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# A REPORT OF LATEST RESEARCH PROGRESS ON THE BEYOND DESIGN BASIS DESIGN CONSIDERATIONS FOR GEN III AND IV NUCLEAR POWER PLANT

***(Part2: Regional Seismic Sources Characteristic for NPP in China)***

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## ABSTRACT

Author's SMiRT-22 paper discussed the lesson-learned from Fukushima Accident and the rethinking on the method and principles of beyond design basis design (BDB design). Author's same-title-paper published in the Proceedings of SMiRT-25 discussed "structural perspectives"; it was a complete summary of author's research and investigation of this topic regarding to the majority of structural areas in recent years. To bring the contents of above two papers together for fulfilling a comprehensive BDB seismic design based on PSHA, a "seismic source" study and "seismic design input determination" approach should be conducted and developed under the framework of PSHA. This paper takes Chinese inland NPP as a scenario and focuses on the following aspects: (1) The locations of proposed inland NPPs in China; (2) The typical types of seismic source in China; (3) The regional seismic sources characteristic by the means of PSHA method; (4) Recommended framework for PSHA for proposed inland NPPs in China.

## INTRODUCTION

### *Brief Review of NPP in China*

- *The Build*

The first Chinese NPP – "Qinshan NPP" was designed and built in early 1990s in Zhejiang province of China. Several more were added in late 1990s in Dayawan and Tianwan in Guangdong province in southern China. Figure 1 showed the current NPP locations which are in commercial operation. Figure 2 showed the proposed NPP locations pursuing the Seismic Safety Evaluation for future build.

By looking at the distribution of current in-operation NPPs in China, we found that they are all located in the coastal areas aligned with the seashore from southern China to the northern areas. The reason to choose the seashore as the NPP sites in China primarily is considering the convenience of cooling water source for operation; the other reason to use seashore as a preferred site is because of the shallow depth of bedrock, which, as we well known, is the most appropriate subsurface condition for sitting the NPP's mat foundation.


Figure 1 The current NPP locations which are in commercial operation

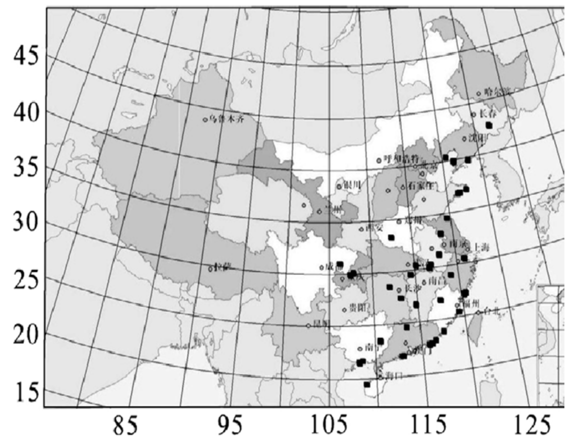



Figure 2 The proposed NPP locations pursuing seismic safety evaluation

With the economical development and the improving of people's life, the power demanding in coastal areas and great inland areas are increasing in a manner of fast-pace. To build new NPPs, fill the demand-supply-gap, and further cope with the emission issues (such as reducing the carbon footprint) in the future; inland NPPs are becoming one of the main options on the table. Inland NPP differentiated from those built by the seashore, the most challenging problems are seismic sources identification and site subsurface soil condition evaluations for determining seismic design input.

- *The Design*

(1) <u>Prevailing Seismic Design Provisions and Guidelines</u> :
As an overall, NPPs design in China basically following a framework of Deterministic Design Approach; hazard analysis and probabilistic techniques are utilized to some design processes but it is not a full integration to the whole design provisions and procedure.

(2) <u>The introducing of Probabilistic Design Approach</u> :
<u>Stage I</u>: In early 21st century, seismic fragility analysis was adopted in hazard analysis for safety-related facilities such as NPPs (2006 and later). After the happening of Fukushima Accident, most of the researches and investigations are focused on seismic margin analysis (SMA), seismic probabilistic risk analysis (SPRA) of the existing NPPs to evaluate their operability and safety (2012 – 2017 and after).
<u>Stage II</u>: Started from 2013, Probabilistic Seismic Hazard Analysis (PSHA) was introduced by Dr. Z. Shang et la., together with the new concepts of Beyond Design Basis Design (BDBD) for GEN III and III+ new NPPs.

(3) <u>Current status of PSHA research in China</u>
Just as stated previously, the introducing of PSHA method in China experiencing a relatively long period of time (stage I... and stage II right now), since in China Nuclear Power (NP) industry was formed and commencing from late1990s (the first NPP was connected to the grid in early 1990s).

Started with the study of seismic fragility analysis, Probabilistic Safety Analysis (PSA) and Probabilistic Risk Analysis (PRA) are introduced into nuclear power industry. The application of PSA and PRA are mostly focused on the studies of earthquakes engineering (seismic design). With the background of Post-Fukushima NPP's safety conditions and status evaluations, PSHA method was introduced by researchers of SNPTC-SNERDI (of SPIC). As the leading author, Dr. Shang from SNERDI published research paper on SMiRT-22 (2013) in San Francisco USA (paper entitled "CONSIDERATIONS AT BEYOND DESIGN-BASIS PHENOMENON DESIGN FOR NEW NUCLEAR POWER PLANT - Seismic and Tsunami"). This is the First paper systematically investigated the nature of BDBD regarding of beyond design basis loadings. As the result, PSHA method was recommended for performing BDBD.

By the year of 2019, Dr. Shang and his research team conducted a nine years comprehensive investigation and study on BDBD and the application of PSHA to BDBD. The results and its details were published in series of papers which have been contributed to international conferences such as SMiRT and ICONE etc.

### *The PSHA Requirements for NPP Seismic Design – Standards and Regulatory Requirements*

As we well know, among the sources of BDB loads, seismic load potentially is the most powerful impact to the whole plant with a relatively higher possibility (rate) during the operating service-life of a plant. With currently more than sixty years of designed operating service-life for new generation NPP around the world, there are numerous research / investigation literatures published in this industry and most of them become the basis of the prevailing standards and codes. The determinations of seismic loadings initially started from the early "strong earthquake concept", and then was the seismic risk / or hazard analysis approach (deterministic-based) to determine "maximum earthquake" for design input.

PSHA approach was developed in U.S. in 1990s. Started from Hazard Analysis, this method (also called conventional PSHA) was established based on LLNL & EPRI Data Base, the Seismic Hazard Curve (SHC) is the main outcome at the early stage. The publishing of RG 1.165 marked the new stage of PSHA advancement, of which Reference Probability Method was used to describe the hazard in a consistent way, new attenuation models and complete (full) PSHA procedure was developed; the outcomes from RG 1.165 were "Controlling Earthquake" and SSE GMRS (site-specific). The latest RG 1.208 which was published in 2007 marked the latest stage of PSHA development, in which the performance-goal-based technique was utilized to achieve a level of "risk-consistent", and this is very useful for design practice.

ASCE43-05 is the first industry Code which was developed based on RG1.165 and RG1.208, and incorporates performance-goal-based PSHA method in structural seismic analysis and design. Here performance goal is set forth to ensure that all structural failure risks are informed in a consistent way (risk-informed and risk-consistent).

## DISTRIBUTION OF SEISMIC SOURCE IN CHINA

### *Seismic Zone and Event*

Figure 3 showed the distribution of major seismic zones in China. As an overall the seismic zones and its distributions exhibit tectonic faults in the earth crust which are related to the continental tectonic movements along the major mountain areas in the Northern, North-western and South-western China. There are also some major seismic zones and faults along the coastal line in the South and East of China; but there is no considerable faults resulting from volcanic activities (earthquakes) and big collapse of deep bedrock layers.

According to the data showed in Figure 4, earthquakes which occurred with the magnitude severity greater than 8.0 (Richter M8.0) are very infrequent in the earthquake history in China. The few observed occurrences ($M \geqq 8.0$) are located in several limited regions such as Tibet Plateau, northwest area of Xinjiang Province, Ningxia Province and Taiwan region. Also based on Figure 4, about three-out-of-five (3/5) the areas of China have experienced earthquakes in history with the magnitude severity between M7.0 – M7.9; this magnitude range is the typical category usually defined as "strong earthquake" in seismic design practices and the building codes could cover it with a relatively high confidence to avoid collapse-type failure. Large areas in the heart-land (Shanxi Province), the southern part, eastern part along the long coastline and the most northern part are those areas with moderate or "quasi-strong" seismic activities. According to the results shown in Figure 1, most of the currently operating NPPs are located in eastern part along the coastline. Further, based on the statistical analysis, the recorded earthquake events shown in Figure 4 are well agreed with the fault distributions shown in Figure 3.

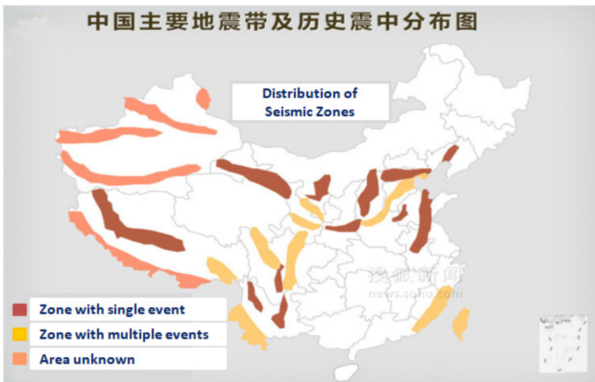



Figure 3 National Seismological Survey & Records of the Distributions of Seismic Zones in China

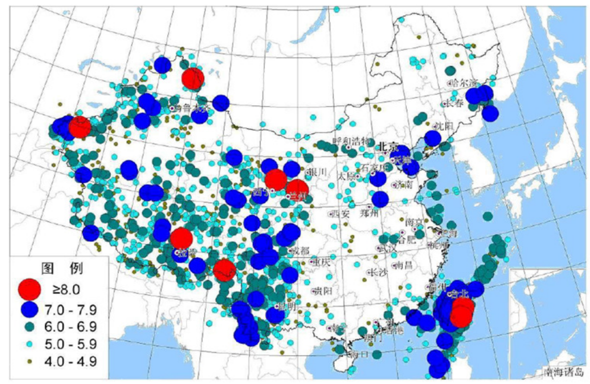



Figure 4 National Seismological Survey & Records of Earthquake Events and Locations

***Earthquake Strong Motion Distribution***

Figure 5 and Figure 6 showed the distributions of strong-motion earthquake sources in Northeast China; data collected and recorded are from early centuries of B.C. to 2010 A.D. (the most recent). From Figure 5 and Figure 6, the great areas of Huabei Plain and Bohai (the inner sea) have experienced strong earthquakes with recorded ground motion (at the source) as high as M8.9. The city of Beijing (the Capital City), Zhengzhou and Jinan (both are province capital city) are located in the close distance to strong motion seismic sources; the Jiaodong peninsula area in Shandong Province is in close distance to strong motion seismic sources in the Bohai inner sea. The very first AP1000 (2 units for stage I currently in operation) locates in Haiyang city in south Jiaodong peninsula; several more units will be added in stage II and III. Two CAP1400 (GuoHe Reactor No.1) units are currently under construction in Rongcheng which is located in the east end of Jiaodong peninsula.

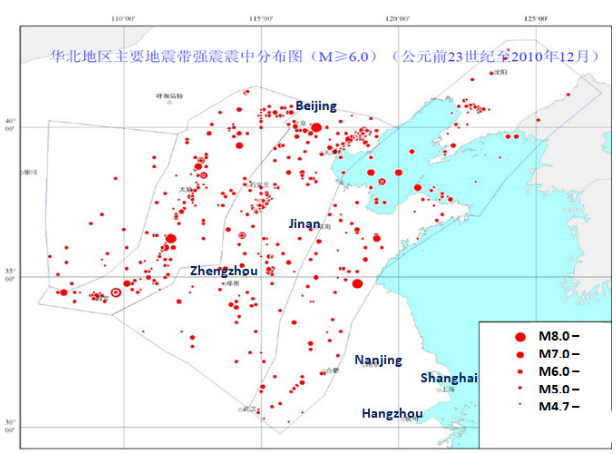



Figure 5 Distribution of strong-motion earthquake sources in Northeast China

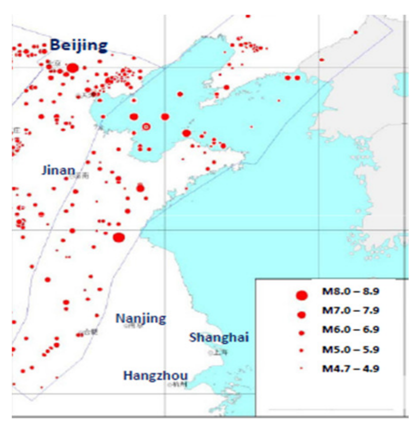



Figure 6 Distribution of strong-motion earthquake sources in Bohai inner sea & Jiaodong peninsula

***The Typical Types of Seismic Source***

- *The Identification of Earthquake Distances*

Earthquake distance for design purpose means "source-to-site-distance", this definition has three tiers of meaning and application from engineering point of view:

(1) Generic description: It is the distance from earthquake source to the plant site of interest.

(2) Epicenter Distance: Is projected ground distance to the site;
Hypocenter Distance: Is actual distance from source to the site.
Both consider the location of rupture initiation only.

(3) The choosing of distance for design will depend upon the required information for analysis, which serves as the input to the ground-motion-prediction-model.

- *Area Source*

Area sources are often used in practices to account for "background" seismicity, or for earthquakes that are not associated with any specific faults. It is assumed that the area source produces earthquakes randomly and with equal likelihood anywhere within 100 Km of the site. In reality, the area source may be larger in dimension, but typically it will be truncated at certain distance, since beyond it earthquakes are not expected to cause damage at the site.

- *Line Source*

For practical purpose, many near or mid-range seismic sources could be taken as two-dimensional source that is to say "line source" to facilitate the evaluation of source distance distribution model. Following Figure 7 gives schematics on the method to calculate the possibility of observing a earthquake with distance (R) less than a certain value of "r"; as we know this is one of the baseline input information when we use PSHA approach to determine the controlling earthquake(s) for new generation NPP seismic design.

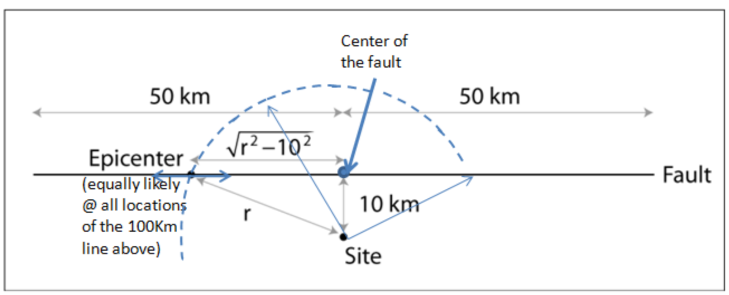



Figure 7 Simplified Line Source Model

Terminology and Equation:

P(R<r) - denote possibility.
$F_R(r)$ - cumulative distribution functions (CDF) of R.
The complete equation for $F_R(r)$ is:

$$F_R(r) = \begin{cases} 0 & \text{if } r < 10 \\ \dfrac{2\sqrt{r^2-10^2}}{100} & \text{if } 10 \le r < 51 \\ 1 & \text{if } r \ge 51 \end{cases} \tag{1}$$

Seismic event sources which can be modelled as Line-Source:

(1) Those faults that exist on the boundary of two tectonic plates

(2) Those faults that can be easily simplified as two-dimensional (a line)

(3) It is also common to treat the earth's structure in three dimensions, meaning that faults will be represented as planes rather than lines.

## THE REGIONAL SEISMIC SOURCES CHARACTERISTIC BY THE MEANS OF PSHA METHOD

### *The Nature and Roles of Ground Motion Intensity (GMI) Distribution*

The engineering purpose of seismic source characteristic is to build a reliable relationship (model) between the event sources and the resulting ground motion intensity in the considered plant site. Following aspects are a summary of the nature and roles of GMI:

- GMI distribution is the most important factor which quantifies the ground motions of targeted sources (earthquakes) for design use purpose.
- Probability distribution of GMI models are function of many predictors: such as magnitude, distance, faulting mechanism, the near-surface site conditions, directivity effects etc.
- Among many other predictor variables, magnitude and distance are taken as the most commonly used factors for predicting ground motions.
- Ground motion prediction models are generally developed using statistical regression on observations from large libraries of observed GMI data.
- One thing need to be mentioned is that "Ground Motion Prediction Model" is replaced with "Attenuation Model" in recent years.

### *Example GMI Prediction Models (Attenuation Models)*

- Basic prediction models recommended by researchers

(1) General form

$$\underbrace{\ln IM}_{(1)} = \underbrace{\overline{\ln IM}(M,R,\theta)}_{(2)} + \underbrace{\sigma(M,R,\theta)}_{(3)} \cdot \underbrace{\varepsilon}_{(4)} \tag{2}$$

Where:

(1): The natural log of the "intensity measure" (i.e. SA, PGA at a given period)
(2): mean value, it is the output element of the model "In IM"
(3): standard deviation, it is the output element of the model "In IM"
(4): standard normal random variable for "In IM"; can be positive and negative

(2) Cornell et al. model (1979)

Over decades of development and refinement, the prediction models for ln IM(M,R,θ ) and σ (M,R,θ ) have become complex, consisting of many terms and tables containing dozens of coefficients. These modern models are no longer simple to calculate using pencil and paper, so here we will illustrate how to use an older and much simpler model to do calculations. The approach is identical when using modern prediction models, but this simple model keeps us from being distracted by tedious arithmetic.

Cornell et al. (1979) proposed the following predictive model:

$$\overline{\ln PGA} = -0.152 + 0.859M - 1.803\ln(R+25) \tag{3}$$

This is the mean of log peak ground acceleration (in unit of g); normally distributed

$$\sigma_{\ln PGA} \equiv \mathbf{0.57} \text{ (The standard deviation of lnPGA)} \tag{4}$$

It is constant 0.57 for all magnitudes and distances

Compute the probability of exceeding any PGA level

$$P(PGA > x \mid m, r) = 1 - \Phi\left(\frac{\ln x - \overline{\ln PGA}}{\sigma_{\ln PGA}}\right) \qquad (5)$$

Where, Φ（ ）is the standard normal cumulative distribution function (CDF).
NOTE: Modern prediction models also provide a mean and standard deviation to be used in previous equation; so the general procedure is identical when using newer models; the equations for predicting the mean and standard deviation are just more complicated.

(3) Other updated modern models (after 2005)

Ground motion prediction models are generally developed using statistical regression on observations from large libraries of observed ground motion intensities. For example, spectral acceleration (SA) values at 1 second observed in the 1999 Chi-Chi, Taiwan, earthquake were shown here in Figure 8, along with lines showing the predicted mean (and mean +/- one standard deviation) of the lnSA values from an example ground motion prediction model. This prediction model, like other modern models, was fit to thousands of observed intensities from dozens of past earthquakes.

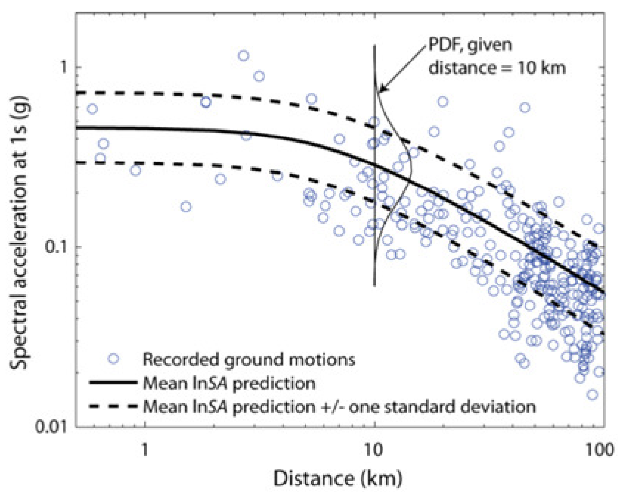



Figure 8 Observed spectral acceleration values from the 1999 Chi-Chi Taiwan earthquake

This figure illustrates variability in ground motion intensity; the predicted distribution comes from the model of Campbell and Bozorgnia (2008).

(4) Summary of Cornell model for analytical computations

- Cornell et al. model is simplified concise model just takes **magnitude and distance distributions** into account. Per calculation verifications, the over-simplification on large variability and incorporation of observational data are appropriate for establishing prediction models in the following methodological framework, especially when seismic source information and observational data accumulated are not adequate enough for performing even complex and advanced analysis.
- Magnitude is used to cover earthquake rupture (which is a complex spatial temporal process releasing seismic energy); Distance here is used to cover seismic non-linear wave scattering and propagation through the crust of earth (which is also a complex structure).

# RECOMMENDED FRAMEWORK FOR PSHA FOR PROPOSED IN-LAND NPPS IN CHINA

## *Multi-Source PSHA Established for Chinese NPP – "CHN-PSHA" NPP Framework*

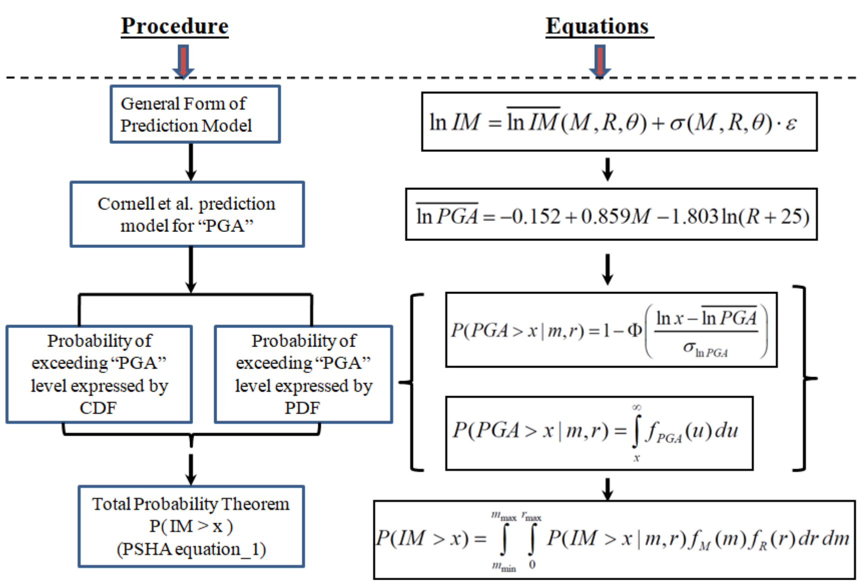
Succeeded the summaries in above section for Cornell model, the "CHN-PSHA" framework essentially is based on Cornell modelling approach with the consideration of needs for BDB seismic design. Stated in other words, current proposed method-framework is intended to predict highly complex events by the way of simplified parameters such as "magnitude (distribution)" and "distance (distribution)" etc. The basis of following proposed prediction equations has evolved over a period of 40 years, and has already calibrated based on thousands of observation data (ground motions); also with the integration and incorporation of many theoretical and physical insights. One thing to be noticed is that current proposed prediction models are applied with the fact that more uncertainties have to be considered to calibrate prediction model in the upcoming investigations and research for "CHN-PSHA" framework.

## *Description of Framework Basis*

- PSHA procedure is fundamentally based on observed data, also integrated through the utilization of scientific studies and simulations.
- The most useful result is – "the rate of exceeding IM (Intensity Measurement) levels of varying intensity", which is the basis for engineering decision making.
- PSHA results also provide window through which "rare intensities" (low-exceedence-rate) could be determined by direct observations.
- A typical PSHA procedure has integrated the knowledge bellow:
  (1) Rates of occurrence of earthquake
  (2) The possible magnitudes & distances
  (3) Distribution of ground shaking intensity
- The Tools for integration: Statistics, Accounting, Regression Analysis, Variability Analysis, Data Simulations were utilized.

## *"CHN-PSHA" Procedure and Equations (Recommended)*

***PART I*** : The Probability of (IM > x )




Where,

$P(IM > x)$ | : Total probability of occurrence.

$f_M(m)$, $f_R(r)$ | : are PDFs for magnitude and distance.

$\int_{m_{\min}}^{m_{\max}}\int_0^{r_{\max}}$ | : are the integrations of all possible magnitudes and distances.

***PART II*** : The rate of (IM > x ) – from one source

**Procedure** | **Equations**

Total Rate Theorem
λ( IM > x )
(PSHA equation_**2**)

$$\lambda(IM > x) = \lambda(M > m_{\min}) \int_{m_{\min}}^{m_{\max}} \int_{0}^{r_{\max}} P(IM > x \mid m, r) f_M(m) f_R(r)\, dr\, dm$$

Where,

$\lambda(IM > x)$ | : the occurrence of earthquakes greater than designated Levels *( i.e. 0.1g  0.2g  0.5g ... 1.0g)*

$\lambda(M > m_{\min})$ | : is the rate of feasible earthquakes which are greater than $m_{\min}$

$\int_{m_{\min}}^{m_{\max}} \int_{0}^{r_{\max}} P(IM > x \mid m, r) f_M(m) f_R(r)\, dr\, dm$ | : integrations of all possible magnitudes and distances

***PART III*** : The rate of (IM > x ) – from multiple sources

**Procedure** | **Equations**

Total Rate Theorem
λ( *IM* > *x* )
(PSHA equation_**3**)

$$\lambda(IM > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{\min}) \int_{m_{\min}}^{m_{\max}} \int_{0}^{r_{\max}} P(IM > x \mid m, r) f_{M_i}(m) f_{R_i}(r)\, dr\, dm$$

Rate of IM > x when considering all sources is simply the sum of the rates of IM > x from each individual source.

Where,

$\sum_{i=1}^{n_{sources}} \lambda(M_i > m_{\min})$ | : the summation of all sources

$n_{sources}$ | : the total number of sources under consideration

$M_i / R_i$ | : denote the magnitude / distance distributions from source i

For refine calculation a joint distribution $f_{M,R}(m, r)$ should be used ; $f_M(m)\, f_R(r)$ is the product of their marginal distance

$f_{M,R}(m, r) = f_M(m) \times f_R(r)$ only when m and r are independent

***PART IV***: The application of discretization technique

**Procedure** | **Equations**

Total Rate Theorem
λ( *IM* > *x* )
(PSHA equation_**4**)

$$\lambda(IM > x) = \sum_{i=1}^{n_{sources}} \lambda(M_i > m_{\min}) \times \sum_{j=1}^{n_M} \sum_{k=1}^{n_R} P(IM > x \mid m_j, r_k) P(M_i = m_j) P(R_i = r_k)$$

Where,

$n_{sources}$ | : the total number of sources under consideration, start from source(1) to … source(i ). **i** denotes source number here.

$n_M$ | : the discretized $n^{th}$ intervals of possible Mi -distribution of source(i ) $n_M$ start from Mi - interval(1) to Mi - interval( j ). **j** denotes Mi interval number here.

$n_R$ | : the discretized $n^{th}$ intervals of possible Ri -distribution of source(i ) $n_R$ start from Ri - interval(1) to Ri - interval( k ). **k** denotes Ri interval number here.

$M_i$ | : possible range of Magnitude ($m_{min} \sim m_{max}$)

$R_i$ | : possible range of Distance

***The Integration of PSHA with BDB Design for New NPPs in China***

- The problems arising from the application of DSHA to BDB Design

(1) The approach of DSHA
The fundamental approach of DSHA is to consider earthquake hazard in a way of "worse-case scenario", with which the uncertainty (variability) of earthquake design inputs are simplified as convenient criteria such as maximum magnitude and closest fault distance; therefore the design basis can be deterministically selected from existing database.

(2) The problems arising from the application of DSHA
(i) Regarding of period
Considering vibration periods, there is no a single "worse-case" that can always envelope the spectra and thus to be selected as the real maximum "Sa" for all periods' range (e.g. small-magnitude @ short periods, large-magnitude @ long periods can both lead to large spectra acceleration - Sa). That means the selected "worse-case" probably is not the true One.
(ii) Regarding of fault distance
Location of near-site faults have to be quantified as areal source; so in this case the worse-case event has to be the one with the maximum conceivable magnitude – at the location directly below the site of interest (i.e. the fault distance = 0), this is clearly the maximum event no matter how unlikely its occurrence might be.
(iii) Regarding of variability of "ground motion intensity"
The concept of "worse-case scenario" of a earthquake event can be further specifically classified as the "worse-case earthquake" and its resulting "worse-case ground motion"; but worse-case earthquake from a source not necessarily resulting in worse-case ground motion in a certain site (selected site for NPPs).

- The advantages of PSHA

(1) PSHA accounts for seismic source uncertainty by the use of multiple alternative source models.
(2) PSHA method can create a comprehensive new computational environment, in which the subsequent "worse-case earthquake" can be probabilistically redefined as "control earthquake(s)" to ensure, through this way, the annual exceeding rate will objectively below a fairly low level.
(3) The essential part of PSHA is De-aggregation of Mean Hazard Curve: the de-aggregation provides a channel to look into (insight) the seismic source, and determine the controlling earthquakes (i.e. magnitude and distance).
(4) The outcomes of PSHA are (i) full distributions of levels of ground motion intensity, (ii) The associated rates of exceedance (such as probability of occurrence / rate of occurrence / return period

- Application of "CHN-PSHA" to inland GEN III & IV NPPs in China
  The application of "CHN-PSHA" to inland NPP design-analysis in China not only improve the seismic safety level in a fundamental manner but also open a new stage for nuclear power in clean energy industry in this country. Follows are some sparkles of application serving as the hints for future:

(1) The lower the PGA threshold level, the higher the probability of exceeding the threshold.
(2) The choice of the minimum considered earthquake can be important in some cases; such as $m_{min}$ maybe have non-zero probability of causing PGA greater than a selected level of interest.
(3) Small-magnitude earthquakes have considerable probability of causing PGA greater than smaller-levels; meanwhile moderate/large-magnitude earthquakes have the highest probability of causing PGA greater than median to large-levels that the design selected.
(4) Intuitively, we can imagine that the PSHA output information would be useful for identifying the earthquake scenarios which is most likely to damage a structure at the site of interest.
(5) Normally PSHA is performed using computer software in all practical analysis cases for the following reasons: (i) Many earthquake sources and distances / or likely hood, (ii) when using "modern ground motion prediction models" , (iii) when use finer magnitude and / or distance interval (spacing) in the discretization process.

## CONCLUSION

Through the application of PSHA method, the regional seismic sources (with records) were investigated and analyzed to determine "controlling earthquakes" for using as the seismic design input information for inland NPPs in China. The general background, framework, specific procedures and models were established to describe the characteristics of the "controlling earthquake sources"; the analysis results and outputs serve as the basis to develop design response spectrum (DRS) in the way of probabilistic. Such DRS subsequently can be used for geotechnical and structural design.

## REFERENCES

Shang, Z., Zhu, J. and Zheng, M. (2013). "CONSIDERATIONS AT BEYOND DESIGN-BASIS PHENOMENON DESIGN FOR NEW NUCLEAR POWER PLANT - Seismic and Tsunami", SMiRT22, San Francisco, USA

Shang, Z., Huang, X., Chu, M., Zhang, L., Wu, C. and Chang, C. (2016), "THE APPLICATION OF PSHA METHOD IN THE DETERMINATION OF BEYOND DESIGN BASIS EARTHQUAKE FOR NEW NPP DESIGN", ICONE24, Charlotte, USA

Shang, Z., Sun, Y., Gou, H., Zhang L., Chu M., and Ge, H. (2017) "DETERMINATION OF DESIGN GROUND MOTION FOR POTENTIAL GEN III & PLUS PLANTS IN CHINA - A Regulatory Level Review", ICONE25, Shanghai, China

Shang, Z., Sun, Y., Huang X,, Gou, H., Chang C,. Han, B., and Wu, C. (2019)"A REPORT OF LATEST RESEARCH PROGRESS ON THE BEYOND DESIGN BASIS DESIGN CONSIDERATIONS FOR GEN III & IV NUCLEAR POWER PLANT - Review of Structural Perspectives" SMiRT25, Charlotte, USA