APPLICATION OF THE KERNEL METHOD FOR THE SEISMIC HAZARD ASSESSMENT OF A NEW NUCLEAR SITE IN THE UK, WYLFA NEWYDD

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Abstract

The United Kingdom (UK) is a region of low-to-moderate seismicity where seismic design is only required for strategic facilities such as nuclear power plants [4]. Arup, appointed by Horizon Nuclear Power, carried out a seismic hazard assessment for the Wylfa Newydd site, which included capable fault assessment, tsunami hazard, probabilistic seismic hazard assessment (PSHA). The seismic source characterization logic tree adopted in the PSHA included five area source models which were developed based on the observed seismicity, geological and tectonic data and previous seismic hazard studies at the site. The IAEA [1,2] and ONR [3], allow the use of non-uniform distributions of seismicity, if supported by available data. Therefore, zoneless approaches such as those proposed by Frankel [5] and Woo [6] are also acceptable. This paper presents the implementation of the kernel method for the Wylfa Newydd site. Although not included in the main PSHA, the kernel method (Woo [6]) was adopted as part of a range of sensitivity studies. The kernel parameters were computed based on the Wylfa Newydd earthquake catalogue and compared with those from previous studies. A logic tree approach was developed to model the epistemic uncertainty in the definition of the computational parameters, such as the calculation of the kernel (finite or infinite) and the treatment of the seismicity (through rates or Gutenberg-Richter, GR). The results from the kernel method were compared with those obtained from the Wylfa Newydd PSHA.

Keywords: PSHA; Kernel Method; Nuclear Power Plant

1. Introduction

The United Kingdom (UK) is a region of low to moderate seismicity and a probabilistic seismic hazard assessment (PSHA) is mandatory only for strategic facilities such as nuclear power plants (BS PD 6698 [4]). Ove Arup and Partners Ltd. (Arup), supported by the British Geological Survey (BGS), was appointed by Horizon Nuclear Power to provide seismic hazard assessment consultancy services for the proposed Wylfa Newydd Nuclear Power Plant on the Isle of Anglesey, North Wales. Horizon aimed to construct Advanced Boiling Water Reactors to provide at least 5,400MW, enough to power around 10 million homes. The assessment comprised a PSHA of ground motion, a tsunami hazard assessment and a capable faulting assessment (Lubkowski et al. [7]).

The PSHA for Wylfa Newydd was carried out at a bedrock horizon with a V_S of 3,000 m/s, which corresponds approximately to a depth between 80-100 m. The process involved adapting aspects of the SSHAC process (Buidnitz et al., [8]) through careful considerations of issues and continuous interaction with independent reviewers and subject of matter experts with the final aim of capturing the centre, body and range of the technical defensible interpretations. The study is documented in Villani et al. [9]. Based on the observed seismicity, the geology and tectonic of the region and the review of previous studies at the site, two main source models were developed: SM1 mainly driven by the observed seismicity and SM2 guided by the geology and tectonics. To capture epistemic uncertainty, variations of boundaries were included in the logic tree, resulting in five different models. All the seismic models consisted of only area sources. However, the IAEA [1,2] and ONR [3] allow the use of non-uniform distributions of seismicity, if supported by available data. Therefore, zoneless approaches such as those proposed by Frankel [5] and Woo [6] are also acceptable. In the Wylfa Newydd PSHA, the kernel method of Woo [6] was adopted as part of the sensitivity studies. In this paper the seismic hazard at Wylfa Newydd is computed through the kernel approach and the results compared with those obtained for Wylfa Newydd PSHA (Villani et al., [9]).

2. Theoretical Background of the Kernel Method

Woo [6] proposed an approach to define the seismic source model entirely based on the distribution of the seismicity. Referring to the original paper of Woo [6] for the details of the method, herein the main equations are summarised. Starting from the distribution of earthquake epicentres within a region, the kernel method defines the number of earthquakes per unit area. Woo [6] proposed that from a catalogue of N historical epicentres xi of magnitude M associated with an observation time $T(x_i)$, the mean activity rate is:

$$\lambda(M,x) = \sum_{i=1}^{N} K(M, x - x_i)/T(x_i) \quad (1)$$

Where K(M, x) is the kernel which is a multi variate probability density function. Different kernel functions and different assumptions can be adopted in the definition of the smoothing parameter, which can lead to different PSHA results.

In this paper, we explore two options:

1. Infinite kernel as defined by:

$$K(r) = \frac{a-1}{\pi} h(M)^{-2} \left(1 + \frac{r^2}{h(M)^2}\right)^{-a} \quad (2)$$

Where r is a separation distance between the earthquake epicentre and the grid point and h(M) is a magnitude dependent bandwidth parameter:

$$h(M) = H \exp(kM) \quad (3)$$

In the above equation, H and k are based on the spatial distribution of earthquake epicentres. These are calculated by forming various magnitude bins and for each earthquake event within the bin, the distance to the nearest epicentre is determined. The mean nearest distance for each bin is obtained and through a least-square fit between the magnitude and nearest event distance, the parameters H and k are computed.

2. Finite kernel. In this case the kernel function is defined as:

$$K(r) = \begin{cases} \frac{1}{R_{\min}} & r < R_{min} \\ \frac{1}{2\pi(R_{max}-0.5R_{min})} \times \frac{1}{r} & R_{min} \leq r < R_{max} \\ 0 & r \geq R_{max} \end{cases} \quad (4)$$

Where R_{min} and R_{max} are two distance values defined based on the catalogue. Therefore, contrarily of the infinite kernel, in the finite case the activity rate at a distance from the epicentre of an earthquake greater than R_{max} is 0.

3. Application to Wylfa Newydd

3.1 Computation of the earthquake recurrence rates

The earthquake catalogue of the Wylfa Newydd PSHA documented in Villani et al. [9] is adopted to compute the rates from the kernel approach. The catalogue includes earthquakes within 300 km of the Wylfa Newydd site above local magnitude M_L of 2.0 between 1500 and June 2015. The processing of the catalogue (fore and aftershocks removal, magnitude conversion, completeness thresholds, depth distribution) is described in Villani et al. [9]. For ease of reference, Fig. 1 shows the dataset including fore and aftershocks and their location uncertainty as well as the location of Wylfa Newydd.

In the case of infinite kernel, Fig. 2 and Fig. 3 show the definition of the bandwidth as defined in equation (3) and kernel function (equation 2) respectively. These are compared with the kernel function defined by Seismic Hazard Working Party (SHWP) [11] and by Goda et al. [10]. The regression, performed using equation (3), was based on (a) the average of the data in each bin (black squares in the figure) and (b) all the data (grey circles). The differences between the two types of regressions is small, as it was also found by Goda et al. [10] green and red dashed curves. The results from Goda et al. [10] and this study are similar but largely differ from the assumptions in SHWP [11], blue curve. The larger kernel adopted in SHWP [11] would lead to much higher hazard, but it is not supported by the UK current catalogue. In this study, the infinite kernel was implemented using the coefficients obtained from the average points, solid black line in Fig. 2. It is noted that the results are dependent on the minimum magnitude of the earthquake catalogue (herein a value of $2M_W$ was assumed consistently with the magnitude recurrence calculations) and on the magnitude bin (here a value of $0.25M_W$ was used).

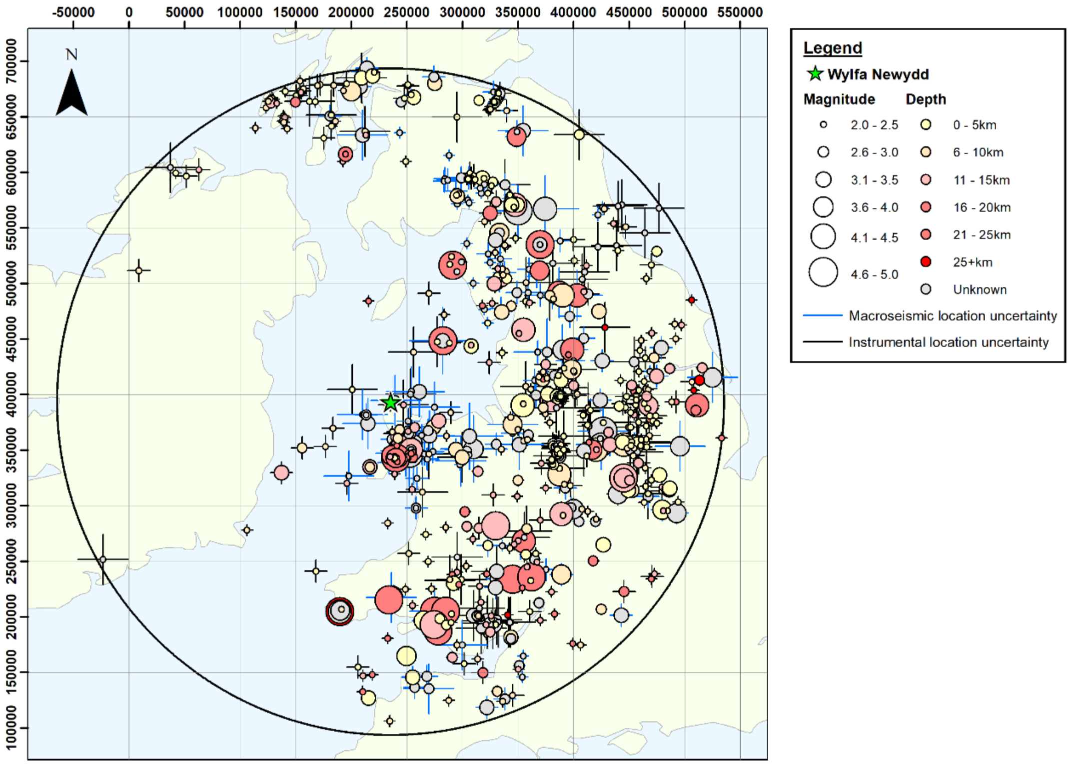

Fig. 1 Earthquake Catalogue for Wylfa Newydd PSHA. The circle shows a 300 km radius from the site (green star). From [9].

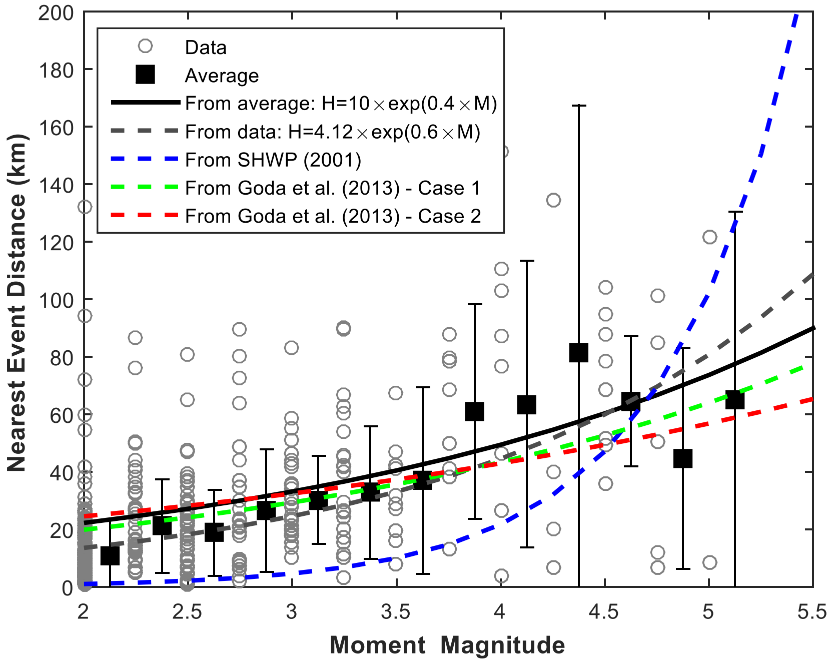

Fig. 2 – Nearest Event Distance Obtained Using the Wylfa Earthquake Catalogue and Comparison with Other Studies.

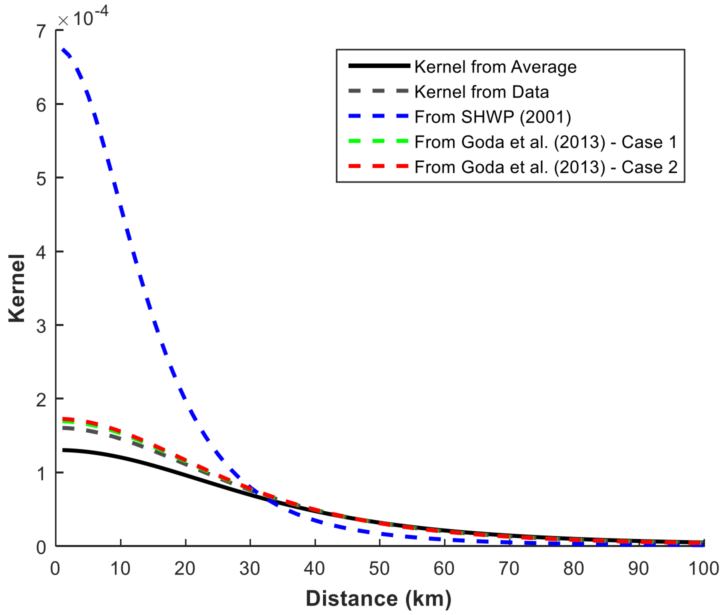

Fig. 3 – Infinite kernel function from the Wylfa earthquake catalogue compared with previous studies.

In the case of finite kernel, R_{min} in equation (4) is assumed equal to 5 km and R_{max} is defined as the average distance of the nearest neighbour analysis for the Wylfa catalogue. For an area of 100 km around Wylfa the nearest neighbour analysis provides an average value of 25 km. In this PSHA, a conservative value of 30 km has assumed for R_{max}.

The annual numbers of earthquakes for each magnitude bin is computed at each point of a grid (a spacing of 0.1 degree has been here assumed) with both approach 1, the infinite kernel and approach 2, the finite kernel, using the original code provided by Dr. Gordon Woo. Fig. 4 shows the annual number of earthquakes for magnitude greater than or equal to 4.0 (top panels) and to 5.0 (bottom) for the assumption of infinite (left) and finite (right) kernel function. The infinite kernel function provides lower rates; however, the distance of influence is much larger. In the finite case, although the absolute value of some points of the grid are much higher than in the infinite case, for distances greater than 30 km from the epicentres of the earthquakes the grid points display rates equal to 0, in agreement with Equation (4). A minimum magnitude, M_{min}, of 4 is assumed in the code.

However, in the Wylfa catalogue the maximum observed magnitude is 5.0, while in the Wylfa PSHA a best estimate maximum value of 6.5 was assumed. To be consistent with the Wylfa PSHA and avoid an underestimation of the hazard with the kernel approach, in this study two options are explored and represented in Fig. 5 for two cells of the grid, one in Anglesey, an area of low seismicity where the site lies, and one in the Lleyn Peninsula, where most of the seismicity is located:

a) "Gutenberg – Richter, GR" option (blue lines in Fig. 5). For each cell, the magnitude recurrence is represented by a Gutenberg Richter relationship: the b-value is assumed equal to the b-value obtained from the entire catalogue (1.026) in Fig. 1 while the annual activity rate for M_{min}, $\nu_{Mmin}=\nu(M\geq M_{min})$ plots as blue circles in Fig. 5, is computed directly from the rates of the kernel code as the sum of the incremental rates for each magnitude bin. The M_{max} of the Gutenberg – Richter is assumed equal to 6.5.

b) "Rates" option. For each cell the magnitude recurrence is represented directly by the individual cumulative rates (red squares in Fig. 5). To compensate for the absence of earthquakes with magnitude larger than 6 in the catalogue, fictitious rates are added. These are computed from the Gutenberg – Richter of the entire Wylfa catalogue scaled to the cell area:

$$\upsilon_{cell,M\geq Mx} = \upsilon_{cat,M\geq Mx}\frac{A_{cell}}{A_{tot}} \quad (5)$$

Where M_x is 6.0, 6.25 and 6.5, $\nu_{cat,M\geq Mx}$, is the rate of the entire study area, A_{tot} and A_{cell} is the area of the single cell.

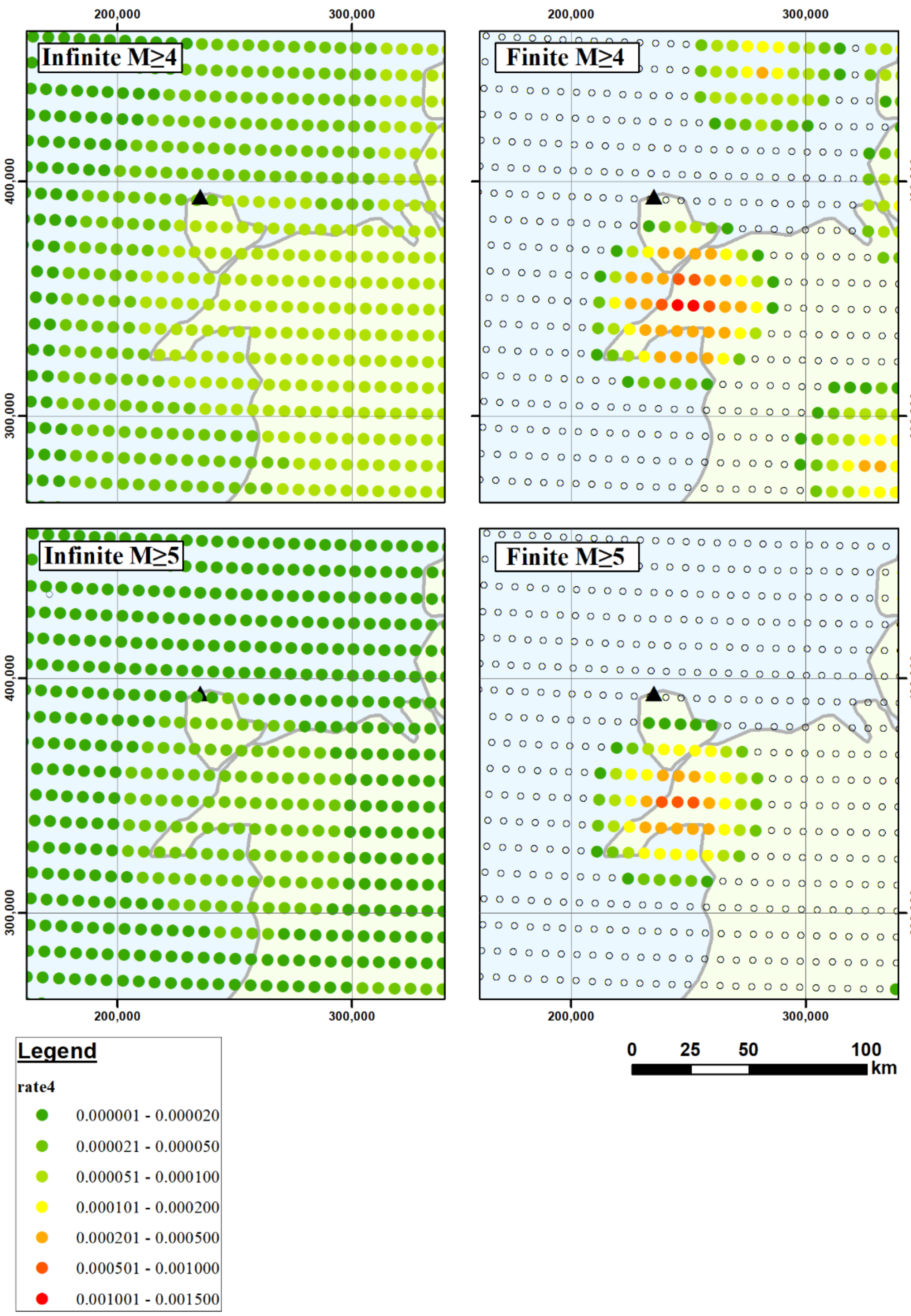

Fig. 4 – Annual number of earthquakes for magnitude greater than or equal to 4.0 (top) and 5.0 (bottom) computed using the kernel method with finite (left) and infinite (right) kernel functions

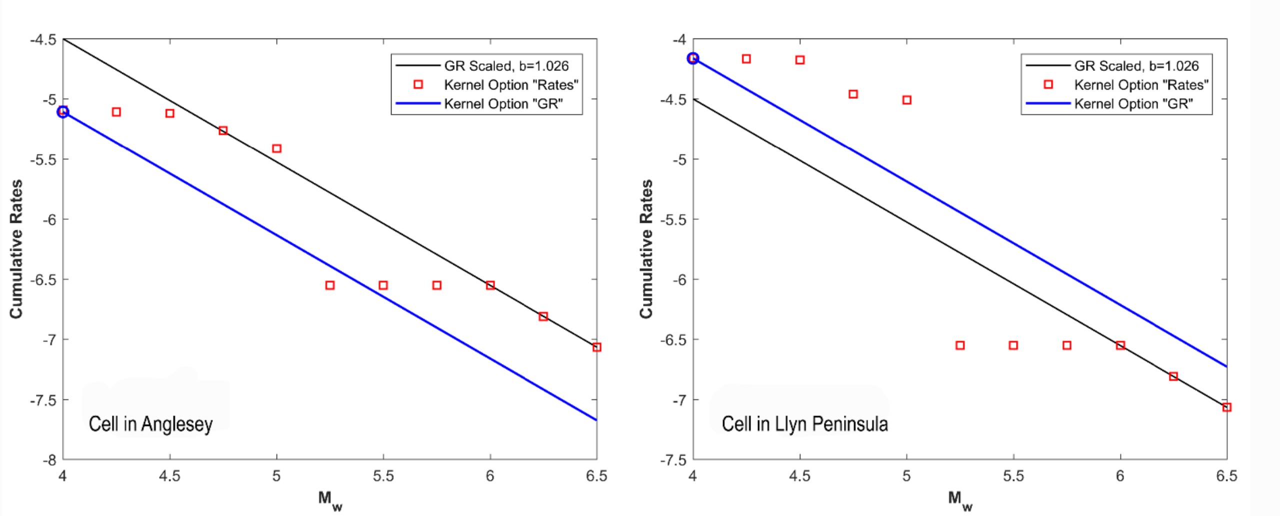

Fig. 5 – Examples of the magnitude recurrences implemented in the kernel PSHA for two cells of the grid for the two options implemented in the kernel PSHA:

A total of four possible approaches to determine the kernel activity rates have been therefore explored in a logic tree approach. The same weighting is applied to all:

1a) Infinite kernel function with GR option;
1b) Infinite kernel function with "rates" option;
2a) Finite kernel function with GR option; and
2b) Finite kernel function with "rates" option.

The seismic source characterisation (SSC) logic tree is shown in Fig. 6: for each kernel options the depth distributions defined in Villani et al. [9] were implemented, while only the best estimate maximum moment magnitude of 6.5 was adopted.

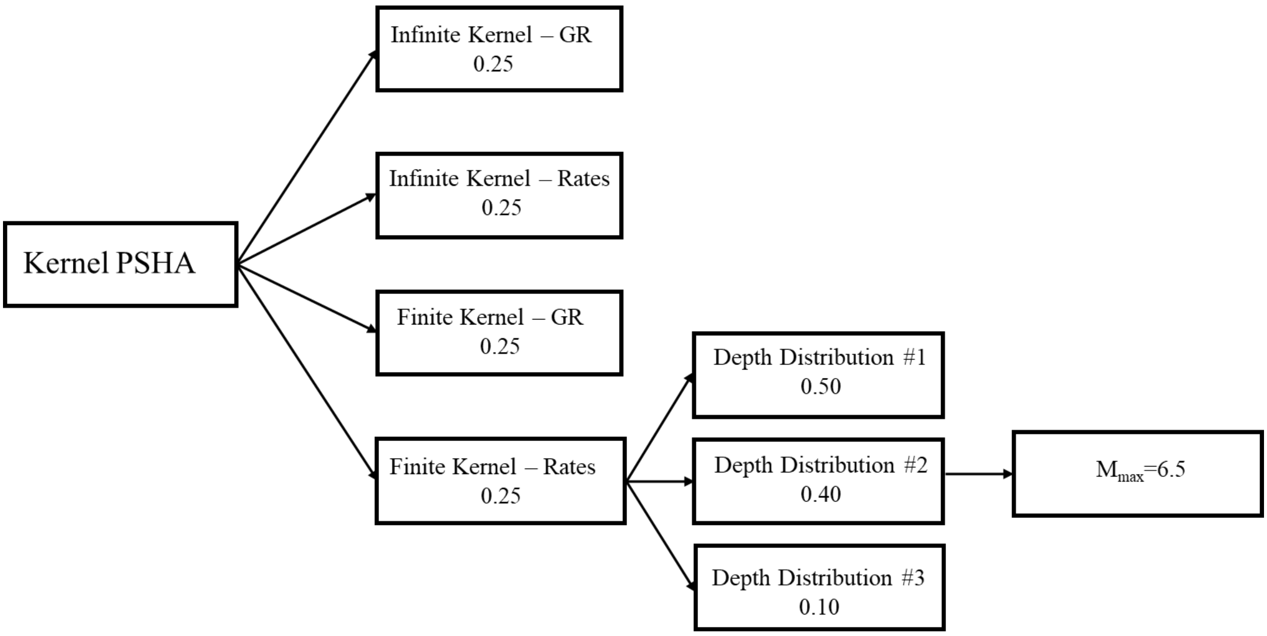

Fig. 6 – Logic tree used for the kernel PSHA.

3.2 Seismic hazard results

The PSHA calculations were performed in the Arup in-house software Oasys SISMIC version 9.5, which was part of the PEER Verification project [12]. As in Villani et al. [9], the results of the PSHA were computed in terms of geometric mean (the square root of the product of the two horizontal and orthogonal ground acceleration components) of the horizontal outcropping motions for a bedrock horizon with V_S of 3,000m/s. The same logic tree for the ground motion characterization was used.

Fig. 7 shows the hazard curves for 100, 20, 10 and 1 Hz for the four options of the logic tree in Fig. 6 and the weighted mean (black curves). The corresponding uniform hazard response spectra UHRS for 10^{-4} and 10^{-5} annual probabilities of exceedance are shown in Fig. 8.

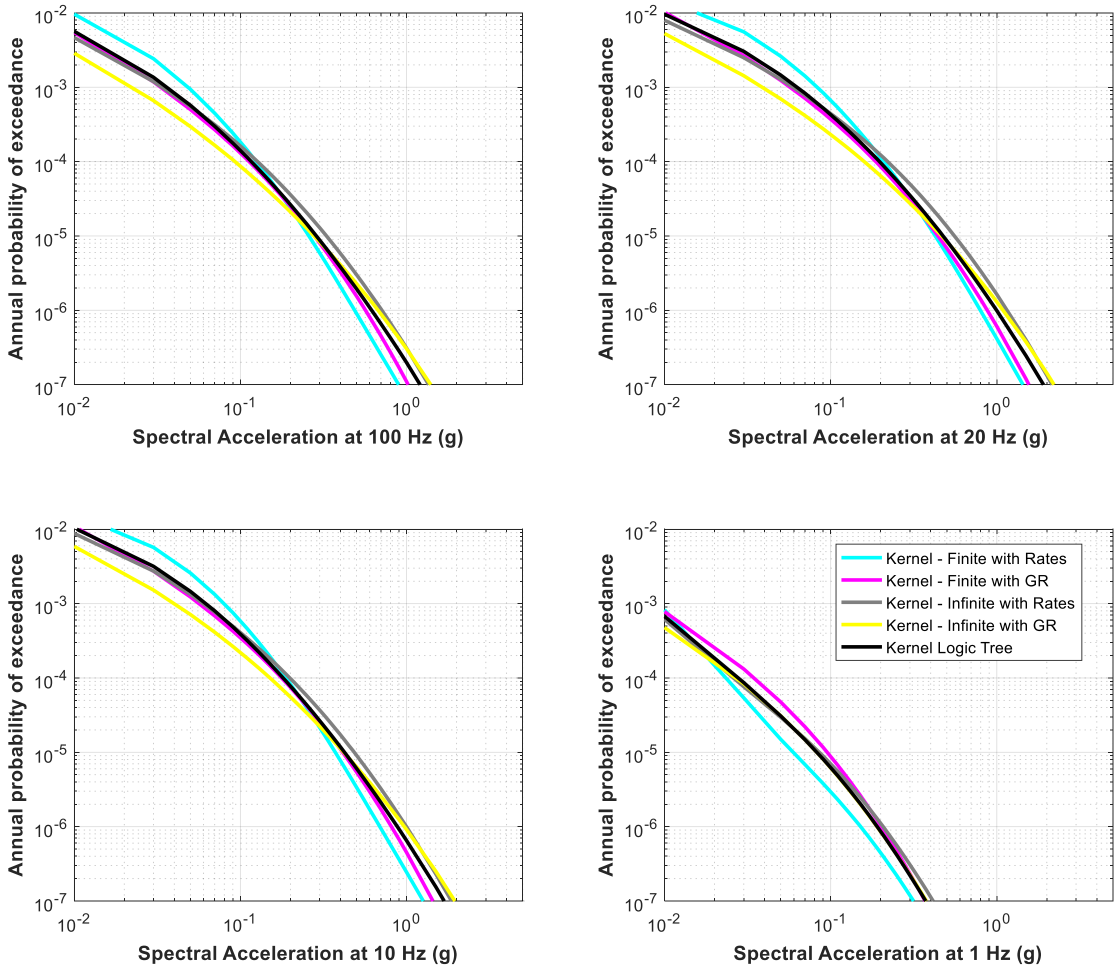

Fig. 7 – Hazard curves for mean spectral acceleration at 100 Hz (PGA), 20 Hz, 10 Hz and 1 Hz using the different kernel models

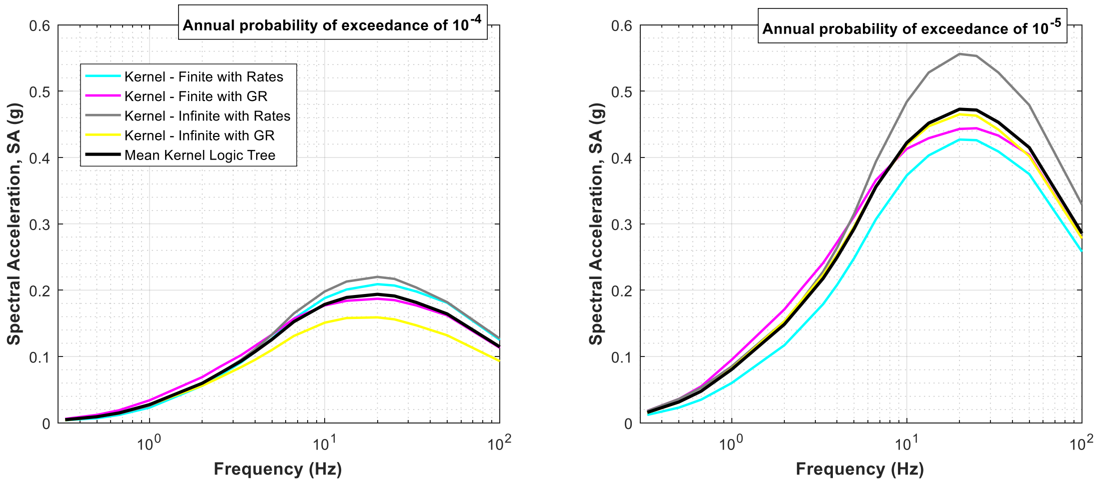

Fig. 8 – Uniform hazard response spectra at annual probabilities of exceedance of 10^{-4} and 10^{-5} using the different kernel models

4. Discussion and Conclusions

The original PSHA for Wylfa Newydd [9] did not include the kernel approach in the main logic tree, although the latter is fully valid for a nuclear PSHA (ONR [3]). The aim of the work was to capture the “centre, body and range of the technical defensible interpretations” following the SSHAC guidelines. It does not therefore require the implementation of all possible alternative models, as far as they would be captured by the epistemic uncertainty included in the PSHA. The kernel method was therefore used as a sensitivity study.

In this paper, the kernel approach, as developed by Woo [6], for the Wylfa Newydd is presented. The results of the kernel PSHA is compared with the weighted mean (“mean” in the plots) from the Wylfa Newydd PSHA and its band of uncertainty (here shown as the 16th and 84th percentiles) presented in Villani et al. [9]. Fig. 9 shows the comparison in terms of seismic hazard curves, while Fig. 10 in terms of UHRS. The kernel approach leads to lower results, which is expected given the low seismicity in Anglesey. If included in a seismic source characterisation logic tree for a site in the UK, the authors would recommend a lower weighting is considered. Firstly, the method does not include explicit consideration of the geology and tectonics of the region. Secondly, the base assumption that future seismicity can be determined by past observed seismicity both in terms of rates and location is difficult to prove in a region of low seismicity such as the UK.

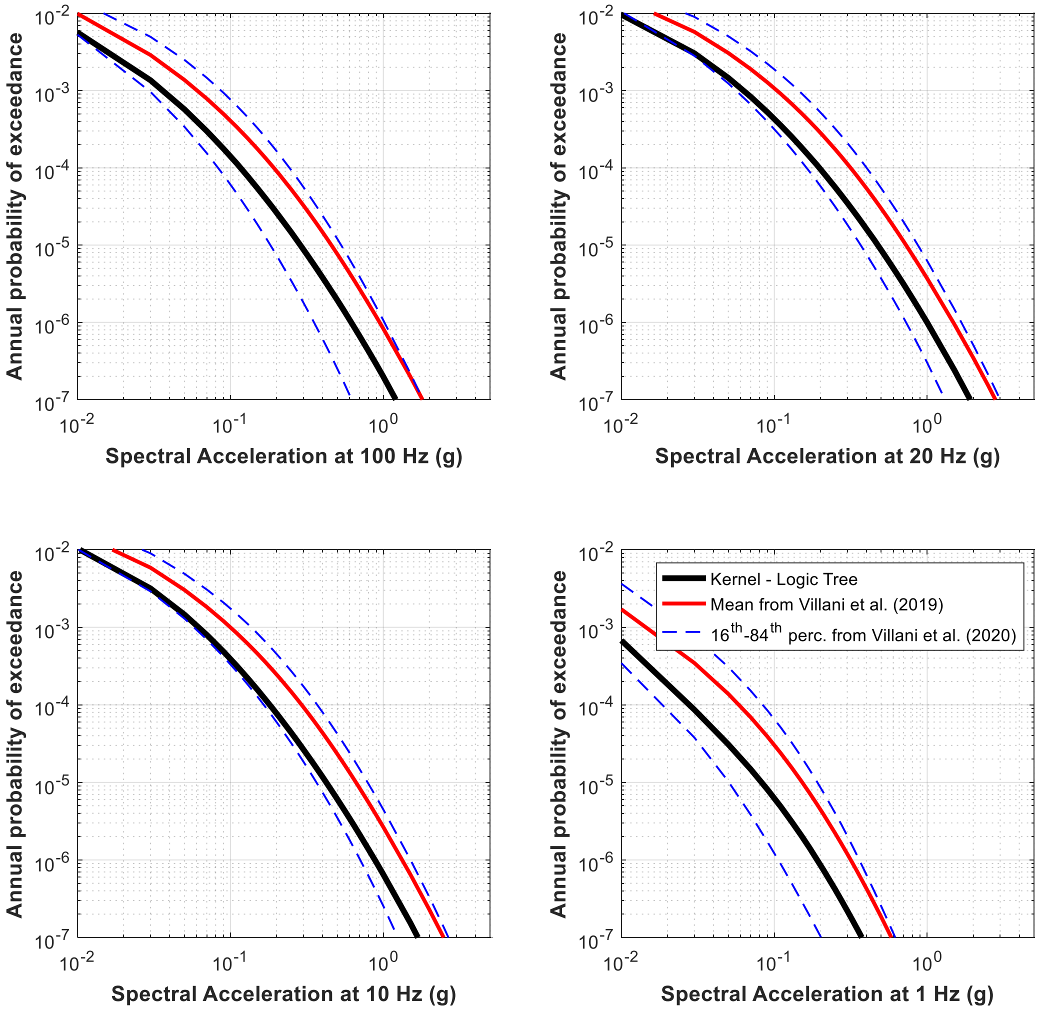

Fig. 9 – Comparison of the mean hazard curves from the kernel logic tree at 100 Hz (PGA), 20 Hz, 10 Hz and 1 Hz with the mean and 16th and 84th percentiles from the Wylfa Newydd PSHA as in [9].

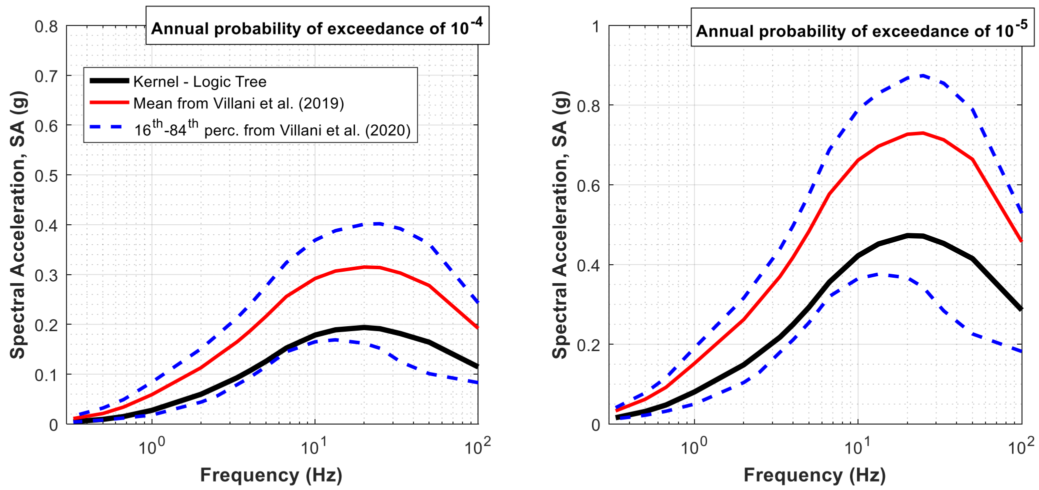

Fig. 10 – Comparison of the uniform hazard response spectra from the kernel logic tree at annual probabilities of exceedance of 10^{-4} and 10^{-5} with the mean and 16th and 84th percentiles from the Wylfa Newydd PSHA as in [9].

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6. References

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