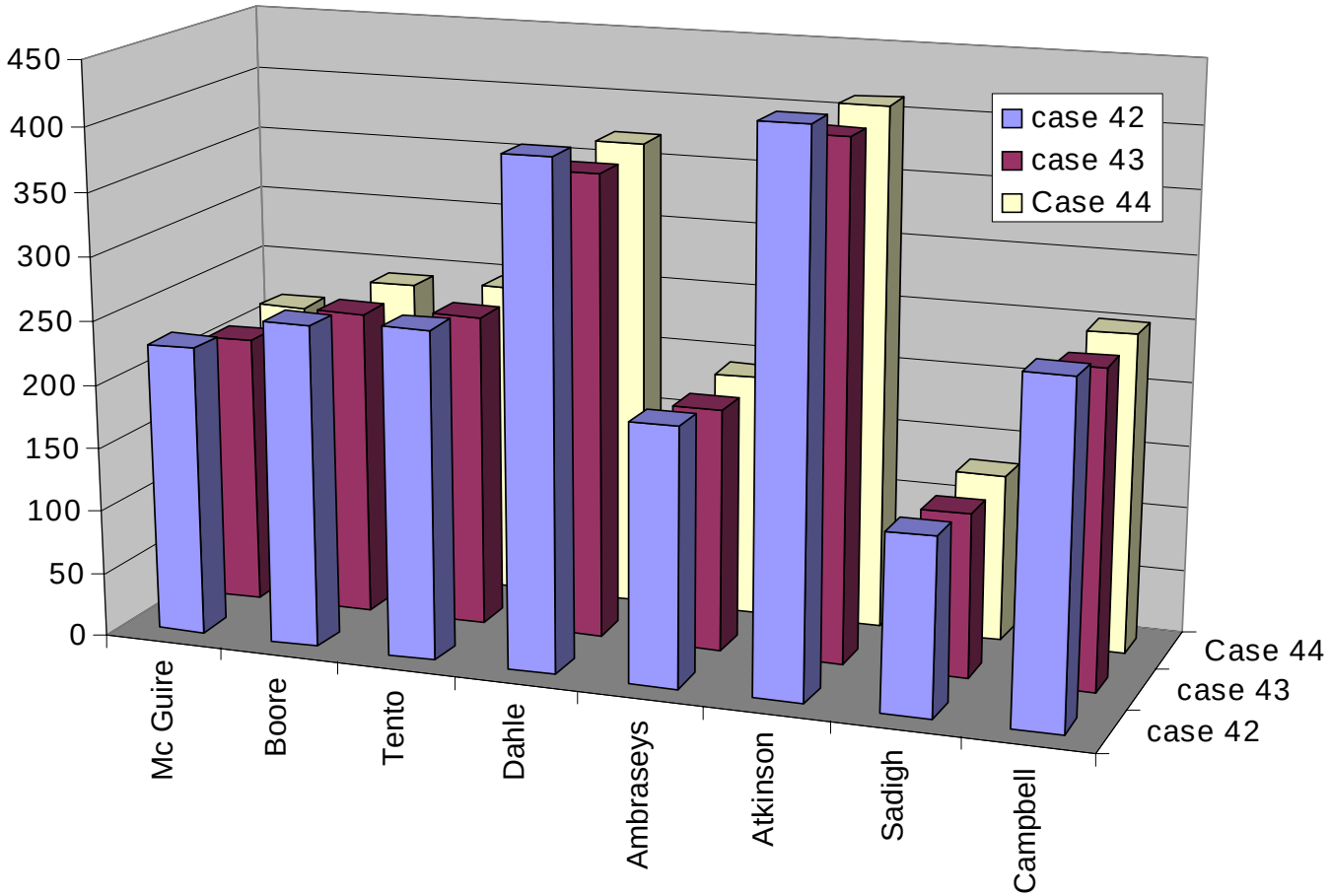
Analysis III…



Variation of acceleration corresponding to a exceedence probability of $1x10^{-4}$, source type SM3

Examination of Uncertainties…

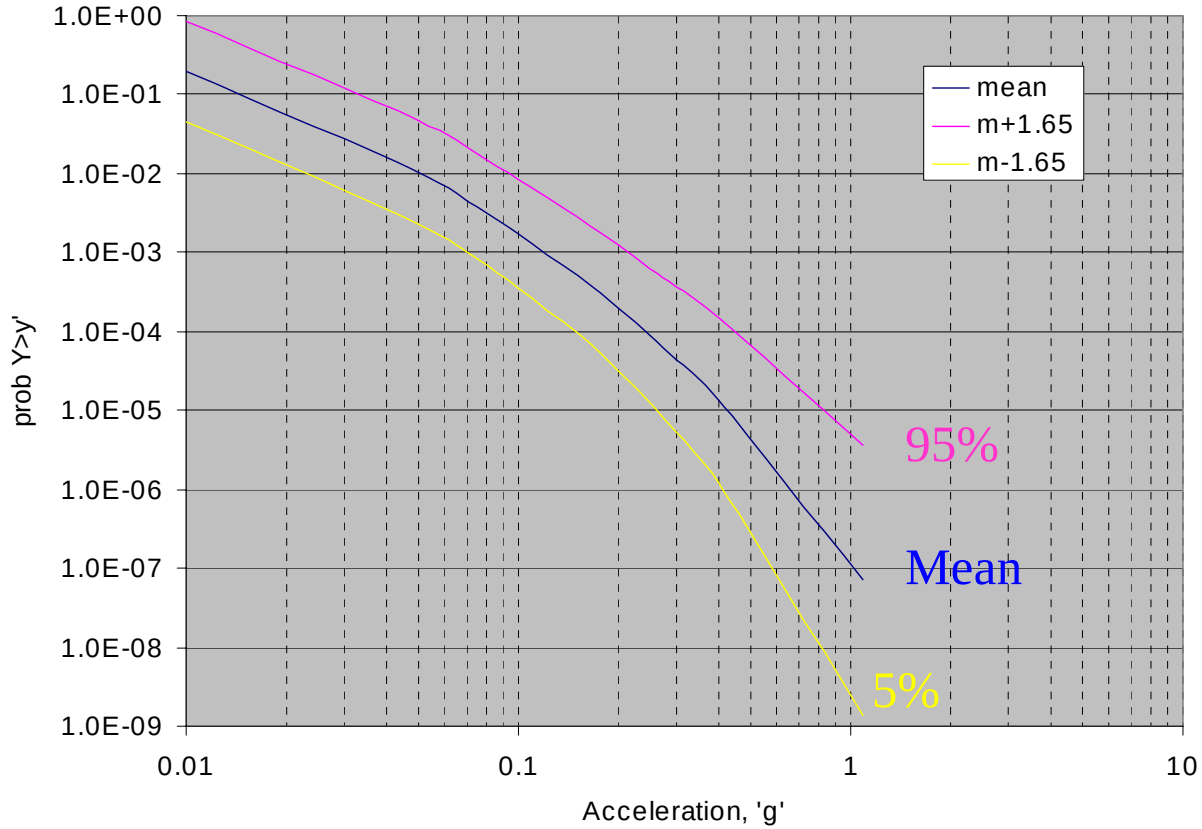
Analysis III…



Variation of acceleration corresponding to a exceedence probability of $1x10^{-4}$, source type SM4

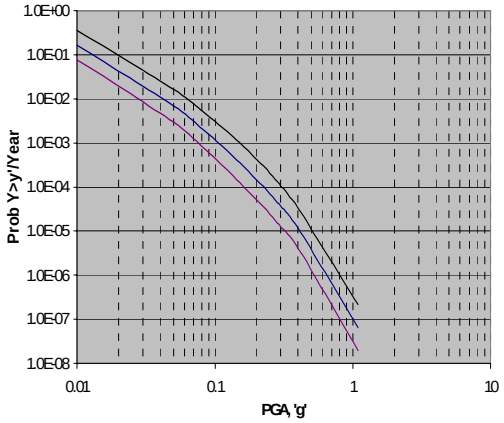
Examination of Uncertainties…

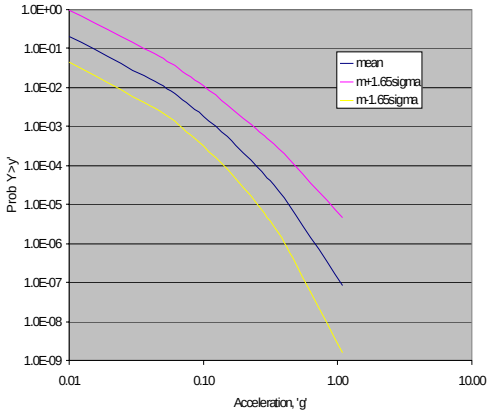
Analysis III…

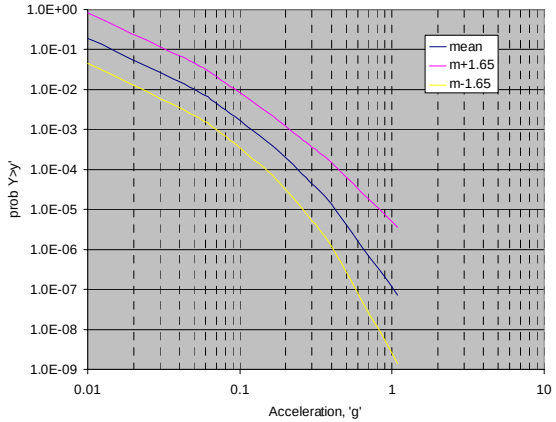


Hazard band III (3 source geometry models, SM2, SM3 & SM4; 3 combinations of a & b values, a_2b_2, a_3b_3, & a_4b_4; and 8 attenuation equations)

Examination of Uncertainties…Analysis II







Hazard bands I, II & III

Lessons learnt

- Construction of hazard band is a convenient approach to tackle epistemic uncertainties in PSHA.
- Single source geometry is not suitable
- For stable continental region like peninsular India, m_{min} may be taken as 3.0
- Attenuation relations is a large contributor to uncertainties
- Suitable attenuation relationship for stable continental region?
- Available attenuation relationships do not, in general, handle near field earthquakes

Lessons learnt…

- Appropriate guidelines are required to reduce the subjective ness in
  - Assigning m_u of a source
  - Apportioning activities among different sources, when a common database is used to derive the ‘a’ & ‘b’ value.

Summary

- Work on PSHA for Indian NPPs has been started
- Further work will be carried out with
  - Extensive checking of catalogues
  - Refining estimation of ‘a’ and ‘b’ values
  - Appropriate attenuation relationships
  - Use of alternative source area models
  - Considering alternative approaches for proportioning of activities

References

- IS 1893 (2002), Criteria for Earthquake Resistant Design of Structures, BIS, New Delhi
- AERB/SC/S, Code of Practice on Safety in Nuclear Power Plant Siting
- AERB/SG/S-11
- IAEA TECDOC 724
- Users manual, EQRISK

- E(z) is the expected number of exceedences of ground motion level z during a specified time period t (usually taken as one year),
- α is the mean rate of occurrence of earthquakes between the lower and upper bound magnitudes (m_0 & m_u) considered for the i^{th} source (=N(m_o))
- $f_1(m)$ is the probability distribution of magnitude (i.e., recurrence relationship) for the i^{th} source,
- f(r) is the probability distribution of the distance to the source for the various locations within the source i, and
- P(Z>z|m,r) is the probability that a given earthquake of magnitude m and epicentral distance r will exceed the ground motion level z.

Back