Lessons Learned from the Sinop NPP SSHAC Process

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Abstract. This paper is intended to provide some feedback from the Sinop NPP SSHAC study, which has been finalized at the end of 2017. These may be considered as lessons learned on topics both specific to the Sinop site as well as on more general aspects of SSHAC and of the specific topics addressed in the workshops.

As part of the feasibility study for the Sinop NPP Project, a SSHAC Level 3 (for SSC) and Enhanced Level 2 (for GMC) was conducted. The project required the following analyses:

- Fault Capability assessment (and if required a fault displacement hazard analysis)
- Vibratory ground motion assessment following three approaches: PSHA and DSHA using the approach recommended in the IAEA Safety guide SSG-9 and DSHA using the Japanese methodology parts of which were based on simulations as required by the Japanese Nuclear Regulatory Agency.

An originality of the project was to conduct vibratory ground motion assessments based on both the classical use of empirical ground motion prediction equations, eventually adjusted, and on physics-based fault rupture modelling. One of the major challenges was to develop a sufficiently robust database to characterize the seismic sources in a region where the deformation remains low despite the neighboring of the North Anatolian Fault requiring a tremendous effort in site investigations, and to conduct the ground motion simulation despite the scarcity of recorded data to calibrate the physics-based modelling.

All activities were treated under the SSHAC process. The decision to have all the hazard evaluations under the same SSHAC process proved to be extremely useful in terms of providing consistency in the basic physical models. It also streamlined the project in terms of cost and schedule.

Key Words: Sinop feasibility study. PSHA. DSHA. Fault capability. Physics-based fault rupture simulation. SSHAC process.

1. INTRODUCTION

The Seismic Hazard Assessment (SHA) for the Sinop nuclear power plant Site was performed in support of the Technical Feasibility Study (TFS) required by the Project Sponsors to take an informed decision regarding the investment for the project. It had as primary objective to identify any issues that may constitute an exclusionary attribute, either from a regulatory standpoint or a technical/economical basis. It was also important to identify and estimate key design basis parameters associated with site characteristics that may significantly influence cost and schedule. The SHA addressed both the vibratory ground motion hazard and the fault capability issue, consistently with the Turkish Atomic Energy Authority (TAEK) regulatory requirements [1] and the IAEA Safety Guide SSG-9 [2]. Because the investment would be coming to a large extent, from Japan, it was also important to conduct the studies in compliance with the requirements of the Japanese Nuclear Regulatory Agency (NRA) [3].

With all the different aspects to be considered, the SHA project became multi-faceted and required a special strategy to keep coherence and consistency between all the different approaches. In order to manage the project with the required consistency and coherence and to efficiently identify and represent the epistemic uncertainties that would be significant it was decided to use the SSHAC approach (NUREG, 1997 [4] and NUREG, 2012 [5]).

The fault capability assessment was conducted in establishing criteria complying with the three regulatory documents. To assess the vibratory ground motion hazard a Probabilistic Seismic Hazard Analysis (PSHA) and Deterministic Seismic Hazard Analysis as outlined in Chapter 7 of the IAEA Safety Guide SSG-9 (DSHA-1) [2] were adopted and a Deterministic Seismic Hazard Analysis as required by the Japanese Nuclear Regulatory Agency (DSHA-2). The first two rely on empirical ground motion prediction equations while the DSHA-2 makes extensive use of physics-based modelling and simulations.

Not all of the aspects of the project will be addressed in this paper. We will much more focus on few components of the model that required a specific attention or development:

- The extensive geological database compiled and acquired to achieve a consensual assessment on the fault capability and the impact of the findings on the development of the seismic source characterization (SSC) model.

- The level of effort in building a fault portfolio continuously enriched during the project to implement, in a coherent way the three vibratory ground motion assessments and fault capability assessment.

- The remaining difficulties to calibrate the simulation models in a seismotectonic setting were very few data are available to calibrate and validate the simulation models requiring an adaptation to the approach generally applied in active areas where the calibration is easier.

2. SSHAC organization

One of the preliminary steps was to identify the key roles of SSHAC, i.e. the compositions of the TI(Technical Integrators) team, technical evaluators and the PPRP (Participatory Peer Review Panel). The scope of the Sinop NPP SHA was broader than that of SSHAC projects conducted so far in the sense that it also included the issues of fault capability and DSHA. All of these needed to be addressed both in the ‘evaluation’ and ‘integration’ part as well as the ‘review’ part. Because of the wider scope, it was not possible to draw all the necessary guidance from the two NUREGs. Therefore, the Quality Plan [6] and the Work Plan [7] for the SSHAC process were developed as ad hoc documents defining and describing all the relevant elements of the SSHAC process as provided in the two NUREGs and any additional considerations that were deemed necessary because of the broader scope. Here, compliance with the principles of SSHAC is used to express the continuous and deliberate intention to represent the Center, Body and Range of the Technically Defensible Interpretations at every step in a satisfactory manner to the extent possible.

At the onset of the project, there was more technical controversy and diversity related to the SSC, due to the unclear seismogenic nature of the faults in between the North Anatolian Fault Zone and the Black Sea, and variety of potential interpretations regarding the ‘Pontic escarpment'. For this reason, a SSHAC level 3 was adopted for the Seismic Source Characterization (SSC) which also included the Fault Capability assessment. The GMC model development was estimated less contentious and a level 2 was adopted. However mainly because local strong motion records were scarce in the Central Pontides region, the GMC part of the project was enhanced during the TFS to better address the uncertainties. Between Workshops 2 and 3, the GMC process was further enhanced by additional review mechanisms, technical meetings and technical developments. The Project Manager and the Quality Manager were from the Owner’s Engineer Tractebel.

The multi-national character of the Sinop Project organization was taken into account for the selection of SSHAC experts (from Turkey, Japan, and wider international community) as well as the technical positions to be fulfilled and the specificities of the Project.

Two TIs were considered appropriate for the SSHAC with five Technical Evaluators (TEs). Collectively the TEs covered the needed disciplines of geology, geophysics, seismology and seismic hazard analysis. There were specialists in GMC both for the PSHA and DSHA-1 as well as the adapted Japanese approach (DSHA-2). For the Fault Capability issue (which is potentially an exclusionary attribute), there were three geologists all with field experience and expertise. Due to the nature of this issue, it was decided to collect sufficient data in relation to fault capability so that a **consensus** can be reached between the three geologists and the two TIs.

Collectively the PPRP also had very wide experience. There were two members who had very significant SSHAC experience in order to review the processes. There was one member who had profound knowledge of the Japanese regulations and two members with extensive experience of the project and in the country. All members were well versed in the technical aspects of SHA.

It was possible to find both international and local experts as resource experts or proponents as required. The HCTs were two very experienced companies GEOTER (for PSHA and DSHA-1) and Ohsaki Institute (for DSHA-2).

3. Database, Fault portfolio and SSC model

3.1.Databases

The initial database was rich in field investigations and surveys from various sources initiated in the 1980’s, completed between 2005 and 2008 by TAEK. New programs of surveys were launched in parallel in the frame of the Sinop NPP development in 2013 and completed during the feasibility study upon request of the Technical evaluators and Technical Integrators.

The acquisition and development of very extensive database has been recognized by all the experts involved in the project. The database has been enriched continuously to develop SSC and GMC models of evolving Pilot and subsequent SHA models, providing sensitivity analyses and interim results in advance of each SSHAC workshop to eventually lead to the final SHA outputs.

An overview of the main sources of data (existing/new) and interpretative reports made available to the project is presented *FIG. 1*. This timeline includes both reports and contracted entities description related to each deliverable.

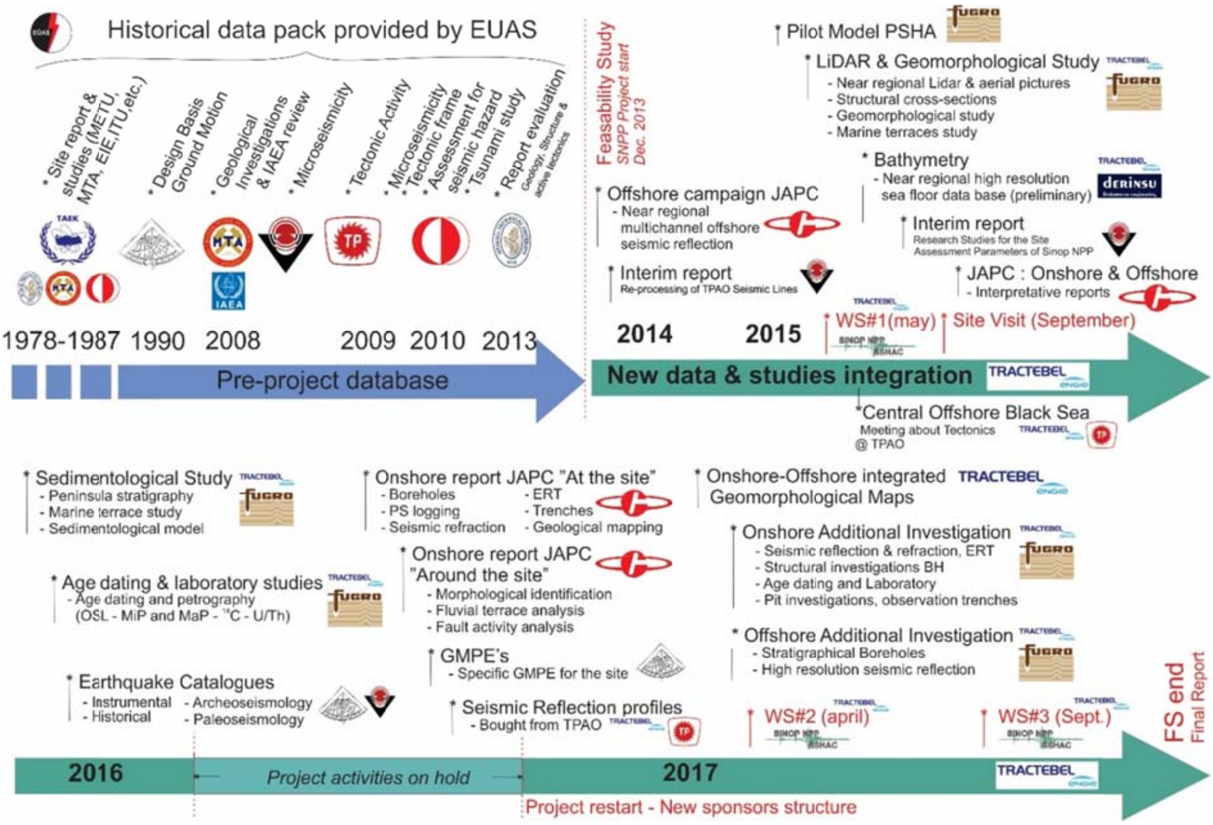

FIG. 1. Historic of the SNPP project data acquisition and studies available. Timeline and contracted parties.

To confirm the suitability of the site, sufficient amount of good quality data has been collected adopting a strategy based on a literature review, on a gap analysis at the various steps of the project and specifically in between the workshops. New data were finally acquired to adequately resolve the technical issues raised by the SSHAC experts. The project database structure has been developed and maintained according to project GIS Guidelines. The GIS database and its metadata allow storing, organizing, describing, controlling, and representing all the geological data according to the IAEA SSG-9 recommendations and feasibility study requirements. Aside from the historical site selection survey programs and geophysical profiles available in the Oil&Gas national company (TPAO), a large amount of new data has been acquired during the project, including:

- A series of surveys both offshore and onshore carried out by Japanese Atomic Power Company (JAPC)
- Various campaign and interpretative reports produced by TÜBITAK-MAM for EÜAŞ in the frame of "The research studies for the site assessment parameters of the SNPP".
- Additional Onshore and Offshore survey programs supervised by Tractebel Engineering resulting from a survey strategy defined by the SSHAC Technical Evaluators and Integrators during the 3 years of the SSHAC process *(FIG. 2)*: acquisition of high-resolution surface morphometric data at near regional scale on both onshore (1000 km² of Lidar survey) and offshore zones (4000km² of Bathymetry), with associated onshore geomorphological interpretative report and bathymetry data report; Offshore stratigraphic cored drillings (12 boreholes); Offshore

high resolution (HR ~ 104km) to ultra high resolution (UHR ~ 76 km) profiles; Onshore geophysics, located within the site vicinity to near regional: high resolution seismic-reflection (~ 41km), seismic refraction (~ 48 km) and ERT(~43km) mostly on the same footprints, penetration depth up to 500m; Onshore drilling, deep vertical (up to 600m, including Vp measurements) and inclined stratigraphic boreholes, two geotechnical; including borehole imagery (total: 20 boreholes; total ~ 4000m); Observation trenches (7 sites; total length ~500m) within the site vicinity (radius of 10 km) and at the site; Laboratory works for age determination on both onshore and offshore samples;

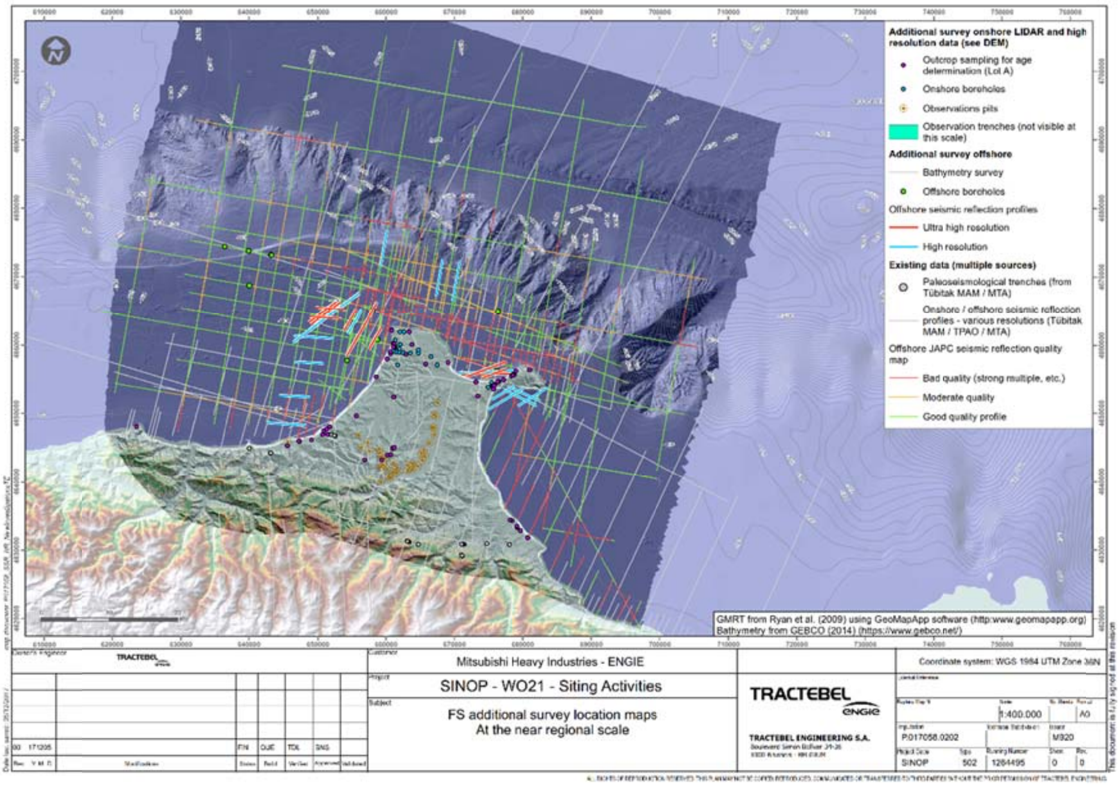

FIG. 2. FS additional survey location maps at the near-regional and site vicinity scales.

3.2.Fault portfolio

Based on a continuous evaluation and integration of all the data and information collected within the regional to site scale, an original idea was to create and maintain a fault portfolio. This allowed for a traceability of the different interpretations and assigning the characteristics and parameters for more than thirty attributes, required to implement both approaches based on empirical GMPEs and physics-based simulations. The project evolved all along the process through continuous interaction between Evaluators and members of the Technical Integration team and Hazard calculation team, to assign the fault parameters and uncertainties as appropriate to implement the three types of SHA (PSHA and DSHA consistent with the IAEA SSG-9 guideline, DSHA based on the Japanese Physics-based simulation). Faults included in the final version of the fault portfolio and considered as seismically active by at least one evaluator expert, were included in the fault source model.

3.3.Fault capability and SSC model. Introduction of the ZDI concept.

The objective of the expert elicitation process regarding fault capability differed from other topics in the sense that due to the regulatory requirements which may lead to potentially exclusionary conditions, expert consensus was sought. This was only possible with a wealth of data especially those that the TEs required in order to understand all the characteristics of the features within or near the site vicinity. As this topic is closely associated with the SSC part of SSHAC, it was treated as SSHAC Level 3 similar to the SSC.

This was the opinion of all the Technical Evaluators and Technical Integrators involved in the fault capability issue, and also of the PPRP that the database collected for the fault capability issue conformed to and in some aspects exceeded the recommendations of the IAEA Safety Guide SSG-9. In order to reach consensus on the issue of fault capability, a very significant amount of high quality data was collected in the site vicinity, which, in the case of the Sinop NPP is an area having a 10 km radius, based on TAEK regulation.

First the criteria for fault capability were to be determined; interpretation of existing data and field observations by the technical evaluators, acquisition of missing data and new interpretation by the experts and integration of the data by the technical evaluators, followed a step by step approach to discard the suspect geological features.

To comply with the three regulations (TAEK, NRA, IAEA), the criteria (Table 1.) were selected using a conservative approach.

For and area in a radius 5<R<10 km	
35 000 years	One movement
500 000 years	Multiple movement
For and area in a radius R<5 km	
120 000 to 130 000 years	One movement

Table 2. Criteria adopted for the fault capability to comply with the three regulations.

The consensus on absence of fault capability was reached after a detailed analysis of three suspect features within or near the site vicinity that were identified at the onset of the project as potentially capable due to a lack of geological arguments regarding the age and nature of the suspected contacts to discard the presence of a fault.

All the Technical Evaluators recognized the high quality and quantity of data to make an informed judgement on capability of features in the site vicinity (i.e. 10 km radius) and they confirmed after their analysis, that the three features were not capable with respect to the criteria. The absence of capability was never questioned by the PPRP in their commenting process.

The fact that such an area is demonstrated to have no capable fault, also had consequences in relation to vibratory ground motion hazard. As clearly stated in the IAEA Safety Guide SSG-9, absence of capable faults implies that certain magnitude-depth combinations may be screened out from this 10 km radius area.

In the construction of the SSC model adopted to conduct the PSHA and DSHA, the concept of Zone of Detailed Investigations (ZDI) was introduced. The magnitude-depth characteristics of potential fictitious faults within this zone have been given special considerations.

Ultimately, the SSC model defines the seismogenic potential of the seismogenic sources (faults, areas), the location, size, and rate of future earthquake activity, with due consideration of all defensible interpretations prevailing in the scientific community and of all interpretations specifically developed based on the new data generated by the project. The Sinop NPP site lies within a tectonic environment that is adjacent and located North to a major and active plate boundary (the North Anatolian fault). In between this major plate boundary and the more stable region of the Black Sea, the Central Pontides belt has undergone more recent tectonic deformation than the Black Sea. However, the expression of the deformation in the Central Pontides is characterized by a lack of a clear definition of the causative faults giving rise to the observed diffuse seismicity. Because of this, the SSC methodology was developed in such a way to account for the state of knowledge of fault locations and their seismogenic behaviour as well as for the unknown locations of the faults giving rise to the "background" seismicity. In the Central Pontides, geodetic data on contemporary crustal strain are currently limited in their duration and it remains difficult to establish a reliable association between the geodetic strain and earthquake processes. Therefore, the adopted methodology was based on the identification of hazard-significant technical issues. This was done through the compilation of available data and models developed during previous phases of the Sinop development project, the gathering and evaluation of new data generated by the present project, the identification of seismic sources according to explicit criteria and the characterization of each identified seismic source, including the associated uncertainties and using a logic-tree approach. A budget of deformation was also undertaken to tentatively demonstrate the consistency of the alternative models with the deformation as characterized by data representative of various time periods.

Because the ultimate use of the SSC model was for hazard analyses, it was decided, to conduct a hazard-informed approach, based on an initial pilot model that evolved in between the workshops and after the third workshop to conduct the final calculations. Nine seismotectonic models were developed covering a radius of 350 km to 400 km around the site composed of two types of seismic sources:

- Seismogenic structures such as faults (segmented/unsegmented) described by 3D fault plans, and for which the activity parameters can be estimated for each individual fault or segment (maximum magnitude, characteristic magnitude, style of faulting, slip rate);
- Volumes of diffuse (or distributed) seismic activity, where seismicity is not clearly correlated to specific structures. In these volumes two alternative strategies were adopted to characterize the activity rates: either considering a uniform distribution based on the Gutenberg-Richter earthquake-frequency relationship of each zone of the seismotectonic models, or considering a distributed grid of activity rates based on a smoothed seismicity grid established for large super-domains.

The ZDI was introduced in all the models as a zone with a 10 km-radius around the SNPP site remain consistent with the consensual Sinop FS results that there is no capable fault within the 10 km-radius around the site. This ZDI should not be considered as a distinct seismotectonic area source within the Central Pontides, but much more as an area where the quality of data and the subsequent geological and seismological knowledge reached a sufficient level to discriminate the seismic activity parameters against adjacent areas (seismogenic depth, maximum magnitude, style of faulting), in such way that no surface rupture can be produced, consistently with the fault capability assessment.

Outside ZDI, the fault model for the PSHA includes 8 faults *(FIG. 3.)*:

- The North Anatolian fault as major interplate strike-slip dipping almost sub-vertical;
- The Ekinveren back-thrust dipping to the north;
- The Erikli thrust dipping to the south;
- The north-verging Ayancık thrust;
- The north-verging Balıfakı thrust;
- The Western Graben fault dipping to the west;
- The Northern Basement fault dipping to the south;
- The Pontic Escarpment fault.

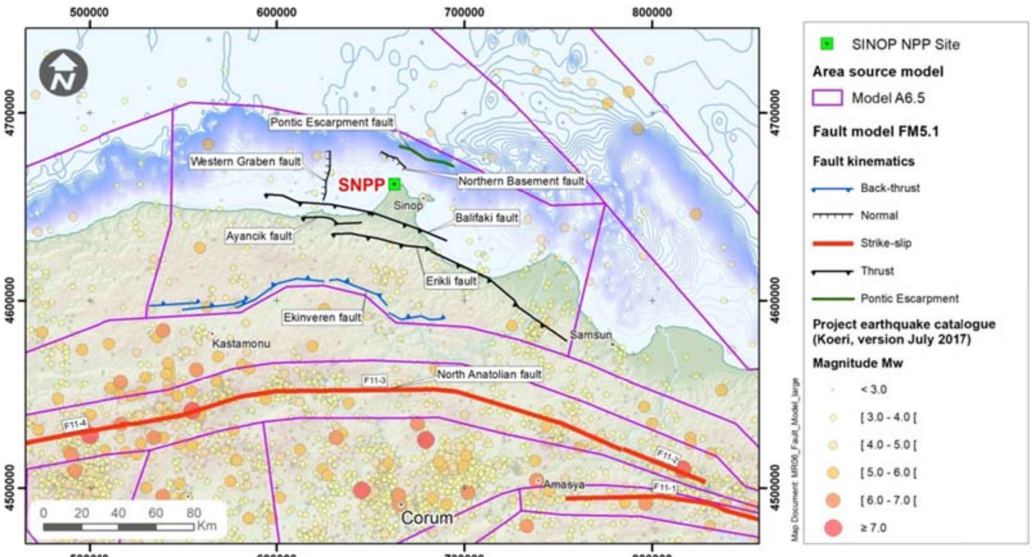

FIG. 3. Fault sources included in the fault model.

Contrary to the consensus established on the fault capability, opinions about the seismogenic character and activity parameters differed among the experts and this was reflected in the SSC Logic tree.

As an output of the iterative integration process the final SSC logic tree was composed of *(FIG. 4.)*:

- A set of two smoothed seismicity models composed of two super-domains areal source models for which strict boundary conditions are applied for the seismicity rates and two alternative Kernel functions (adaptive and fixed Kernels);
- A set of 4 area source models ;
- A set of 4 fault source models based on the consideration of two segmentation models, three alternative style of faulting for the Pontic Escarpment fault and two earthquake recurrence models (Poisson model and characteristic earthquake model).

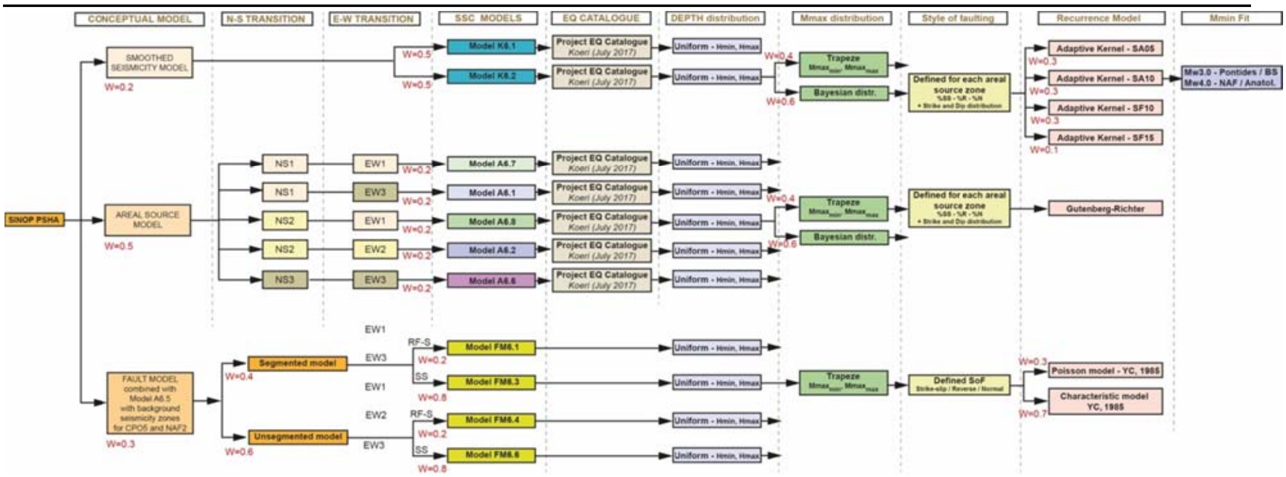

FIG. 4. Main branches of the SSC Logic Tree.

4. GMC model

The initial idea, elaborated in the Quality Plan [6] and Work Plan [7] was to adopt a SSHAC level 2for the GMC model. One of the main reasons being an assumed lower level of controversy on the GMC model, in a country prone to a significant, seismic activity with a rich strong ground motion database. However, the works conducted to develop the first Pilot model evidenced that the ground motion hazard at the site was mainly controlled by the seismic sources distributed in the Central Pontides (an area of low to moderate seismicity compared to the North Anatolian Fault) and poorly represented in the Turkish strong ground motion database. Decision was then taken by the Technical Integrators and Project management, supported by the PPRP to adopt an enhanced level 2. Compared to a Level 2, the enhancement was made of several actions not initially identified : conduct of 3 topical meetings, implementation of the GMC as part of the workshops and PPRP review, consideration of the PPRP feedback, involvement of a third party (KOERI Institute) to conduct technical tasks to increase the robustness of the GMC Logic Tree, external review of the proposed GMC model. All these actions reaching a level of efforts closer a Level 3.

Sufficient flexibility in the initial SSHAC work plan was accepted by all the parties and the sponsors to adapt the project to the technical circumstances encountered during the implementation phase of the project.

The adopted procedure led to the selection of two set of GMC models, with adjusted sigma models: one representative of the seismic sources belonging to the Pontides and Black Sea superdomains, one representative of the North Anatolian fault.

For Central Pontides and other zones north of the North Anatolian Fault:

- The Bindi et al. (2014) model [8] for the Joyner-Boore distance, with a weight of 0.2;
- The Chiou and Youngs (2014) NGA2 model [9], with a weight of 0.3;
- The Akkar et al. (2014) model [10] for the Joyner-Boore distance, with a weight of 0.2;
- The Idriss (2014) NGA2 model [11], with a weight of 0.15;
- The Boore et al.(2014) NGA2 model [12], with a weight of 0.15.

For NAF zone and other zones to the south:

- The Abrahamson et al. (2014) NGA2 model [13], with a weight of 0.25;

- The Chiou and Youngs (2014) NGA2 model [9] with a weight of 0.25;
- The Gülerce et al. (2016) [14], as a modification of the Chiou and Youngs (2008) GMPE [15], with a weight of 0.50.

The modified sigma model defined by the GMC team for CPO and NAFZ was used as lower bound model for each GMPE. In practice, when the native sigma model of a GMPE was higher than the modified sigma model, the native was used. This was adopted as a conservative approach due to the absence of natural records to increase the robustness of the model in the Central Pontides region.

5. Seismic Hazard Assessment

As indicated aboven one originality of the project was to conduct a seismic hazard assessment following three approaches: PSHA and DSHA-1 consistent with the TAEK [1] and IAEA [2] requirements and a DSHA-2 according to the NRA regulation [3]. In the latest case, the vibratory ground motion is based, for the so called “specific sources”, on physics-based ground motion simulation rather than on GMPEs models which is the case for the two first approaches. For the simulation, the fault parameters are evaluated consistently with the presecribed procedure, so called “Recipe”, developed by the Headquarters for Earthquake Research Promotion, Japan, 2016 [16].

The objective of applying an approach conforming the NRA guidelines had the purpose of analyzing how the PSHA and DSHA (DSHA-1) results which were conducted in compliance with TAEK and IAEA requirements, compared with the results obtained when applying a methodology more familiar to Japanese operators and regulator (DHSA-2).

For sake of consistency, the same database and SSC models were considered to conduct the three approaches and, in each case,, the TIs ultimately defined the PSHA and DSHA Logic Tree and associated weights. Deterministic scenarios were defined with uncertainties associated to each parameter and characterized by a probability distribution, the objective being to identify the Center Body and Range in the ground motion assessment. While it was recognized by the TIs and PPRP that the CBR was properly identified in the PSHA and DSHA-1, the principles that support the DSHA-2 does not allow to satisfy this condition in an adequate manner. It this case, the seismic parameters describing the scenarios were purposefully biased towards the conservative side to better replicate the ‘assumed NRA position’.

In that sense, the DSHA-2 followed more closely the NRA requirements rather than the SSHAC principle and therefore considered two major methods with less extensive consideration of the uncertainties:

- Earthquake ground motions generated by specific sources. The ground motion is defined based on simulation of earthquakes occurring on an identified fault, each scenario being characterized by inner and outer parameters describing the fault rupture process. Earthquake ground motions are in this case calculated by fault rupture and propagation simulation models. In this calculation, the fault parameters are evaluated by the procedure, prescribed by [16]. The short-period motions are calculated by the Stochastic Green’s Function (“SGF”) method, and the long-period motions are calculated by the Wavenumber Integration (“WI”) method. Earthquake ground motions at the site are then obtained by the hybrid method, which combines the motions by the SGF and the motions by the WI methods [16].

- Earthquake ground motions generated by non specific source, i.e. scenarios that can be produced anywhere including under the site with magnitudes and locations remaining consistent with the level of geologic knowledge acquired at the site. The ground motions are evaluated by two approaches: one based on treatment of real records corrected assuming the occurrence of earthquakes below the site (Kato et al. (2004) [17], the other one relying on a pseudo probabilistic approach (Motohashi et al. (2005) [18], Kagawa et al. (2005) [19]), removing from the hazard integral the scenarios able to generate surface rupture.

The logic trees adopted for the PSHA and DSHA-1 were developed to capture the center body range with the objective to include the full range of uncertainties identified during the SSHAC process. For the DSHA-2, calculations were performed with limitation in the number of simulations and precedence of the NRA principle over the SSHAC concept: consideration of best estimated input parameters rather than parameter probability distribution, assumptions on the asperity model and on the short period scaling factor like they are applied in practice in Japan, rather than a complete consideration of the range of uncertainties, involving a certain level of conservatism.

The seismic hazard calculations were conducted adopting different calculation methods and theories, based on empirical GMPEs and simulations. These methods were applied by two independent hazard calculation teams, without prejudging the differences that could be observed in their respective results.

The SHA has been achieved with the main objective to seek for consistency in the basic physical models supporting the ground motion estimates, and with the final goal to compare the outputs of these estimates and to appreciate their consistency and robustness.

Albeit different concepts in the seismic hazard assessment approaches have been applied, the results from the various methods are in general in good agreement with each other, with a coherency in the shape and amplitudes of the response spectra (*FIG. 5*).

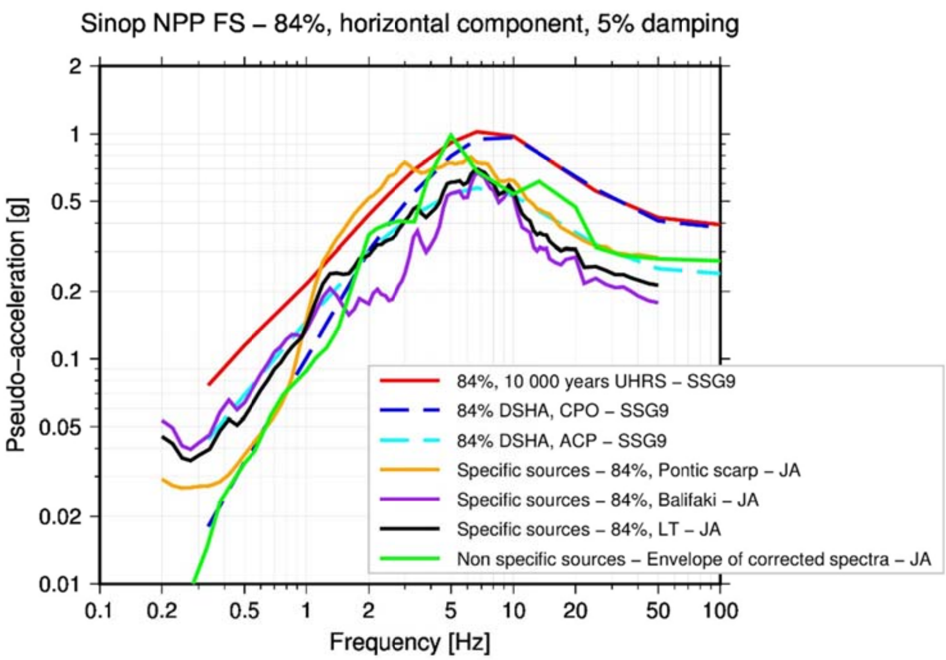

FIG. 5. Comparison between the response spectra obtained using the various methods applied during the project (PSHA and DSHA, SSG-9 and DSHA-2). Horizontal component 5% damping. (centile 84%).

The centile 84% of the PSHA at 10 000 year return period, almost envelopes all the deterministic scenarios (centile 84%) obtained through the different methods conducted to implement the two DSHA, based on GMPEs, simulations and adjustment of natural records. The 84% confidence 10 000 years return period UHRS is associated with a mean return period very close to 20 000 years and it has a 20% margin over the mean 10 000 years UHRS.

Compared to most of the deterministic spectra, the spectral shape of the UHRS is richer in low frequencies (below 2 Hz). This is because the PSHA better accounts for the contribution to the total hazard of distant but more active seismic sources, that are not controlling the ground motion level in the deterministic approaches. Above 5 Hz, there is a good agreement between the PSHA and the two DSHA, when considering in both approaches, the centile 84%.

The return periods of the spectral accelerations of the centile 84% of DSHA-1 response spectra are in between 6 000 and 7 000 years for frequencies lower than 2 Hz and between 17 000 and 20 000 years in the frequency range 10-100 Hz.

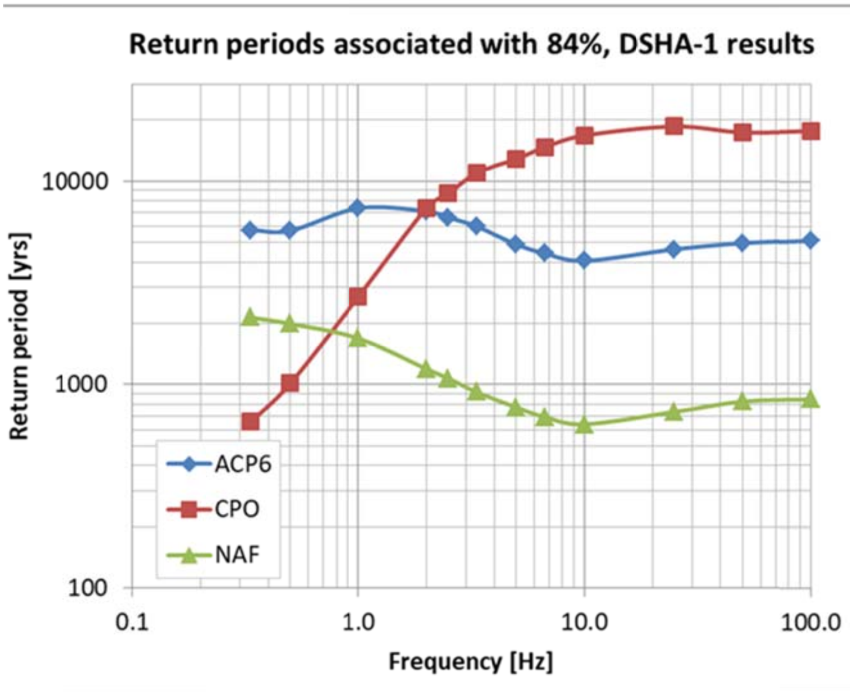

FIG. 6. Return periods of the DSHA-1 response spectra inferred from the post-treatment of the PSHA model. Horizontal component 5% damping. (centile 84%).

6. Main lessons

6.1.SSHAC process

At the onset of the project, a significant challenge was to develop a seismic hazard model compliant with three guidelines (TAEK, IAEA and NRA), based on different approaches probabilistic/deterministic and relying on different concepts based on GMPEs and simulation, involving teams with different background and culture. The decision to conduct all the seismic hazard activities under a SSHAC process, proved to be extremely useful in terms of providing consistency in the basic logic tree models and to favor fructuous stimulation among the various technical groups involved in the project.

For such site specific SSHAC it was extremely important to have a diversity of expertise background within the technical evaluators and within the PPRP panel, notably to manage the requirements inherent to the different regulations.

This diversity was also a key facilitator to address the uncertainties at near region and especially the site vicinity scales, where the largest amount of new data has been acquired. It is always possible to invite resource or proponent experts on topics that pertain to regional modelling issues for which several studies and research works exist. However, for near-regional and the site vicinity scales, invited experts cannot adequately provide diversity because they do not possess the specific and newly data acquired for the project. It is, then, the diversity of the expertise within the technical evaluators, that makes it possible to address the epistemic uncertainty representation.

The consensus on the fault capability issue was eventually reached only because of a very significant effort made during the project in the acquisition of very good quality data. The evaluation and integration of the historical and newly collected (Lidar, Bathymetry, geophysical seismic reflection) data set by the SSHAC process, at the beginning of the project, led defining complementary surveys aimed at providing the sufficient evidence to support the fault capability claims and reducing the epistemic uncertainty on seismic source characterization. The quality of the data obtained from those surveys was highlighted as a key success factor for the seismic hazard evaluation.

Another notable component of the Sinop SSHAC was the capacity to introduce flexibility in the work plan and in the SSHAC level envisaged at the beginning of the project. The process itself, conducted under a high quality requirement, has been flexible enough to allow adaptations to the technical issues that appeared during the project, through the continuous integration of new data acquired and interpretation of interim results during the course of the project. This flexibility has led to a modification in the SSHAC level initially planned (in our case GMC level 2 to enhanced level 2) and new developments or technical approaches not necessarily planned at the initial stage of the project.

Eventually the QA documentation prepared for the project was a real support for a good traceability and to promote the communication between the SSHAC actors and sponsors all along the project. It was essential to prepare and update a set of Quality documents relevant to the specific SSHAC process. While the NUREGs that explain SSHAC are very useful, the guidance they provide may be interpreted in different ways. An unambiguous set of Quality Documents (Quality Plan, Work Plan and Procedures) which also contain all the criteria that are applicable in the project, contributes significantly to transparency and good communication.

6.2.Development of the SSC and GMC models

Several tools were extremely useful to manage this flexibility: the successive Pilot models developed prior each workshop and technical meeting, provided very valuable information to focus on the key actions supporting the process. The preparation and maintenance of a ‘fault portfolio’ for the near region and site vicinity, and its continuous improvement throughout the process, thanks to the new data acquired, proved to be a very useful tool summarizing the acquired data, the interpretations and the parameters describing the fault sources geometry and activity.

To reduce the uncertainties and increase the robustness of the seismic hazard estimate, we encourage the acquisition of data in various disciplines and at the earliest staged of nuclear projects.

As for many similar projects, one never insists enough on the benefits of acquiring ground motion data from the site itself. Various uncertainties would have been reduced and better calibrated if a local accelerometric network would have been installed at the beginning of the feasibility study (or earlier). To conduct site-specific ground motion hazard assessment, such data offer a larger perspective to reduce uncertainties (confirm/deny expert judgment, consideration of analogues, verification of assumptions) for various topics: GMPEs adjustments, calibration of ground motion simulation models, single sigma station, soil response analysis.

The macroseismic information is also very valuable not only to characterize the historical seismicity, but also in region of moderate activity, to support the estimates of the crustal attenuation properties. Albeit a progress has been made during the project to revise the historical seismicity, discovering new events not identified so far, the historical database remains quite poor for a country affected by major plate boundaries. The constitution of a robust catalogue of historical seismicity and macroseismic data points should be key point of attention for future nuclear projects in Turkey. This effort goes well beyond what can be done in a single project and a short time period and requires a national effort. All countries in Europe that have nuclear energy programs have historical earthquake catalogues that have been developed or revised by nuclear operating organizations and/or nuclear regulators through multi-years programs and continuous exploration of historical documentation. It is extremely useful to follow this practice to enrich the historical catalogue and the macroseismic information.

6.3.GMPEs approach versus physics-based simulation.

Physics-based simulations are of significant interest to conduct ground motion hazard estimates, especially when the seismic scenarios are poorly represented in the strong ground motion database. They contribute to better analyze the influence on the ground motion of various parameters either related to the complexity of the seismogenic rupture process or to the path effect.

One of the challenges during the project was to properly transpose the ‘Recipe’ usually applied in Japan to the Sinop case. This was made possible, within the SSHAC, for a number of parameters and notably the definition of common deterministic scenarios, later on considered as input data to the classical approach relying on GMPEs and to the simulation based method.

However, one of the difficulties, not totally solved, was the calibration and validation of the physics-based simulations, in absence of ground motion records generated by seismic sources located in the Central Pontides, the main contributor to the total hazard. Additional research and development efforts are deemed necessary to make the approach more common in areas with scarce empirical data.

Guidelines on the proper use of physics-based models and their limitations when calibration data are poor or limited and when uncertainties are difficult to quantify for various physical parameters, would be beneficial to promote the simulation approach for projects located in regions of moderate activity.

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