Commentary

Design Basis Ground Motion Required on New Regulatory Guide
−Introduction of Lessons Learned from Recent Disastrous Earthquakes−

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The Nuclear Regulation Authority is developing new regulatory standards in response to the disaster that occurred at the Fukushima Daiichi Nuclear Power Plant operated by the Tokyo Electric Power Company (TEPCO). As well as providing an explanation of the requirements of the new regulatory standards, this commentary describes changes in the evaluation of the design basis seismic ground motions to be established as the basis of seismic design. It also presents new findings concerning the damage sustained in the 2011 Tohoku earthquake (Mw 9.0) and other recent destructive earthquakes to explain how these findings may help secure advancements in the evaluation of design basis seismic ground motions.

I. Introduction

On March 11, 2011, a giant earthquake occurred at 14:46 off the Pacific coast of Tohoku. In the morning of that day, the Special Committee on Seismic Safety Evaluations of the former Nuclear Safety Commission conducted a review of the Tokai Daini Nuclear Power Plant operated by the Japan Atomic Power Company (JAPC). Ironically, the review had just validated the method by which active faults were identified as well as the evaluation conducted using design basis seismic ground motions and the seismic safety of major facilities (seismic safety backcheck). The moment magnitude (Mw) of the earthquake was 9.0, making it the largest ever to have been recorded by the Japan Meteorological Agency (JMA). This magnitude scale was adopted because it has a wider scope than the magnitude scale usually adopted by the JMA (Mj). The enormous tsunami that the earthquake triggered inflicted widespread damage along the Pacific coast. On March 6, 2013, the National Policy Agency announced that this disaster had resulted in 15,881 deaths and 2,676 missing persons. The scale of the tsunami induced by this earthquake far exceeded that anticipated by TEPCO for the Fukushima Daiichi Nuclear Power Plant. The station blackout caused by the tsunami impaired the cooling function of the nuclear reactors, which led to a core meltdown, a hydrogen explosion, and ultimately to a severe and grievous nuclear disaster involving the leakage and dispersal of radioactive materials. Two years later, the circumstances surrounding nuclear

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power plants have changed substantially.

The Nuclear Regulation Authority (NRA) has been established as an agency affiliated to the Ministry of the Environment (MOE). The tasks formerly handled by organizations such as the Nuclear Safety Commission and the Nuclear and Industry Safety Agency were unified under the newly established NRA Secretariat. Prompted by the disaster that struck the Fukushima Daiichi Nuclear Power Plant, the NRA is working urgently to develop new safety standards and revise guidelines for nuclear disaster countermeasures.

In relation to the topic covered in this commentary, the public is concerned about not only whether faults located at the site or just below nuclear power plant facilities with important safety functions are active faults (fracture zones) to be considered in seismic designs, but also how the NRA defines this through the following procedures. The NRA is expected to convene a panel of experts to discuss how such active faults should be evaluated in an appropriate procedure and deliver an objective judgment on the conclusion based on scientific findings.

The new regulatory standards for earthquakes and tsunamis require that facilities with important safety functions be constructed on ground that has been confirmed to have no exposure to active faults. The expert panel is expected to conduct careful discussions based on scientific facts as their judgment will have decisive implications.

With the above in mind, this commentary begins by explaining how the evaluation of design basis seismic ground motions has advanced as a crucial element in terms of the seismic safety of nuclear power plants. It describes the process by which the Regulatory Guide for Reviewing the Seismic Design of Commercial Nuclear Reactor Facilities (established in July 1981 and revised in September 2006) was refined to produce the new regulatory standards for earthquakes and tsunamis (enforcement scheduled for July 2013). The commentary then explains how the lessons learned from the 2011 Tohoku earthquake and other recent destructive earthquakes have been incorporated into this refinement process. A design basis seismic ground motion provides a vital nexus between the identification of active faults, the evaluation of the magnitude of resulting earthquakes, and the necessary seismic designs for key facilities and equipment. Obviously, it is vital for this ground motion to be determined by incorporating new findings from observation data and other scientific evidence.

II. Evolution of the Evaluation of Design Basis Seismic Ground Motions for the Seismic Design of Nuclear Power Plants

In September 1978, the Japanese Atomic Energy Commission (AEC) established the original guidelines for the seismic design of commercial nuclear power plants. In October of the same year, the Nuclear Safety Commission (NSC) was separated from the AEC to form an independent organization (the NSC was subsequently transferred from the General Administrative Office of the Cabinet to the Cabinet Office in 2001 as a part of a government reorganization). Following a partial revision of the original guidelines, the NSC established the Regulatory Guide for Reviewing the Seismic Design of Commercial Nuclear Reactor Facilities (hereinafter referred to as the “Seismic Guide”) in July 1981. The Seismic Guide was established based on engineering judgments related to earlier experiences obtained from safety reviews, seismologic and geologic findings, and so forth. Its basic principles were presented in the Regulatory Guide for Reviewing the Safety Design of Commercial Light Water Nuclear Reactor Facilities, which was established by the AEC in June 1977. After that, discussions concerning a revision of the Seismic Guide began in 2002 based on new findings in seismology, earthquake engineering, and other relevant fields as well as dramatic improvements and advancements in anti-seismic technologies. A significant trigger for this revision was the occurrence of the Great Hanshin earthquake, which struck in 1995 with a magnitude of Mj 7.3. Discussions on this revision took four years. After an overhaul, the Revised Seismic Guide was established in September 2006 by the former NSC. Subsequently, seismic backchecks were conducted by the former Nuclear and Industrial Safety Agency (NISA) and the former NSC based on the Revised Seismic Guide at each of Japan's 54 nuclear power plants. Meanwhile, these rigorous backchecks continuously incorporated findings from later destructive earthquakes in Japan (e.g., the 2007 Chuetsu offshore earthquake (Mj 6.8), the 2007 Noto earthquake (Mj 6.9), and the 2009 Shizuoka earthquake (Mj 6.5)) as they became available.

The 2011 Tohoku earthquake (Mw 9.0) marked another turning point. A review team was established at the NRA to discuss new safety design standards for commercial light water reactor facilities in relation to addressing earthquakes and tsunamis. A skeleton plan for developing these new regulatory standards for earthquakes and tsunamis was formulated. Following the completion of a public comment, work is under way toward enforcement of these standards in July 2013. In the new regulatory standards, numerous new safety design requirements related to tsunamis were added in consideration of the fact that the disaster at the Fukushima Daiichi Nuclear Power Plant was caused by the 2011 Tohoku earthquake triggering a tsunami of a scale that far exceeded expectations. Although details were omitted, additional rigorous requirements included measures for preventing tsunamis from being able to reach and flood the premises of key facilities directly. As the above demonstrates, the devastation caused by destructive earthquakes prompted efforts to ensure and enhance the seismic safety of nuclear power plants. This section focuses on design basis seismic ground motions as essential inputs in the development of seismic designs. **Table 1** summarizes important changes in the formulation of design basis seismic ground motions.

Extremely novel and unique concepts have been adopted in the dynamic analysis conducted alongside static analysis for vital As-class, A-class, or S-class facilities (the As-class

Table 1 Important changes in the formulation of design basis seismic ground motions

Item	Original Seismic Guide (1981)	Revised Seismic Guide (2006)	New regulatory standards for tsunamis and earthquakes
Classification by importance	Four categories (As, A, B, and C)	Three categories (S, B, and C)	Three categories (S, B, and C)
Assigned types of earthquakes	Historical earthquakes Inland crustal earthquakes (triggered by active faults)	Inland crustal earthquakes (triggered by active faults), interplate earthquakes, and intraplate earthquakes	Inland crustal earthquakes (triggered by active faults), interplate earthquakes, and intraplate earthquakes
Assessment of active faults	Dating back 10,000 years (for S_1 earthquakes) Dating back 50,000 years (for S_2 earthquakes)	Dating back to the Late Pleistocene (ca. 120,000–130,000 years ago) or even earlier depending on the survey results	Dating back to the Late Pleistocene (ca. 120,000–130,000 years ago) or even to the Middle Pleistocene (ca. 400,000 years ago) depending on the survey results
Epicentral earthquakes	M 6.5 (hypocentral distance of 10 km)	Defined as seismic ground motions with no specific epicenters (defined as ground motions instead of relying on a magnitude)	Defined as seismic ground motions with no specific epicenters (definition as ground motions instead of relying on a magnitude) (latest findings must be reflected)
Assessment of seismic ground motions	Assessment of two types of design basis seismic ground motions (S_1 and S_2) based on a response spectrum method (point source evaluation: Osaki spectra, etc.)	A combination of two methods employed with respect to design basis seismic ground motions: one method based on a response spectrum (e.g., Taisen spectrum) and another based on a fault model	A combination of two methods employed with respect to design basis seismic ground motions: one method based on a response spectrum (e.g., Taisen spectrum) and another based on a fault model
Tsunamis	No rules	Simple rules as events associated with earthquakes	Rules are defined for the assessment of design basis tsunamis and the safety design for a tsunami

and A-class categories were integrated in the S-class category in the Revised Seismic Guide (2006)). The original Seismic Guide (1981) required design basis seismic ground motions to postulate seismic activity along active faults in addition to historical earthquakes experienced in the past. Design basis seismic ground motions S1 and S2 in the Seismic Guide (1981) have been evaluated by postulating two types of earthquakes (the maximum design basis earthquake and an extreme design basis earthquake) depending on the level of seismic activity along active faults. A requirement to postulate a hypothetical epicentral earthquake with a magnitude of Mj 6.5 was added to the evaluation of S2. As key criteria for the level of seismic activity along active faults, a timeframe encompassing the past 10,000 years was assigned for determining the maximum design basis earthquake, while a timeframe encompassing the past 50,000 years was assigned for determining an improbable extreme design earthquake. In the Revised Seismic Guide (2006), the definition of active faults was changed to cover activity that undeniably took place in the Late Pleistocene (ca. 120,000–130,000 years ago) or later. A newly introduced judgment criterion was the presence of any fault displacement or deformation identified in the last interglacial strata or on the geomorphic surface.

According to the new standards, active faults must be investigated by integrating geomorphological, geological, and geophysical methods. In the identification process, a comprehensive judgment was required by combining these methods depending on the distance of each active fault from the target site. In the Revised Seismic Guide (2006), earthquakes that must be considered for seismic designs are called "earthquakes for investigation." Three types of such earthquakes must be assigned taking into consideration the modes of earthquakes, etc.: inland crustal earthquakes triggered by active faults (including those in the near offshore areas of the coasts), interplate earthquakes, and oceanic intraplate earthquakes (**Figure 1**). The same definition of active faults and the same method for selecting earthquakes for investigation were carried over to the new regulatory standards for earthquakes and tsunamis. Importantly, a clarification was added to the effect that active faults must be defined as dating back to the Middle Pleistocene (ca. 400,000 years ago) if a clear judgment cannot be made on the active faults for the Late Pleistocene or later. Reportedly, this is a clarification to ensure that the Revised Seismic Guide (2006) can be implemented properly rather than a change to the definition of active faults.

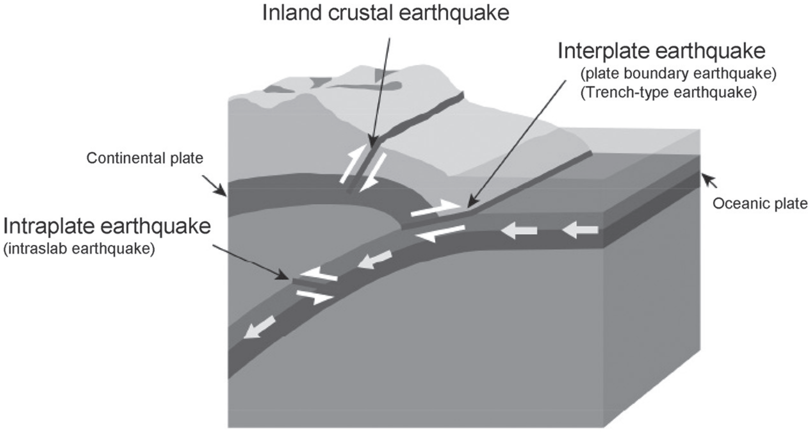

Figure 1 Earthquakes for investigation that must be considered in determining the design basis seismic ground motions

An earthquake is essentially a shearing rupture that spreads over a finite fault plane. The original Seismic Guide (1981) recommended a method for simulating design basis seismic ground motions empirically for an assessment. More specifically, an empirical spectrum (spectrum that expresses the intensity of a ground motion in a period, such as the Osaki spectrum, for example) was applied to a simple model of an earthquake source expressed using the scale (magnitude) and distance from the hypocenter to the target site.

The Revised Seismic Guide (2006) required that the assessment method based on the fault model advanced following the 1995 Kobe earthquake be applied in combination with the compilation of new findings in seismology, earthquake engineering, and other relevant fields. This guide clarified that the results obtained using this method should be prioritized if a source fault is close to the site. The effectiveness of this type of fault model in the assessment of design basis seismic ground motions is discussed in the next chapter. The design basis seismic ground motions assessed in this manner were treated as seismic ground motions with specific epicenters, and they were carried over to the new regulatory standards.

Nevertheless, even detailed surveys, including active fault surveys, cannot assess all possible earthquakes triggered near a site. Therefore, the guide required that all applications commonly consider seismic ground motions defined with no specific epicenters based on observation records. This requirement is the same as that stipulated in the original Seismic Guide (1981) for all applications to consider ground motions from a hypothetical epicentral earthquake with a magnitude of Mj 6.5. The revision was presumably encouraged by the fact that the development of earthquake observation networks in Japan and around the world had made it possible to obtain observation data in near source areas. Another possible reason is the validation of a magnitude of Mj 6.5 and the reliability of near source ground motion predictions due to an Mj 6.5 earthquake. These ground motions define the minimum levels of external forces generated by earthquakes, and they must be continuously revised based on accumulated observation records. The latest findings have been adopted for the implementation of the new regulatory standards for earthquakes and tsunamis.

The basic policy of the Revised Seismic Guide (2006) clarified the need to consider the existence of residual risks (i.e., risks associated with severe damage to facilities, massive releases of radioactive materials from facilities, and resultant disasters involving public exposure to radiation) and required that efforts be made to minimize residual risks by giving appropriate attention to the possibility of seismic ground motions being larger than the design basis seismic ground motions. In practice, however, this guide required that consideration be given to the probability of seismic ground motions exceeding the design basis. Residual risks had not been addressed sufficiently. There was no mention of specific risks and tsunamis were considered only as events associated with earthquakes. The concept of these residual risks was carried over to the new regulatory standards for earthquakes and tsunamis, which require not only reinforced designs to withstand earthquakes, tsunamis, and other external forces, but also countermeasures against severe accidents that may occur if the design basis earthquakes are exceeded.

Lastly, as mentioned at the beginning of this commentary, the new regulatory standards for earthquakes and tsunamis require that important facilities to safety be constructed on ground without any exposure to faults and the like that may become active. In these standards, faults and the like include not only faults that trigger earthquakes, but also those that may secondarily cause a permanent displacement or a slip surface of a landslide that cuts across any support foundation. This requirement has great relevance to the debate over on-site faults, which is obscuring the relationship between active faults and the seismic safety of nuclear power plants. It seems that discussions involving experts from many different fields will be extremely important in reconsidering what active faults are and how their activities affect nuclear power plants in terms of residual risks.

III. Overview and Incorporation of Findings from Recent Earthquakes

Destructive earthquakes involving casualties or property damage (**Figure 2**) have struck many parts of Japan since the 1995 Kobe earthquake prompted the revision of the Seismic Guide. Such earthquakes can be divided into three categories taking into consideration their modes, as illustrated in Figure 1. Some of these earthquakes had a strong impact on discussions concerning the seismic safety of nuclear power plants. Valuable data was obtained from the 1995 Kobe earthquake with the aim of understanding the relationship between an earthquake and an active fault (Rokko-Awaji fault zone) and identifying the characteristics and mechanisms of ground motions near the source. This data led to the development and practical application of ground motion predictions based on fault models [1]. This effective ground motion prediction method based on fault models is also required in the field of nuclear energy under the Revised Seismic Guide (2006) and the new regulatory standards for earthquakes and tsunamis for assigning design basis seismic ground motions. Some time later, the 2007 Chuetsu offshore earthquake (Mj 6.8) directly struck TEPCO's Kashiwazaki-Kariwa Nuclear Power Plant right in the middle of a seismic backcheck that was being conducted in accordance with the Revised Seismic Guide (2006). The intensity of the observed ground motion easily exceeded (about double) the level that would be postulated based on the original

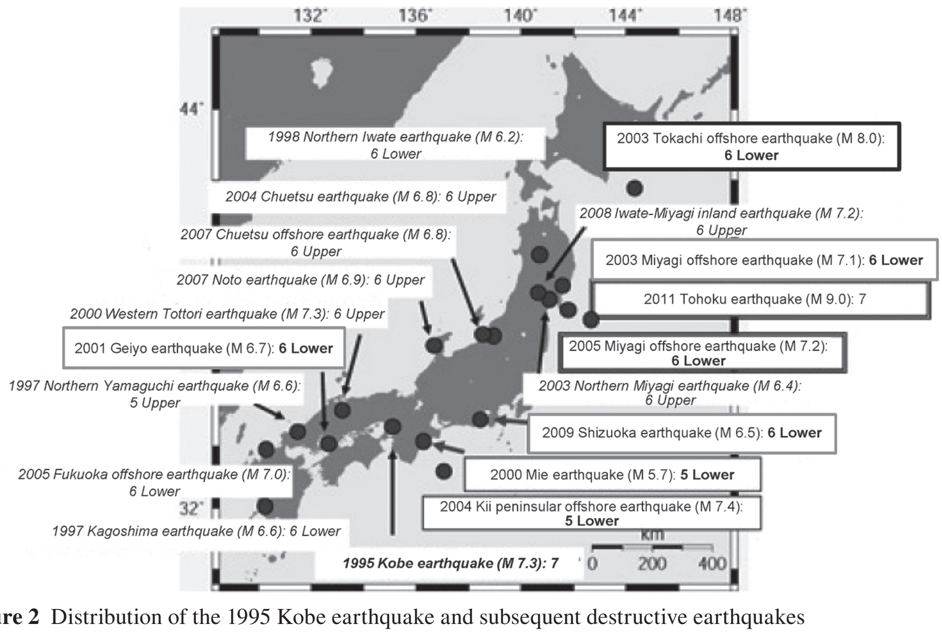

Figure 2 Distribution of the 1995 Kobe earthquake and subsequent destructive earthquakes
A single-border box indicates an intraplate earthquake, a double-border box indicates an interplate earthquake, and other boxes indicate inland crustal earthquakes. The name of each earthquake is followed by the JMA magnitude and the observed maximum seismic intensity according to the JMA scale.

Seismic Guide (1981). The reported seismic intensity of the earthquake at the site was around 7 on the JMA scale. All of the reactors that were in operation shut down properly and no problems arose with regard to the cooling of reactors. All of the important safety functions for the shutting down, cooling of reactors, and containment of radioactive materials were maintained. A later survey found that the earthquake had caused no noticeable damage to important facilities and equipment. The importance of safety margins in the design was pointed out.

This earthquake (1995, Kobe) posed some questions for us. First of all, where was the fault that triggered it? Had this fault been recognized before the earthquake? Sufficiently precise data could not be obtained immediately after the earthquake. The answers to these questions were found a few months later. An investigation clarified that the source fault mainly inclined to the south east, which largely corresponded to an active fault (F-B fault) that had already been identified. Nonetheless, further discussions were necessary to determine whether a seismic source fault can be identified before an earthquake with a medium magnitude of about Mj 6.8. As mentioned earlier, the magnitude corresponds to ground motions with no specific epicenters.

However, could the observed ground motions be predicted as being those from an earthquake with a magnitude of Mj 6.8 before the earthquake occurred? An examination of the source model began immediately after the earthquake. Various analyses revealed that the stress drop in the strong motion generation area (SMGA), which generated short-period ground motions, was slightly larger (about 1.5 times) than the average level for past inland crustal earthquakes. This finding was consistent with the attenuation characteristics of the maximum amplitude. The extremely large maximum amplitude of the observed ground motions in Kashiwazaki-Kariwa Unit 1 proved to be the product of the propagation path characteristics of the seismic waves (i.e., the focusing effect of seismic waves caused by folding). These findings were carried over to the new regulatory standards for earthquakes and tsunamis. This served as a reminder of the importance of conducting surveys on underground structures and the subsequent application for a model based on a fault model.

A similar event took place at the Hamaoka Nuclear Power Plant. During the 2009 Shizuoka earthquake (Mj 6.5), Unit 5 reported a significantly stronger shaking intensity than other units at the same site. Although surveys and analyses are still being conducted, the findings so far point to the possible amplification of the ground motion caused by the low-velocity layer just beneath Unit 5, rather than by the effect caused by the folding structure that occurred around the Kashiwazaki-Kariwa Plant. According to the new regulatory standards for earthquakes and tsunamis, these findings require consideration to be given to the three-dimensional underground structure of the site and the surrounding area, as necessary. Nonetheless, it is debatable whether the phenomenon that occurred at the Hamaoka Plant could have been predicted by any viable calculation of the propagation of the seismic waves based on a three-dimensional model of the underground structure. Given this, it is important to strengthen earthquake observations and to continue analyzing and investigating as much data as possible concerning earthquakes that affect nuclear power plants, and thereby assign design basis seismic ground motions more precisely.

Lastly, the following describes the implications of the 2011 Tohoku earthquake. Located in the northeastern part of Japan, Tohoku has experienced a series of major earthquakes triggered along the Japan Trench by the subducting Pacific Plate. As **Figure 3** demonstrates, the Headquarters for Earthquake Research Promotion had already publicized its long-term assessment of likely earthquakes (scales and probabilities) according to the postulated source zones off the coast between Sanriku and Boso based on records of past earthquakes with a

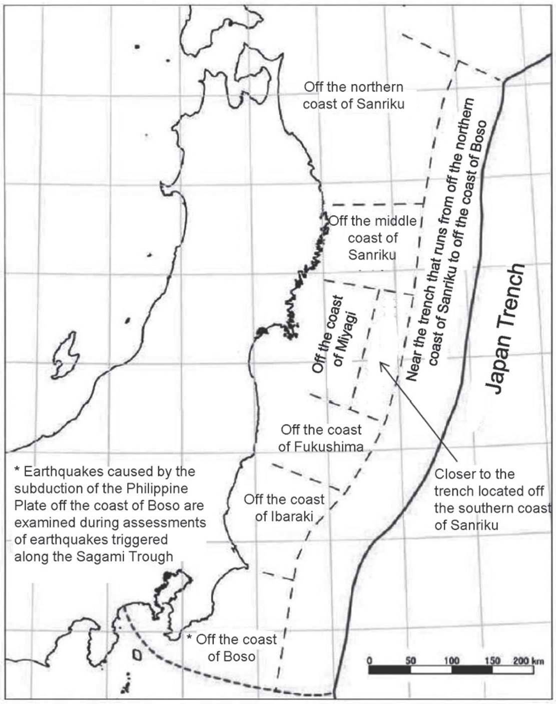

Figure 3 Target areas for the long-term evaluation of seismic activity by the Headquarters for Earthquake Research Promotion and Earthquake Research Committee from off the coast of Sanriku to off the coast of Boso

magnitude of around Mj 7 and 8 [2)].

The 1995 Kobe earthquake prompted the nationwide development of networks for observing strong ground motions, such as the K-NET and KiK-net networks developed by the National Research Institute for Earth Science and Disaster Prevention (NIED). **Figure 4** presents part of the observation records from Aomori in the north to Chiba in the south using aligned timelines. Valuable observation records have been obtained from the Fukushima Daiichi Nuclear Power Plant and all of the other nuclear power plants along the Pacific coast. Figure 4 demonstrates that a characteristic ground motion was recorded in each region. Although two distinct wave groups were recorded in Miyagi and further to the north, only one wave group was recorded in Ibaraki and Chiba. Located in-between these regions, Fukushima reported a very complex wave group composition. In Figure 4, the travel time for each wave group (i.e., the time required for a seismic ground motion to travel from the epicenter to a site) was represented with a dashed line (a constant propagation velocity would have been expressed with a straight line). **Figure 5** presents a source model with five SMGAs based on the assumption that each intersection of a dashed line corresponds to a source area (SMGA) [3)] that generated a wave group. This model was proposed to explain seismic ground motions with periods of 0.1 to 10 seconds, so it cannot provide an entire source process for the 2011 Tohoku earthquake. We can determine the entire source process from **Figure 6**, which shows that the source model (slip distribution) [4)] estimated using the giant tsunami complements the model shown in Figure 5 to explain the observed strong ground motions.

Given that the magnitude of the earthquake could not be anticipated, what about the prediction of seismic ground motions? Thanks to the availability of numerous observation

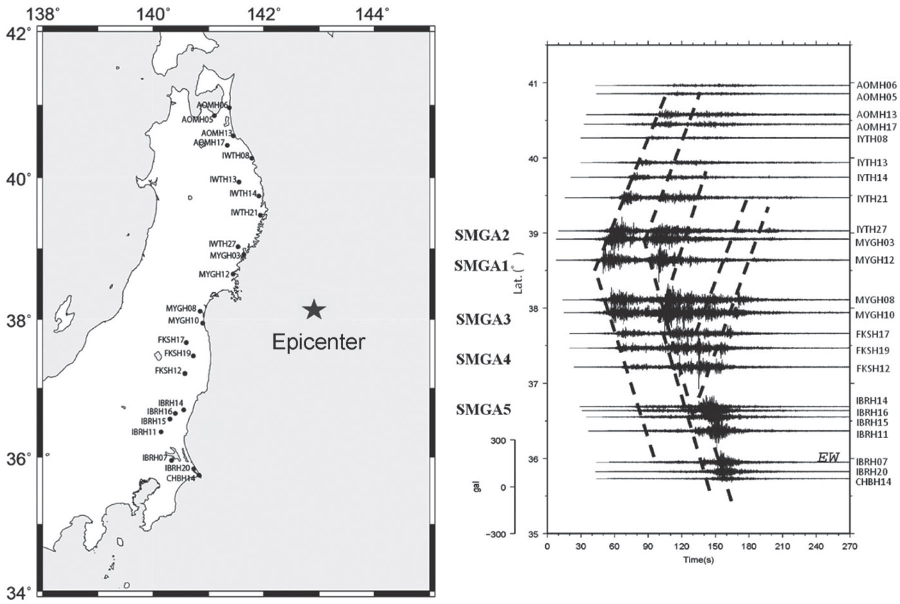

Figure 4 Acceleration waveforms observed during the 2011 Tohoku earthquake and the observation points (source: KiK-net (NIED))
SMGAs 1 to 5 correspond respectively to the five SMGAs shown in Figure 5.

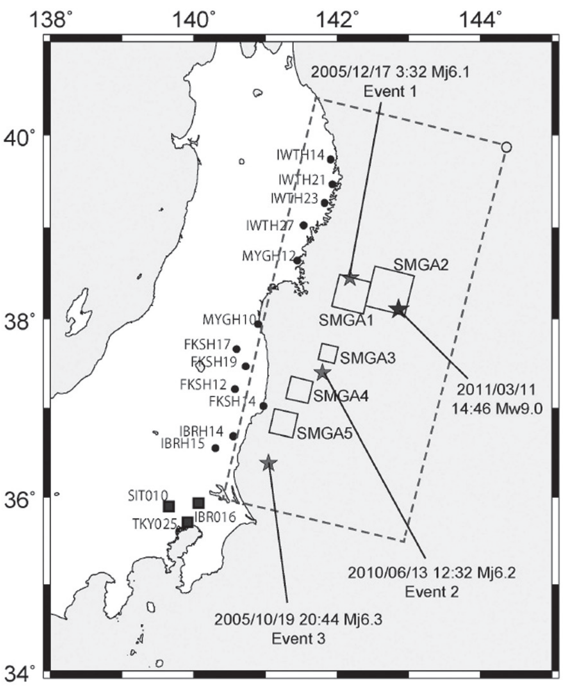

Figure 5 Source model for the 2011 Tohoku earthquake (locations and size of the five SMGAs)

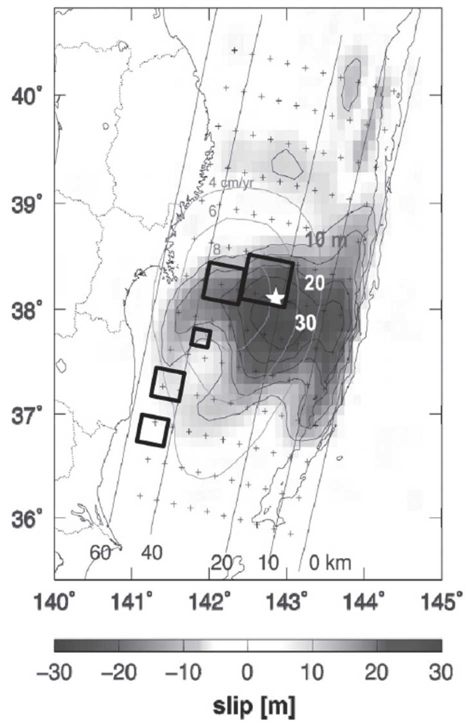

Figure 6 Comparison of the source model (slip distribution) from tsunami data and SMGAs (enclosed in five rectangles)

records, a comparison of ground motion characteristics could be made using the empirical characteristics of past earthquakes (e.g., the attenuation characteristics of maximum amplitudes). In the resulting report, the seismic ground motion was sufficiently within the predictable range taking into consideration the extent of the source zone and the inhomogeneous rupture process, although the magnitude of Mw 9.0 was admittedly beyond the scope of the empirical formula [5]. As described earlier, another report suggests that the assignment of plural simple SMGAs enables the reproduction of a seismic ground motion from 0.1 to 10 seconds, which is the most critical time range in terms of engineering. Moreover, the locations of the respective SMGAs (i.e., the ones off the coast of Miyagi, Fukushima, and Ibaraki) proved almost consistent with the source zones of the interplate earthquakes postulated for the three target sites in seismic backchecks (i.e., the Onagawa Nuclear Power Plant, the Fukushima Daiichi and Daini Nuclear Power Plants, and the Tokai Daini Nuclear Power Plant) (**Figure 7**). The report pointed out that the peak amplitudes of the assessed design basis seismic ground motions did not differ greatly from the observation results. An important task for the future is to consider how any new findings and the identified challenges should be applied under the new regulatory standards for earthquakes and tsunamis to postulate earthquakes for investigation (interplate earthquakes) and to model their sources as well as to estimate the design basis seismic ground motions.

In this figure, the source zones for the linked Miyagi offshore earthquake are postulated for the Onagawa Nuclear Power Plant, the hypothetical Shioyazaki earthquake for the Fukushima Daiichi and Daini Nuclear Power Plants, and the 1896 Kashima Sea earthquake for the Tokai Daini Nuclear Power Plant.

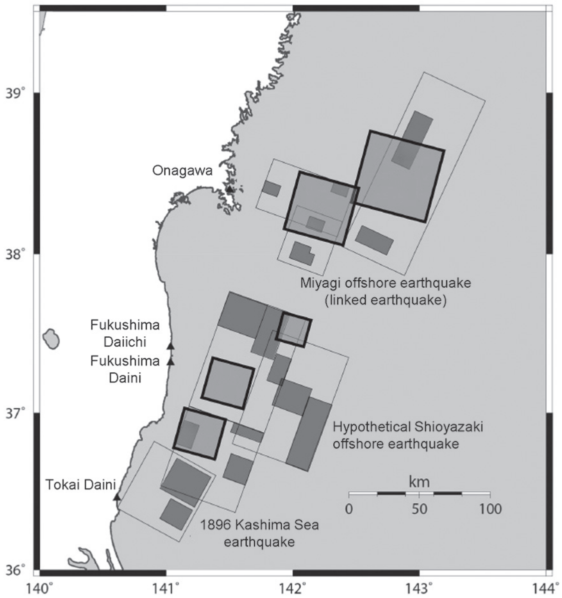

Figure 7 Comparison between the postulated source zone (model) for the interplate earthquake at three nuclear power plants on the Pacific coast (i.e., the Onagawa Nuclear Power Plant, the Fukushima Daiichi and Daini Nuclear Power Plants, and the Tokai Daini Nuclear Power Plant) and the source model for the 2011 Tohoku earthquake with five SMGAs (□).

IV. Conclusions

This commentary provides a brief explanation of the evolution of assessments of design basis seismic ground motions, which greatly influence the seismic safety of nuclear power plants. More specifically, it describes how the original Seismic Guide was established in 1981, how it was revised in 2006 by incorporating new findings, and how it evolved into the new regulatory standards for earthquakes and tsunamis. Advancements in seismology, earthquake engineering, and other relevant fields combined with the data accumulated from earthquake observations have made it possible to predict the seismic ground motions of future earthquakes scientifically. Such predictions have also been employed in the assignment of design basis seismic ground motions. These prediction methods have arguably been advanced by their application to nuclear facilities. Nonetheless, uncertainty concerning seismic sources remains an important factor, particularly in evaluating those earthquakes that have a seismic source located near the target site. The assessment of residual risks as required under the Revised Seismic Guide (2006) should be conducted by not only referencing the exceedance probabilities of design basis seismic ground motions, but also taking into consideration the fragility of the facilities and equipment, the accident sequences, and other overall risks as well as by minimizing such risks through the necessary efforts and measures. As a result, I believe that it is possible to respond to an earthquake that exceeds the postulated scale, such as the 2011 Tohoku earthquake.

The assignment of seismic ground motions as the design basis is extremely important, and it must be based on scientific evidence. Nonetheless, the seismic safety of nuclear power plants can be continuously enhanced by accepting that stronger ground motions than those assigned can take place. Given this, residual risks must be assessed more specifically according to the requirements that have been carried over from the Revised Seismic Guide (2006) to the new regulatory standards for earthquakes and tsunamis. As the importance of safety margins was demonstrated by the 2007 Chuetsu offshore earthquake, safety margins must be further enhanced with regard to the vulnerability of facilities identified in recent stress tests, thereby continuing to improve the seismic safety of nuclear power plants. Any requirement for excessively stronger design basis seismic ground motions without sufficient scientific evidence only obstructs the positive thinking of engineers and does not enhance safety. Meanwhile, the new regulatory standards for earthquakes and tsunamis require the absence of faults and other outcrops that may trigger seismic activity just below important facilities. Without a doubt, it is still difficult for today's science to provide precise predictions of ground surface displacements (permanent) mainly caused by faulting. Risk assessments should arguably be based on the findings available at present and the extensive future use of current technologies to consider the way each displacement occurs and its past history (survey results), rather than by treating possible faulting and other seismic movements as the same. Such efforts can be expected to result in the development of new technologies.

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