II. Further developments of the nuclear accident since that time

1. The Tohoku District-Off the Pacific Ocean Earthquake and the resulting tsunamis

(1) Investigation of the causes due to the occurrence of the earthquake and tsunamis

1) Matters as stated in the June Report

a. Major characteristics of the earthquake

The major characteristics of the Tohoku District-Off the Pacific Ocean Earthquake (hereinafter referred to as the “Tohoku earthquake” in this clause) are as follows:

- Magnitude: The recent Tohoku earthquake occurred along the Japan Trench as shown in Figure II-1-1 at 14:46 on March 11, 2011. It was estimated that the hypocenter of the earthquake occurred this time was in the area off the coast of Miyagi Prefecture as shown in Figure II-1-1, with a depth of 24 km, a moment magnitude of Mw9.0, and a source area of more than 400 km long and approximately 200 km wide.
- Consecutive rupturing: It was estimated that a plate rupture started at the hypocenter in the area off the coast of Miyagi Prefecture and then propagated consecutively to multiple seismic source areas off Iwate Prefecture in the north and off Fukushima and Ibaraki Prefectures in the south (Figure II-1-1).
- Slip: It was estimated that the area near the southern trench off the Sanriku coast and a part of the near-trench offshore areas from North Sanriku to Boso had large slip, with a maximum slip of more than 20 m (Figure II-1-1).
- Interplate coupling in source areas: Thus far, it had been assumed that the shallow plate boundary along the Japan Trench in the offshore area of Miyagi Prefecture was unlikely to store a large amount of strain energy since the area was believed to be creeping. In fact, however, there had been a strong interplate coupling in this area, with the strain energy having been stored for a long time, which resulted in a rupture off the coast of Miyagi Prefecture triggering the extensive Tohoku earthquake (Figure II-1-1).

b. Matters to be investigated

Key matters to be investigated are indicated as follows:

- Factors that have significantly effects on ground motions observed at the site include, of the wide source area, the rupture characteristics in the near-site source area, the consecutive rupturing pattern, etc. Meanwhile, factors that have a great impact on the resulting tsunami water levels are the magnitude, the range of the source area, the slip, the consecutive rupturing pattern of an earthquake, etc.
- The rupture starting point in the area off the coast of Miyagi Prefecture, the consecutive rupturing of multiple seismic sources, and the timing of occurrence were found to be almost the same as the assumption. However, the interlocking of multiple sources over a wide range covering the offshore areas of central Iwate Prefecture, Miyagi Prefecture, Fukushima Prefecture, and Ibaraki Prefecture, the consecutive rupturing, the magnitude of M9 and slip of more than 20 m were beyond expectation.

2) Findings obtained since June 2011

a. Situation regarding aftershock activities, etc. and crustal movements since June 2011, and regarding seismic ground motion observations and seafloor topography surveys, etc.

- Situation regarding aftershock activities, the like, and crustal movements

The number of aftershocks has been gradually decreasing, and the interval of occurrences of earthquakes having a seismic intensity of 4 or greater has become longer compared to June and before, as shown in Figure II-1-2. The only earthquake of M7 or greater that occurred after June was one of M7.3 off the coast of Sanriku on July 10, as shown in Figure II-1-2 (having a maximum intensity of 4). This earthquake caused tsunamis, and the observed highest height of tsunami was 12 cm at Sendai port. Figure II-1-2 also shows the main quake on March 11 and the distribution of subsequent major aftershocks. Among these, in land areas of Fukushima Prefecture, where an M7.0 earthquake occurred on April 11, to Ibaraki Prefecture, shallow earthquakes of M3 to M4 have frequently occurred (with intensity of 3 to 4).

In the areas away from the aftershock activities, an M5.4 earthquake with a seismic intensity of more than 5 occurred in central Nagano Prefecture on June 30, with a depth of 4 km. Its relation with the Tohoku earthquake is, however, unknown.

The situation of crustal movements in the Tohoku coastal areas indicates that subsidence aftereffects have been continuing in the areas to the north of the seismic source, while upheaval aftereffects have been occurring in the areas to the south, as shown in Figure II-1-3. However, the velocity of those movements has been decreasing.

- Situation of seismic ground motion observations and seafloor topography surveys, etc.

Following the June Report, universities and research institutes in Japan have been vigorously continuing tocollect and analyzing observation and survey data of earthquakes and tsunamis associated with the Tohoku earthquake.

The observation networks of K-NET and KiK-net operated by the National Research Institute for Earth Science and Disaster Prevention (NIED), an independent administrative institution, have obtained records of strong motions at more than 1,000 observation stations, of which 20 stations recorded peak ground acceleration of 1,000 Gal or above. Of those 20 stations, two stations observed an extremely high level of ground acceleration of 2,000 Gal (MYG004=2,933 Gal at Kurihara City, Miyagi Prefecture; MYG012=2,019 Gal at Shiogama City, Miyagi Prefecture).

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC), an independent administrative institution, conducted a seismic reflection survey and a seafloor topography survey using bathometers, etc. in the source area of the Tohoku earthquake during March 15 to 31, 2011. Based on the results of the seafloor topography survey, JAMSTEC published that a particularly large displacement had been found on the west side of the trench axis. JAMSTEC indicated that the displacement represented a seafloor topographic change caused by the Tohoku earthquake, and also noted that a zone extending from the vicinity of the hypocenter of the main quake to the trench axis (the area on the west side of the trench axis) may have moved in a southeasterly to east-southeasterly direction by about 50 m, and raised about 7 m. In addition, on July 30 to August 14, 2011, JAMSTEC conducted a submersible exploration using the manned submersible research vehicle “Shinkai 6500” at the landward slope along the Japan Trench in the source sea area of the Tohoku earthquake (Figure II-1-4). The results of the exploration confirmed a crack extending about 80 m or more in a north-south direction, with a width and depth of about 1 m, in a location where previous surveys had found no cracks (Figure II-1-4, Site 1). JAMSTEC indicated that the crack was likely to be caused by a sequence of seismic activities including the Tohoku earthquake.

The Port and Airport Research Institute (PARI), an independent administrative agency, published additional observation records, as well as recovering recording instruments and analyzing data obtained, of the observed tsunami waveforms by GPS buoys, which had been unavailable due to the disruption of communications when the tsunamis occurred (Figure II-1-5).

The 2011 Tohoku Earthquake Tsunami Joint Survey Group, organized by domestic universities and research institutes, etc., released its field survey results on tsunami trace height, covering a wide range of regions from Hokkaido to Okinawa, etc, at a briefing session on July 16 and has also made it available on its website (http://www.coastal.jp/ttjt/).

b. Examples of efforts for investigating mechanisms that cause earthquakes

- The Central Disaster ManagementCouncil has summarized the modalities for estimating earthquakes and tsunamis and the objectives for future consideration as follows: "Previous disaster-prevention measures have assumed those earthquakes and tsunamis that recurred in years past are likely to occur on the same scale in the near future, and are imminent. However, the recent earthquake was far beyond the scope of the assumption, resulting in devastating damage. For the purpose of estimating earthquakes and tsunamis in the future, the largest possible earthquake and tsunami that allows for all possibilities should be considered and discussed, by turning away from the old mindset, based on scientific findings including tsunami deposit surveys. Even once a certain earthquake and tsunami is assumed, it is essential to review it, as appropriate, by incorporating the recent scientific findings. Therefore, it will be necessary to review and discuss, area by area, the estimation of earthquakes and tsunamis, as soon as possible".

  Exploration of tsunami sediment is actively proceeding as shown in Figure II-1-6. At a coast of Kesennuma City, Miyagi Prefecture, Hirakawa (2011) found the tsunami traces, which indicate that 10 m class giant tsunamis had arrived six times in the past 6,000 years. This is showing the possibility of repeated occurrence of M9-class giant earthquakes like the Tohoku earthquake at the offshore area of Sanriku, Miyagi Prefecture every 1,000 years.

c. Examples of efforts for investigating mechanisms that generate ground motions

The investigation into mechanisms of seismic source process and the prediction of strong ground motions by using fault models are conducted at universities, research institutes, and other such entities. The fault model method, based on the idea that strong ground motions have three characteristics of seismic source, propagation path, and site amplification as shown in Figure II-1-7, linearly combine these three characteristics by using Green's function to determine strong motions. The prediction of strong motions based on the fault models is frequently performed by evaluating the period characteristics with division of long-period and short-period waves using a modeled seismic source, and subsequently combining and synthesizing the two waves through a hybrid method. The former waves, long-period ground motions, are analyzed theoretically, and the latter, short-period ground motions, are analyzed based on the stochastic or empirical Green's function method.

Presented below are examples showing the analyzed results of long-period ground motions and short-period ground motions, respectively, and also a hybrid-based analysis of ground motions, for the Tohoku earthquake.

- Source rupture process based on long-period ground motions

The Japan Nuclear Energy Safety Organization (JNES), an incorporated administrative agency, estimated the source rupture process in terms of long-period ground motions. The inference conditions are considered as follows. A fault size of 420 km long and 210 km wide is assumed based on the distribution of aftershocks. Non-uniform fault strikes and dip angles were set considering a strike change in the Japan Trench and a dip angle change for the subducting plate. Station-specific velocity structure models were used by considering regional characteristics of the depths of the Conrad discontinuity and the Mohorovicic discontinuity. The source rupture process was then derived accordingly through a waveform inversion analysis, using seismic records of strong motions in the periodic band between 10 and 125 sec. obtained by NIED (Figure II-1-8, left side). JNES analysis results revealed that occurrence of a large slip just less than 70 m in a zone extending from the vicinity of the hypocenter to the trench was estimated, and that the aftershocks were concentrating around the large slip.

Shao et al. (2011), by using teleseismic waveforms, conducted an inversion analysis of the source rupture process of the Tohoku earthquake, and proposed the seismic source model with an estimation of a large slip of about 55 m occurring on the west side of the trench (Figure II-1-8, middle).

The Geospatial Information Authority of Japan (GSI) and the Japan Coast Guard (JCG), based on the results of both land area GPS observation and seafloor crustal movement observation, proposed a model of coseismic slip distribution on the interplate boundary (Figure II-1-8, right side).

All of the above three seismic source models based on long-period ground motions estimated slips in the range of 55 m to just less than 70 m, which are consistent with models based on GPS observation and seafloor crustal movement observation. These studies found that slips caused by the recent earthquake, depending on areas, may have been between 55 m and not quite 70 m. Further refinement in investigation and analysis is expected.

- Source rupture process based on short-period ground motions

Short-period ground motions observed in the vicinity of source areas are made up of multiple pulse wave groups. Records of ground motions observed on the observation lines parallel to the strike of the fault model indicate that these wave groups were generated in five locations in the source areas, including the areas off the coasts of Miyagi, southern Iwate, Fukushima and Ibaraki Prefectures (supposedly generated in asperities).

Irikura and Kurahashi (2011), on the assumption of a configuration of asperities, proposed a seismic source model to simulate strong ground motions based on the empirical Green’s function method (Figure II-1-9, to the left). Meanwhile, Kawabe and Kamae (2011) are also proposing their own model (Figure II-1-9, right side). These models enabled characteristic seismic waveforms observed at observation stations in the coastal areas from Iwate Prefecture to Ibaraki Prefecture to be simulated for the most part. The areas generating short-period strong motions as shown in Figure II-1-9 are not the same asperities estimated from long-period ground motions , in which there occurred a large slip along the Trench, but are mostly found in the deep areas on the west side of the hypocenter (rupture starting point), which is one of the major characteristics common to the models proposed by Irikura/Kurahashi (2011) and Kawabe/Kame (2011). It is considered that such a concentration of asperities in the plate subducting direction from the point of view of the hypocenter is causing a directivity effect, the dependence of the shape and the strength of the short-period waves on the rupture propagation direction. The fault model method allows for the directivity effect. Another major characteristic is that all of the seismic moments released in the areas established as asperities generating short-period strong motions were estimated as having moment magnitudes of Mw8.4 or lower.

Meanwhile, Irikura and Kurahashi (2011) compared the values of peak ground acceleration and maximum velocity observed in the Tohoku earthquake with the findings using an attenuation relationship (strong motion prediction equation) (Figure II-1-10). Based on the comparison results, they note that peak ground acceleration (PGA, Figure II-1-10, right side) was virtually equivalent to an earthquake of Mw8 in terms of strong ground motions. In addition, peak ground acceleration (PGA, Figure II-1-10, left side) was virtually equivalent to an earthquake of Mw8 in the distance of over 100 km. However, confined to the vicinity of the fault, there is a tendency to exceed Mw8.0 earthquake level. The one of the reasons is that, by the attenuation relationship, the directivity effect important for short-period waves is not expressed.

- Seismic ground motion analysis based on source rupture process

JNES, with a view to studying the methodologies for establishing a fault model for the purpose of evaluating short-period ground motions, conducted a seismic ground motion analysis, based on the fault model method, of the postulated Miygaki-ken-Oki earthquake (interlocked type, Mw8.2) by the Headquarters for Earthquake Research Promotion, Ministry of Education, Culture, Sports, Science and Technology published before the Tohoku Earthquake (Mw9), with the Shizugawa observation station (MYGH12) near the Onagawa NPS as the target point for evaluation. Then the Organization compared the analyzed results with the seismic waveforms observed in the Tohoku earthquake (Figure II-1-11). This indicated that the evaluated ground motions at the Shidzugawa station in the vicinity of the Onagawa NPS were virtually at the same level as the waveforms observed in the recent earthquake. From these studies, it may be said that the

Tohoku earthquake was a giant M9 earthquake in terms of long-period ground motions, but at the same time hat the same characteristics of an M8 earthquake in terms of short-period ground motions.

d. Examples of efforts for investigating into the mechanisms that cause tsunamis

Useful observation and survey data in analyzing the tsunami source rupture process of the Tohoku earthquake and resulting tsunamis have been increasing with addition and upgrading, as described in 2) a. "Situation of seismic ground motion observations and seafloor topography surveys, etc." Based on these data, etc., universities and research institutes in Japan are carrying out elaborate analyses of the tsunami source rupture process.

The estimation of tsunami water level involves, first of all, establishing a tsunami source model (tsunami source rupture process), as shown in Figure II-1-12. Then the tsunami source model is used to figure out the amount of seafloor crustal movement through crustal movement analysis, which is defined as the initial tsunami profile. In addition to the initial tsunami profile, far field seafloor topography model, near field seafloor topography model and onshore topography model as shown in the Figure are used to obtain a tsunami water level through tsunami propagation analysis.

In estimating the tsunami source rupture process from the observation and survey data, following the determination of the far field seafloor topography model, near field seafloor topography model and onshore topography model, The tsunami source rupture process is obtained through the inversion analysis fitting with the observed tsunami waveforms by tide gauges in different places (equivalent to the tsunami water level).

Tsunami waveforms in different places are estimated with minor adjustments, based on the above tsunami source rupture process, as well as the established far field seafloor topography model, near field seafloor topography model and onshore topography model.

Presented below are examples showing the estimated tsunami source rupture process, and also the estimated tsunami waveforms at nuclear sites, caused by the Tohoku earthquake.

- Estimation of tsunami source rupture process (tsunami source model)

The International Institute of Seismology and Earthquake Engineering (IISEE) of the Building Research Institute, an independent administrative institution, and the Earthquake Research Institute (ERI) of the University of Tokyo, using the observed tsunami waveforms by the GPS buoy as shown in Figure II-1-13, renewed the tsunami source model of Fujii and Satake (2011) through waveform inversion analysis.

Tohoku University, based on the tsunami source model of Fujii and Satake (2011), proposed the tsunami source model to extend the tsunami source zone further to the north, by using the tsunami trace height surveyed on the Iwate Prefecture side (Figure II-1-14).

JNES, based on the above two findings, as well as three characteristics (M9; consecutive; slip of 20 m or more) relevant to the tsunami resulting from the Tohoku earthquake, estimated a tsunami source model that can determine the tsunami waveforms and inundation height observed at the Fukushima Dai-ichi NPS, etc.

The method used in estimating the tsunami source model is joint inversion analysis, which allows a fault slip to be obtained based on the observed tsunami waveforms and amount of crustal movement. This method, firstly, models the entire tsunami source as an aggregation of multiple sub faults, as shown in Figure II-1-15. Secondly, the changed water level waveforms and the amount of crustal movement, by observation point, with a given unit amount of slip for each sub fault, are supposed to have been obtained, which are called as Green's functions. And it follows that slips by sub faults that, combined with those Green's functions, best fit the observed tsunami waveforms and the amount of crustal movement can be obtained for all intended observation points.

Along with the above three characteristics relevant to the Tohoku earthquake and resulting tsunamis, shallow spray faults as the fourth characteristic, which are becoming a new focus of attention, are also considered for the purpose of modeling the tsunami source.

In terms of the first characteristics of magnitude (M9), an extensive tsunami source model was established, based on the tsunami source models of Fujii and Satake (2011) and of Tohoku University, as the M9-corresponding coverage of about 600 km long and about 200 km wide as shown in Figure II-1-15 being divided into 48 sub faults (40 of 50 km x 50 km, and eight of 50 km x 30 km). For the second and third characteristics of consecutiveness and the amount of slips, respectively, the difference in rupture start time among sub faults (a delay from the start time of the first rupturing) and the duration time were taken into consideration as parameters for a tsunami source model. Before the Tohoku earthquake occurred, these parameters had been considered to have only a small impact on the water level on the coast. However, in terms of the wide-ranging tsunami source area resulting from the Tohoku earthquake, it has been recognized that the parameters could have a considerable impact on tsunami water level, depending on how the long duration time from the rupturing start to stop for several sub faults, and associated delays in rupture start time are dealt with. Accordingly, the rupture duration time of up to 5 minutes was established.

As regards the fourth characteristic, shallow spray faults,long-period waveforms and short-period waveforms found in the observed tsunami waveforms by the GPS buoy, etc. in the offshore area of southern Iwate Prefecture are estimated to be caused by deep faults and shallow faults, respectively. Therefore, in this analysis, shallow spray faults in the offshore areas from northern Miyagi Prefecture to northern Iwate Prefecture along the trench axis were considered as possible causes of short-period waveforms, as shown in Figure II-1-16. Accordingly, following the determination of slightly high-angle spray faults for the relevant sections (the northern half of the easternmost line) of the tsunami source model as shown in Figure II-1-15, a slip for each sub fault was obtained through joint inversion analysis.

The observed tsunami waveform data used in the inversion analysis include some of those data by the GPS buoys of PARI and the tide gauges of the Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism as shown in Figure II-1-17, those by the tsunami gauges of the United States National Oceanic and Atmospheric Administration (NOAA), those by the tide gauges at the Fukushima Dai-ichi, Onagawa and Tokai Dai-ni NPS sites as shown in Figure II-1-18, and those data of vertical crustal movement by the Geographical Survey Institute's GPS observation as shown in Figure II-1-19.

The estimated tsunami source rupture process (tsunami source model) by the joint inversion analysis is as shown in Figure II-1-20(a) to (e) showing trends in distribution of slips, by every minute, after the earthquake occurred. Indicated in Figure II-1-20(f) is the distribution of aggregate slips of these slips by sub faults. The figures above found that, in the first place, plate slips had propagated near the rupture start point. Then supposedly, they propagated into slightly deeper areas on the west side of the rupture start point, after which they shifted to the shallow areas mostly along the trench and continued to propagate. A concentration of asperities of large slips was located in the shallow areas along the trench, resulting in a maximum slip of above 70 m. These findings above are virtually consistent with the estimation results of the seismic source rupture process models, and of the tsunami source rupture process, in universities and research institutes at home and abroad.

- Water level simulation using estimated a tsunami source model

JNES, with a view to making comparisons with the observed tsunami waveforms by the GPS buoys, conducted a tsunami propagation analysis using the tsunami source rupture process (tsunami source model) as shown in the above, taking into consideration the difference in rupture start time and the rupture duration time among the 48 sub faults mentioned above. For the purpose of this analysis, a numerical analysis method based on the linear long wave theory was used.

The analyzed results are shown in Figure II-1-21. Also shown in the Figure are the observed tsunami waveforms by the GPS buoys. From the Figure, it can be seen that the simulated tsunami waveforms have well reproduced the shape of the short-period waveforms of the first wave observed in the offshore areas of southern Iwate Prefecture (G802) and mid-Iwate Prefecture (G804), which is one of the characteristics of the Tohoku earthquake and resulting tsunamis. Figure II-1-22 shows how the tsunamis propagated after the time of occurrence of 14:46. It indicates that as early as about 36 minutes after the earthquake (15:22), the tsunami reached the Fukushima Dai-ichi NPS.

As an analysis example of mechanisms that caused tsunamis after the Tohoku earthquake, JNES compared the analyzed results based on the difference in rupture start time and the duration time, as shown in Figure II-1-21, with those results based on the tsunami source model which establishes the aggregate slips as shown in Figure II-1-20(f) all at once (with no respect to the difference in rupture start time). This enabled the difference in rupture start time and the rupture duration time among multiple seismic sources, which had been considered to have only a slight impact on tsunami water level, to be discussed as well.

The analyzed results are shown by the green line in Figure II-1-23. Also shown in the Figure are the analyzed waveforms (in blue) and the observed waveforms (in red) as shown in Figure II-1-21. From the Figure, it can be seen that, as typically indicated for Off Northern Miyagi Prefecture(G803), the analyzed waveforms based on a tsunami source model that establishes aggregate slips all at once are greatly different from those waveforms based on a tsunami source model which takes into consideration the difference in rupture start time and the duration time, resulting in significant effects being found. These findings indicate that they should be the focus of attention when a tsunami source for estimation in the future is considered and discussed.

Meanwhile, JNES also conducted a tsunami propagation analysis for nuclear sites, using the same tsunami source rupture process (tsunami source model).

The simulation results for the Fukushima Dai-ichi and the Tokai Dai-ni NPSs are respectively shown in Figure II-1-24. Also shown in the Figure are the tsunami waveforms observed at each NPS. (The observed waveforms at the Fukushima Dai-ichi NPS were interrupted during recording, resulting in them not being able to be measured.) From the Figure, it can be seen that the simulated and observed waveforms are consistent for both NPS, respectively.

e. Common matters regarding mechanisms that cause earthquakes and tsunamis

- The seismic source rupture process (seismic source model) and the tsunami source rupture process (tsunami source model) were obtained through inversion analysis using the observed ground motion data and the observed tsunami waveform data, respectively. The analyses for both resulted in slips, as one of the major factors of mechanisms that cause the seismic and tsunami sources, being 55 m to not quite 70 m in the shallow area along the Japan Trench, which was consistent with the observed seafloor topography movement.

- The Tohoku earthquake was likely to be a gigantic earthquake of M9 in terms of long-period ground motions, but at the same time to have possibility of same characteristic as an earthquake of M8 in terms of short-period ground motions. This is an important piece of knowledge, since short-period ground motions are important to seismic design for nuclear facilities.
- It is likely that the factors that had a great impact on the tsunami water level were a large slip of 55 m to not quite 70 m in the shallow offshore areas from northern Miyagi Prefecture to northern Iwate Prefecture along the Trench axis, and the overlap effect of the water level due to a delay in rupture start time associated with consecutive rupturing of multiple seismic source areas.

3) Future considerations

- The Nuclear Safety Commission (NSC) is reviewing the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities taking into detailed consideration the organized analyses, as well as the findings and lessons, of the recent earthquake and resulting tsunamis, the organized experiences and findings from seismic safety back-checks, and matters relevant to residual risks, etc. For the purpose of evaluating "ground motions established with identification of sources," as stated in this Regulatory Guide revised in 2006, long-period ground motions are supposed to be determined through theoretical analysis, and short-period ground motions to be obtained by using the empirical Green function method, etc., both of which are to be combined through a hybrid method. Even for a gigantic earthquake on the same scale as the recent one, short-period ground motions as an important factor in terms of seismic safety can likely be well evaluated once an earthquake of Mw8, and an asperity in the vicinity, have been established, as in the case of the Onagawa NPS.
- For the purpose of estimating earthquakes and tsunamis in the future, the largest possible earthquake and tsunami that allows for all possibilities

should be considered and discussed, by turning away from the old mindset, based on scientific findings including tsunami deposit surveys. Even once a certain earthquake and tsunami is assumed, it is essential to review it, as appropriate, by incorporating the state of art scientific findings. Therefore, it will be necessary to review and discuss, by area, the estimation of earthquakes and tsunamis, as soon as possible.

- The same analysis, to the extent possible, as that of the Tohoku earthquake (2011: Mw9.0) should be conducted for those huge earthquakes on the order of M9 that have occurred around the world, including the Kamchatka earthquake (1952: Mw9.0), the Chile earthquakes (1960: Mw9.5; 2010: Mw8.8), the Alaska earthquake (1964: Mw9.2), and the Sumatra earthquake (2004: Mw9.1), based on which, along with the findings from the Tohoku earthquake, methodologies for establishing fault models and tsunami source models corresponding respectively to strong ground motion evaluation and tsunami water level for such huge earthquakes should be analyzed and considered.
- The applicability of the seismic source model and the tsunami source model obtained based on the Tohoku earthquake to the Nankai Trough and faults in the eastern edge of the Japan Sea should be studied and discussed.
- In developing a seismic source model for the Tohoku earthquake, in which the observation stations of strong motions have only been located on the west side of the main seismic source (in land areas), with a rupture in the area of a larger slip on the Trench side of the publicly-available waveform inversion results being relatively located far off the stations, there results the problem that a generated short-period ground motion has not been observed at the observation points. Therefore, further examination is needed.
- An investigation into causes of the tsunami source rupture process of the tsunamis resulting from the Tohoku earthquake should be further refined and also, the effects of the difference in rupture start time among multiple seismic sources and the duration time on tsunami water level should be studied through detailed analysis.

(2) Restoration and reconstruction status from general disaster

1)Overview of general damage situation shown in the June Report

The general disaster situation as of June, 2011, is shown in Table II-1-1. The whole area flooded due to the tsunamis stretched to 561 km^2. Damaged houses, including complete, half and partial collapses, number approximately 475,000 in total. The number of damaged public facilities and educational facilities amount to approximately 18,000.

Regarding lifeline infrastructure, there were approximately 4,000 damaged parts of roads and approximately 7,280 damaged parts of railroads. Approximately 460,000 households experienced a suspension of natural gas supply, approximately 4,000,000 households were without electricity, and 800,000 experienced disconnected telephone lines, among other issues.

More than 120 sediment disasters, including landslides, slope collapse and ground deformation, occurred across a broad area spanning Iwate, Miyagi, Fukushima, Tochigi, and Ibaraki prefectures. In Fukushima prefecture, a few people went missing due to a dam collapse. In Chiba prefecture, massive ground liquefaction occurred in the bay area, including such cities as Urayasu and Makuhari, as well as at the Kujukuri plain, etc.

The total number of dead/missing due to this earthquake disaster stands at 23,769 (as of 17:00, May 30, Emergency Disaster Countermeasures Headquarters).

2) status since June

Restoration and reconstruction status since the general disaster and lifeline disruption since June are shown in Table II-1-1.

There have been no changes regarding the area flooded due to tsunamis since the report of June. The total number of damaged houses, including complete, half and partial collapses, are approximately 792,000 (released by Emergency Disaster Countermeasures Headquarters, as of August 9 at 17:00), and the numbers are on the rise as damage investigation progresses. The number of damaged public buildings and educational facilities amounted to approximately 18,000 (released by Ministry of Education, Culture, Sports, Science and Technology, as of August 8 at 10:00), and there has been no significant change from the number reported in June.

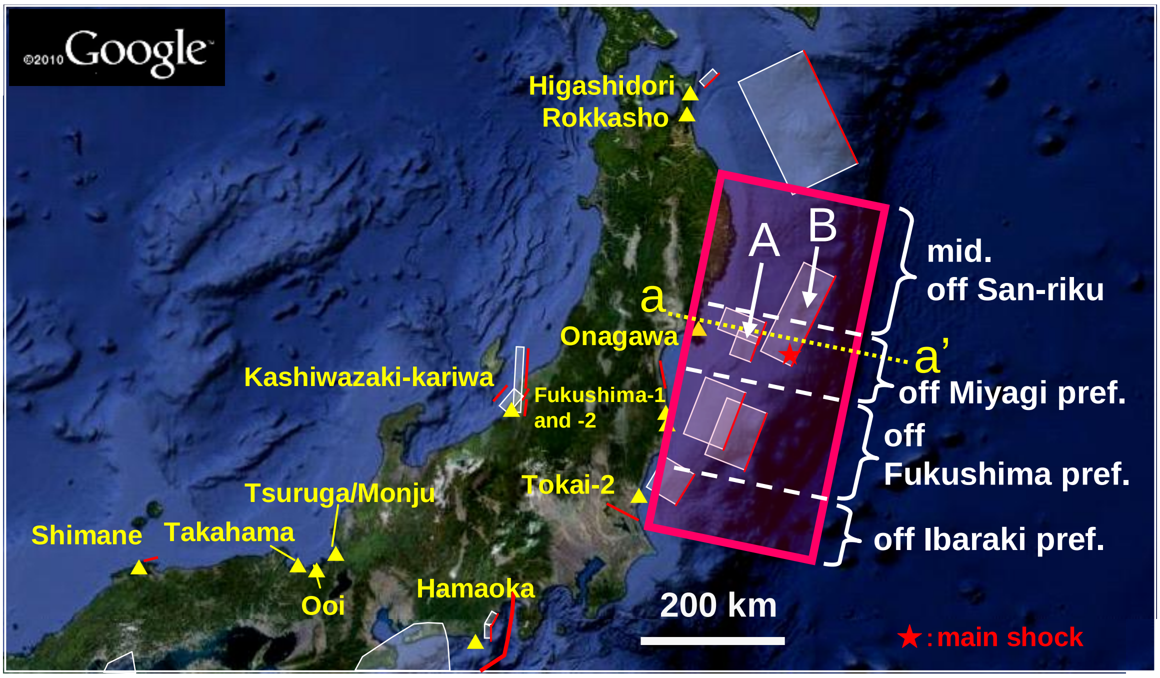
Regarding the current state of lifelines restoration, the damaged parts of roads now number approximately 3,700, the restoration rate of the "Shinkansen" bullet train is 100%, the restoration rate of local trains is 96%, the number of households whose gas supplies have resumed is approximately 420,000, power has been restored throughout the jurisdiction of Tohoku Electric Power Co., Inc. in all regions except those where houses were washed out, and the number of disconnected telephone lines is approximately 14,000. The total number of dead/missing due to the earthquake was 20,444 (as of August 9, 2011 at 17:00, as released by the Emergency Disaster Countermeasures Headquarters) and the numbers of persons missing are generally on the decrease as investigations progress.

Table II-1-1 Restoration and reconstruction status from general disaster and lifeline disruption

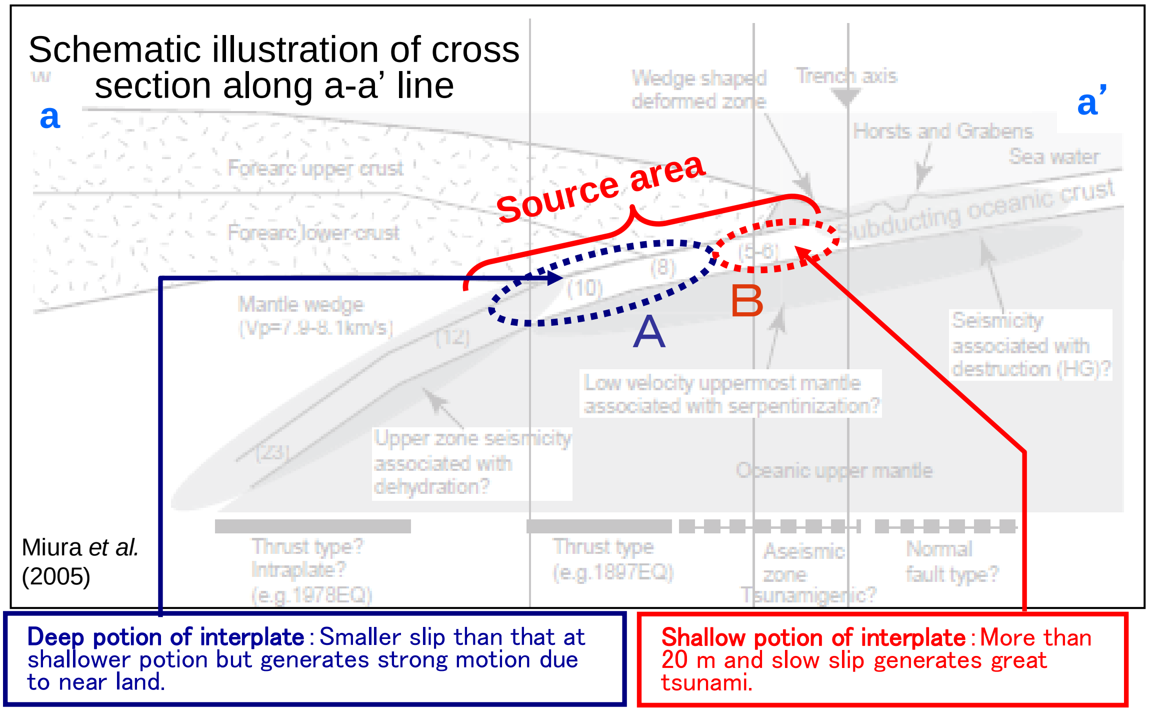
<table>
<tr><th>Human suffering</th><th>The Tohoku District-off the Pacific Ocean Earthquake (September report)</th><th>The Tohoku District-off the Pacific Ocean Earthquake (as of June)</th></tr>
<tr><td>Death</td><td>15,687 (see Note 1)</td><td>15,270 (see Note 8)</td></tr>
<tr><td>Missing</td><td>4,757 (see Note 1)</td><td>8,499 (see Note 8)</td></tr>
<tr><td>Injured</td><td>5,714 (see Note 1)</td><td>5,363 (see Note 8)</td></tr>
<tr><td>Total</td><td>26,158 (see Note 1)</td><td>29,132 (see Note 8)</td></tr>
</table>

<table>
<tr><th colspan="2">Facility-related matters, etc.</th><th colspan="2">The Tohoku District-off the Pacific Ocean Earthquake (September report)</th><th colspan="2">The Tohoku District-off the Pacific Ocean Earthquake (as of June)</th></tr>
<tr><td rowspan="5">Damaged houses</td><td>Complete collapse</td><td colspan="2">112,703 houses (see Note 1)</td><td colspan="2">83,579 houses (see Note 9)</td></tr>
<tr><td>Half collapse</td><td colspan="2">143,760 houses (see Note 1)</td><td colspan="2">31,660 houses (see Note 9)</td></tr>
<tr><td>Partial collapse</td><td colspan="2">511,811 houses (see Note 1)</td><td colspan="2">243,661 houses (see Note 9)</td></tr>
<tr><td>Inundated</td><td colspan="2">23,630 houses (see Note 1)</td><td colspan="2">8,852 houses (see Note 9)</td></tr>
<tr><td>Total</td><td colspan="2">791,904 houses (excluding 263 houses damaged due to fire)</td><td colspan="2">367,752 houses (excluding 260 houses damaged due to fire)</td></tr>
<tr><td rowspan="2">Restoration of houses</td><td>Temporary dwellings</td><td colspan="2">Construction of 49,815 houses underway
(46,050 of such houses have been completed).</td><td colspan="2"></td></tr>
<tr><td>The number of residences for national public employees and public houses, etc. able to be provided as housing for victims.</td><td colspan="2">59,664 houses</td><td colspan="2"></td></tr>
<tr><td rowspan="12">Damage to non-residential facilities</td><td>Educational facilities</td><td colspan="2">Property damage: 12,123 cases; damage to buildings: 6,284 cases (see Note 2)</td><td colspan="2">Property damage: 11,017 cases; damage to buildings: 6,211 cases (see Note 10)</td></tr>
<tr><td rowspan="5">Roads</td><td rowspan="5">3,665 locations
(see Note 1)
Damaged locations are divided as follows.
Roads: 3,559
Bridges: 77
Railways: 29</td><td>(Sections of roads closed to traffic)</td><td rowspan="5">3,970 locations
(see Note 9)</td><td>(Sections of roads closed to traffic)</td></tr>
<tr><td>Expressways (except those in the capital): one route (see Note 3)</td><td>Expressways (except those in the capital): 17 routes (see Note 11)</td></tr>
<tr><td>Roads controlled by the Ministry of Land, Infrastructure, Transport and Tourism: two sections (see Note 3)</td><td>Roads controlled by the Ministry of Land, Infrastructure, Transport and Tourism: 31 sections (see Note 11)</td></tr>
<tr><td>National roads under prefectural control: 10 sections (see Note 3)</td><td>National roads under prefectural control: 45 sections (see Note 11)</td></tr>
<tr><td>Prefectural roads, etc.: 118 sections (see Note 3)</td><td>Prefectural roads, etc.: 256 sections (see Note 11)</td></tr>
<tr><td rowspan="3">Railways</td><td colspan="2">Shinkansen: 100% recovery (see Note 4)</td><td colspan="2">Shinkansen: approx. 1,200 locations (see Note 12)</td></tr>
<tr><td colspan="2">Local trains: 96% recovery (see Note 4)</td><td colspan="2">Local trains: approx. 4,400 locations (see Note 12)</td></tr>
<tr><td colspan="2"></td><td colspan="2">Damage due to the tsunami: approx. 1,680 locations (see Note 12)</td></tr>
<tr><td>Airports</td><td colspan="2">All 13 airports in the disaster-stricken area and surrounding areas are now available (see Note 1).</td><td colspan="2"></td></tr>
<tr><td>Harbors</td><td colspan="2">Presently 199 of 373 berths are in use (see Note 1).</td><td colspan="2"></td></tr>
<tr><td>Rivers</td><td colspan="2">Emergency recovery of 53 locations across six river systems has been completed (see Note 1).</td><td colspan="2">Collapse of embankments, etc.: 2,115 locations (see Note 9)</td></tr>
<tr><td rowspan="6">Lifeline-related matters</td><td>Suspension of water supply</td><td colspan="2">Approximately 48,000 houses (see Note 7)
In areas other than those where residential buildings were washed away due to the tsunami, only 32 houses are suffering from the suspension of water supply. The number of houses to which water supply has been recovered so far is 2,250,000.</td><td colspan="2">Peak number of houses suffering suspension: approx. 2,300,000 (see Note 13)</td></tr>
<tr><td>Suspension of gas supply</td><td colspan="2">Gas supply to approximately 420,000 houses has been restored (see Note 1). (Restoration of gas supply to 401,976 houses was completed on May 3, and subsequently each case has been dealt with individually.) (see Note 5)</td><td colspan="2">Peak number of houses suffering suspension: approx. 460,000 (see Note 14)</td></tr>
<tr><td>Suspension of power supply</td><td colspan="2">Tokyo Electric Power Company, Hokkaido Electric Power Company, and Chubu Electric Power Company: restoration completed (see Note 1)
Tohoku Electric Power Company: restoration completed except in those areas where residential buildings were washed away by the tsunami (see Note 1)</td><td colspan="2">Approx. 4,000,000 houses (see Note 15)</td></tr>
<tr><td rowspan="3">Suspension of telephone service</td><td colspan="2">NTT East Corporation: 13,900 lines (see Note 1)</td><td colspan="2">NTT East Corporation: more than 740,000 lines (see Note 16)</td></tr>
<tr><td colspan="2">Other lines: approx. 300 (see Note 1)</td><td colspan="2">Other lines: slightly less than 60,000 (see Note 16)</td></tr>
<tr><td colspan="2">Other base stations: 542 (see Note 1</td><td colspan="2">Other base stations: approx. 5,500 (see Note 16)</td></tr>
<tr><td colspan="2">The whole flooded area due to tsunami</td><td colspan="2">561 km² (see Note 6)</td><td colspan="2">561 km² (see Note 6)</td></tr>
<tr><td colspan="2">Amount of damage</td><td colspan="2">Approx. 16.9 trillion yen (see Note 1)</td><td colspan="2">Between 16 and 25 trillion yen (see Note 17)</td></tr>
</table>

(Note 1) "On the Tohoku District-off the Pacific Ocean Earthquake" (reporting the status as of 17:00 on August 9) issued by the Emergency Disaster Response Headquarters
(Note 2) "Information regarding the Damage Caused by the 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 149)" (reporting the status as of 10:00 on August 8) issued by the Ministry of Education, Culture, Sports, Science and Technology
(Note 3) "The 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 85)" (reporting the status as of August 9) issued by the Ministry of Land, Infrastructure, Transport and Tourism
(Note 4) "The Status of Recovery of Traffic-related Infrastructure and Functions" (reporting the status as of 10:00 on August 8) issued by the Ministry of Land, Infrastructure, Transport and Tourism
(Note 5) "The Status of Suspension of Town Gas Supplies Caused by the 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 61)" issued by the Japan Gas Association
(Note 6) "On the Regional Areas Inundated by the Tsunami (Approximate Values) (Report No. 5)" issued by the Geospatial Information Authority
(Note 7) "On the Status of Damage Caused by the 2011 off the Pacific Coast of Tohoku Earthquake and Actions Taken in Response (Report No. 93)" (reporting the status as of 14:00 on August 5) issued by the Ministry of Health, Labour and Welfare
(Note 8) "On the Tohoku District-off the Pacific Ocean Earthquake " (reporting the status as of 17:00 on May 30) issued by the Emergency Disaster Response Headquarters
(Note 9) "On the Tohoku District-off the Pacific Ocean Earthquake" (reporting the status as of 17:00 on May 10) issued by the Emergency Disaster Response Headquarters
(Note 10) "Information regarding the Damage Caused by the 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 90)" (reporting the status as of 8:00 on May 11) issued by the Ministry of Education, Culture, Sports, Science and Technology
(Note 11) "The 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 23)" (reporting the status as of March 18) issued by the Ministry of Land, Infrastructure, Transport and Tourism
(Note 12) JR East (East Japan Railway Company) website: http://www.jreast.co.jp/press/earthquake/index.html
(Note 13) "On the Status of Damage Caused by the 2011 off the Pacific Coast of Tohoku Earthquake and Actions Taken in Response (Report No. 66)" (reporting the status as of 14:00 on August 5) issued by the Ministry of Health, Labour and Welfare
(Note 14) "The Status of Suspension of Town Gas Supplies Caused by the 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 12)" issued by the Japan Gas Association
(Note 15) "On the 2011 off the Pacific Coast of Tohoku Earthquake" (reporting the status as of 12:00 on April 28) issued by the Ministry of Economy, Trade and Industry
(Note 16) "On the Tohoku District-off the Pacific Ocean Earthquake" (reporting the status as of 12:00 on March 18) issued by the Emergency Disaster Response Headquarters
(Note 17) Summary of a Press Conference by Mr. Yosano, the Cabinet Minister of Extraordinary Affairs



JNES modified a part of the Google map.

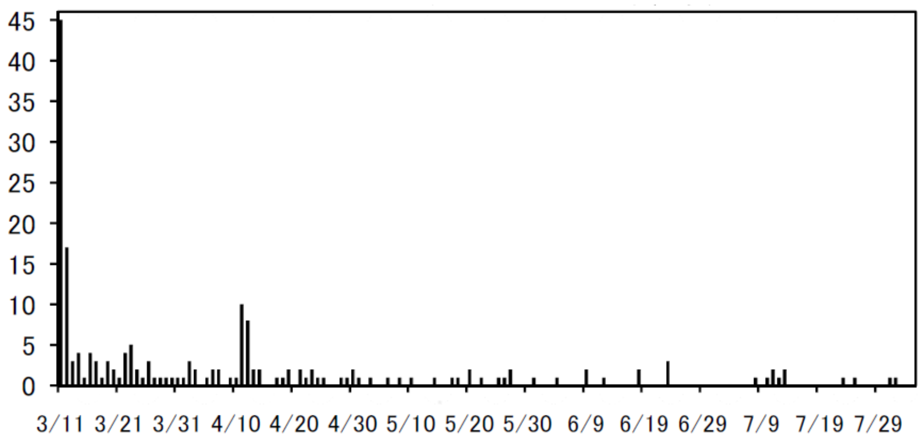


Reference: Miura et al. (2005: Tectonophysics, Vol.407)
Partially modified by JNES.

Fig. II-1-1 The source area of the Tohoku District-Off the Pacific Ocean Earthquake consisting of multiple seismic source areas.

The number of aftershocks per day (occurrences)

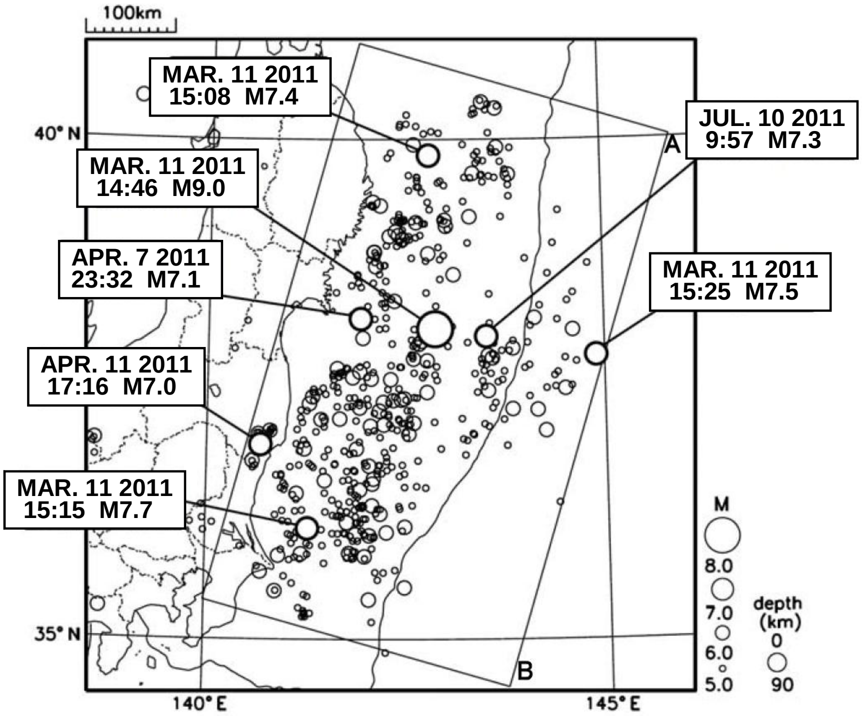
The Tohoku District-Off the Pacific Ocean Earthquake (Earthquakes with the JMA seismic intensity scale of four or greater observed since March 11, 2011 14:00)



Date after the main quake occurrence

Distribution Map of Epicenters

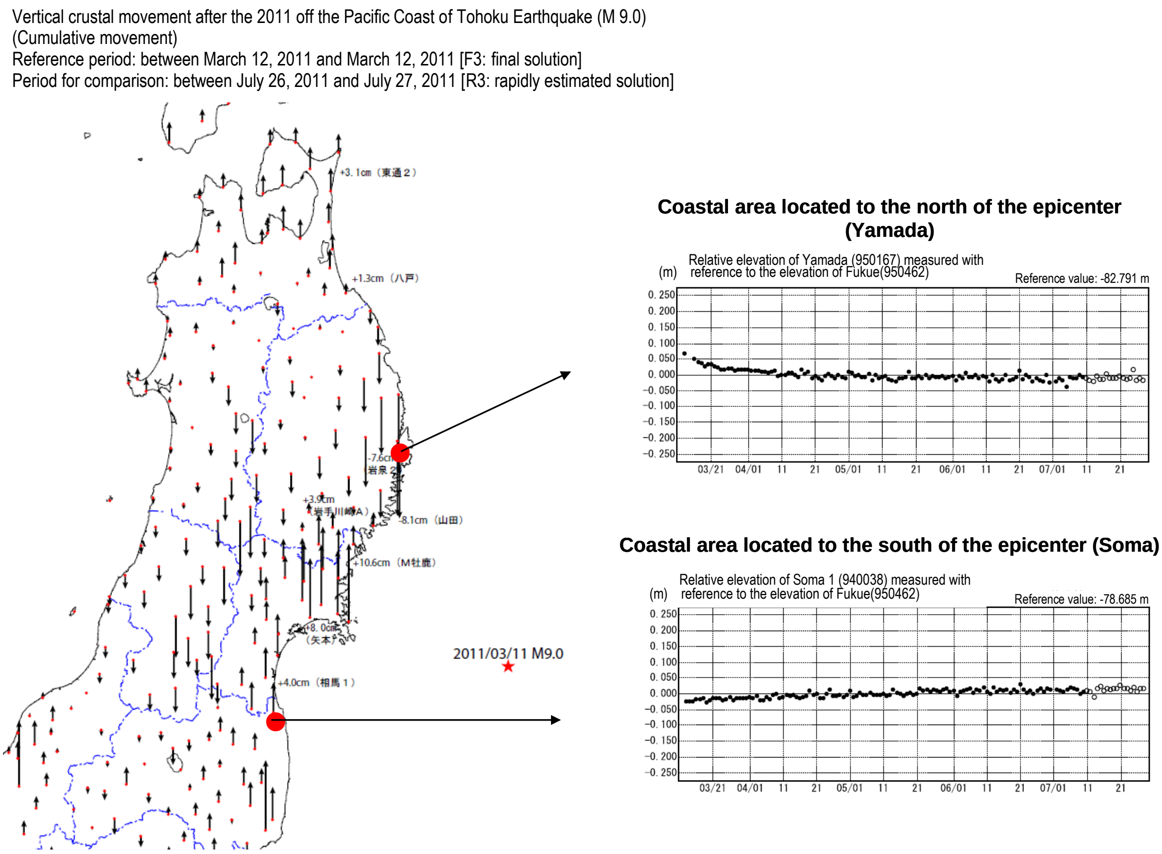
(Target: earthquakes of M 5.0 or greater occurring at depths of 90 km or less between 12:00 on March 11, 2011 and 8:00 on August 4, 2011)



The sizes of the circles indicate the magnitudes of the earthquakes. Earthquakes of M 7.0 or greater are highlighted.

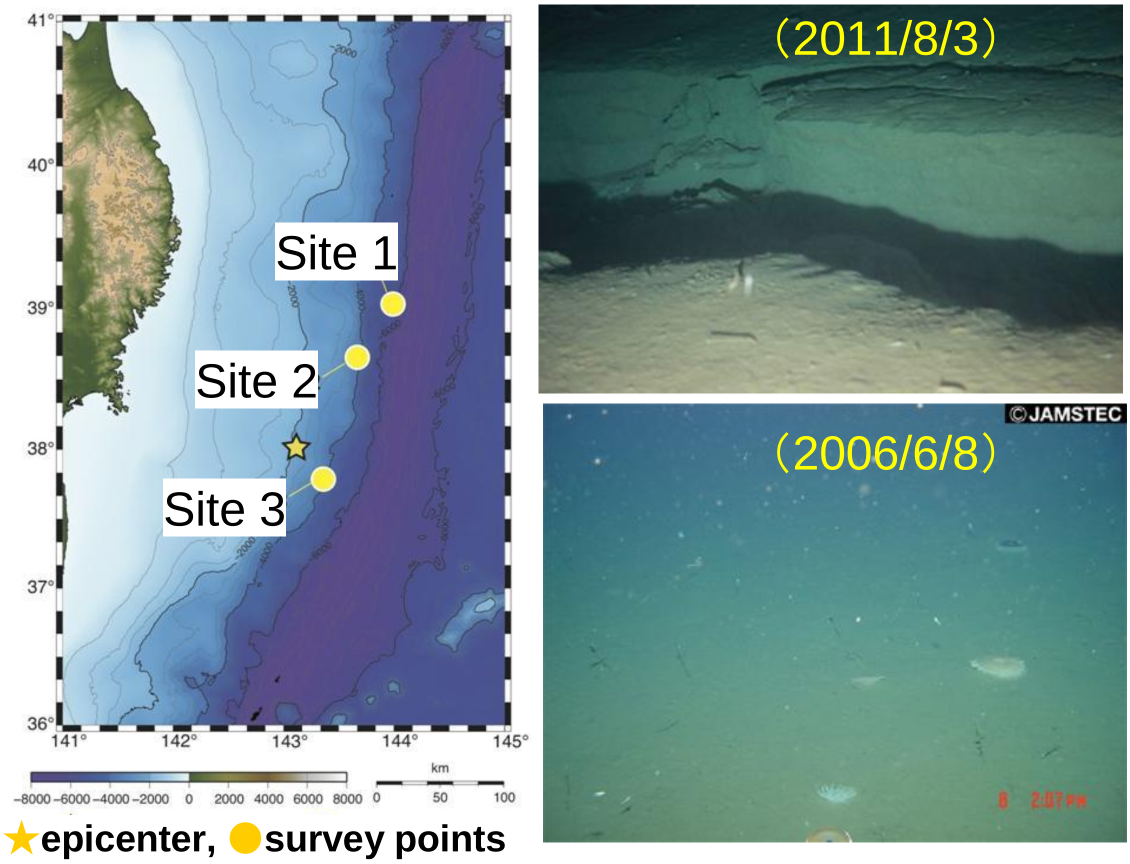
Reference: On the 2011 off the Pacific Coast of Tohoku Earthquake (Report No. 53, the Japan Meteorological Agency)
[Online]. http://www.jma.go.jp/jma/press/1108/04c/kaisetsu201108041600.pdf

Fig. II-1-2 The number of aftershocks and map of epicenters of subsequent major aftershocks.



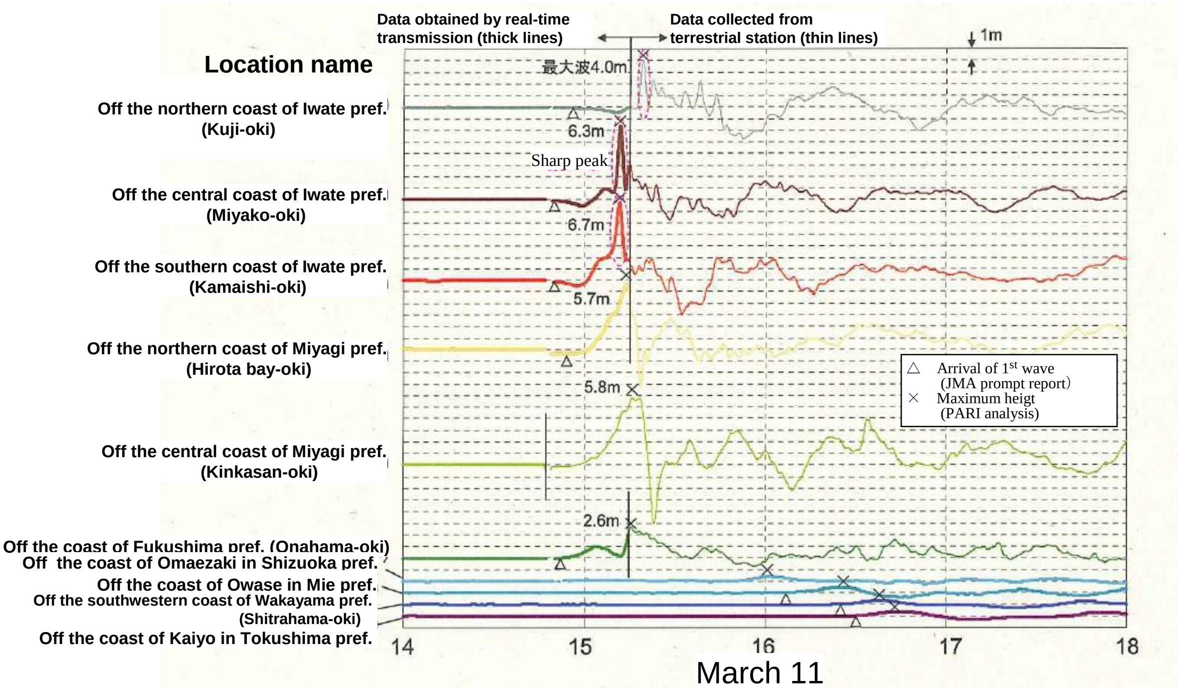
Reference: On crustal movement in July 2011 (the Geospatial Information Authority of Japan). Partially modified by JNES.
[Online]. http://www.gsi.go.jp/WNEW/PRESS-RELEASE/2011-goudou0804.html

Fig. II-1-3 Crustal movement in the coastal areas of Iwate prefecture before and after the Tohoku District-Off the Pacific Ocean Earthquake.



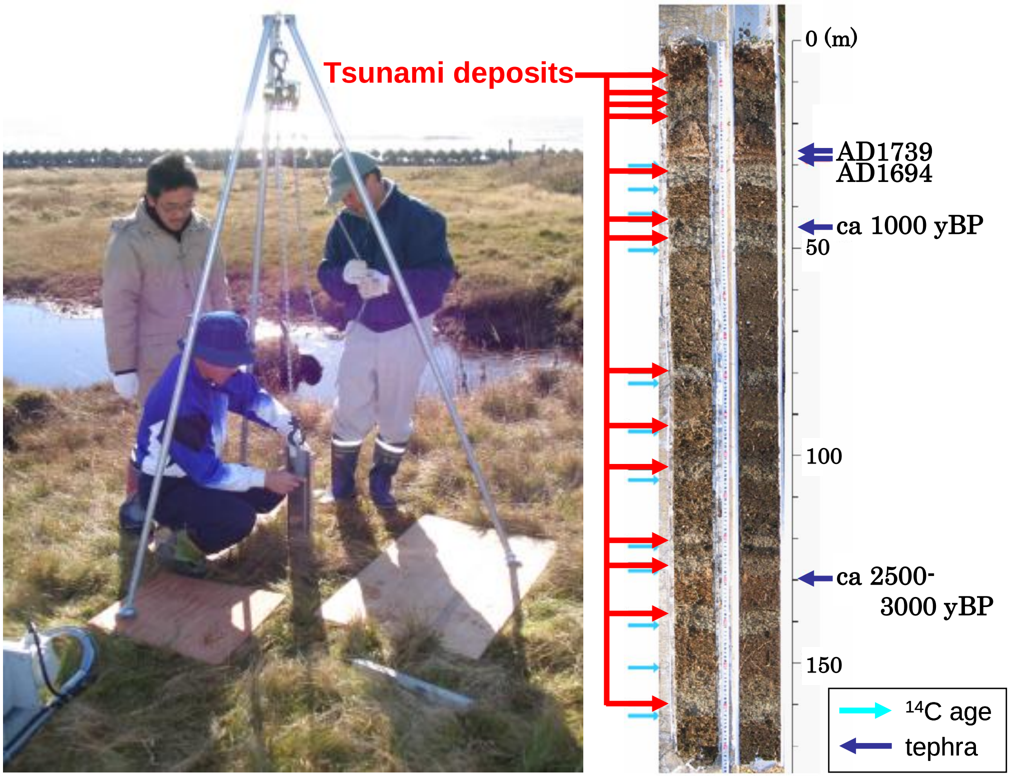
Japan Agency for Marine-Earth Science and Technology.
[Online]. http://www.jamstec.go.jp/j/about/press_release/20110815/#c1

Fig. II-1-4 Results of underwater surveys of the seismic source area by "Shinkai 6500".
Left figure: survey points.
Right top figure: surface crack found at site 1 after the main quake (Aug.3, 2011, No 1256 submerging).
Right bottom figure: surface without crack at site 1 before the main quake (June 8, 2006, No 957 submerging).



Port and Airport Research Institute (PARI) [Online]. http://www.pari.go.jp/files/3651/303113448.pdf

Fig. II-1-5 Observed tsunami height by GPS buoy system.



Reference: Study on evaluation of potential for interplate earthquakes from tsunami deposit survey (Report in 2005, JNES). Partially modified by JNES.

Fig. II-1-6 Landscape of tsunami deposit survey.

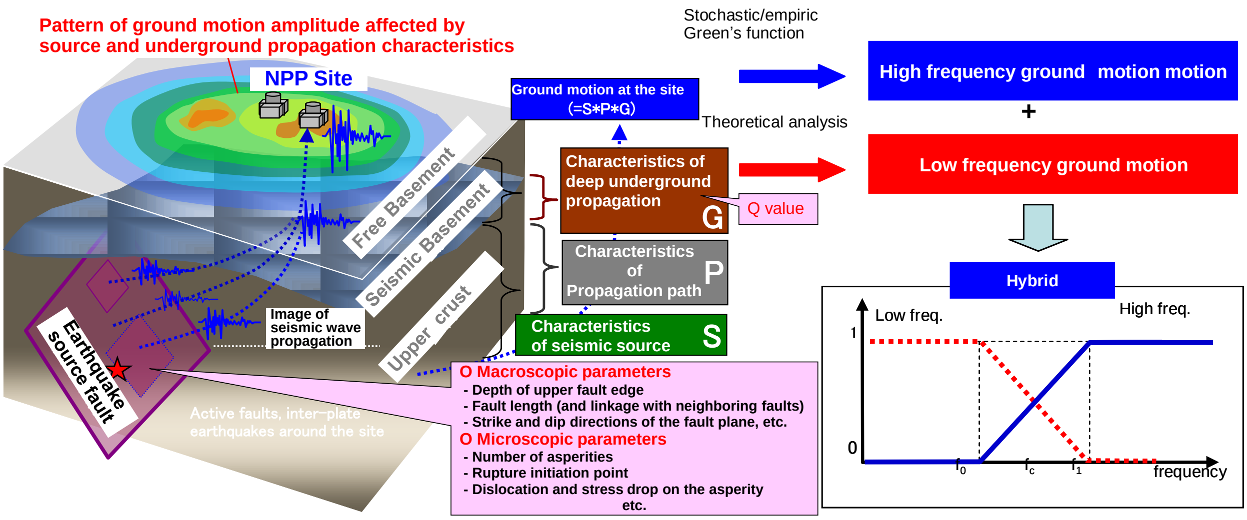
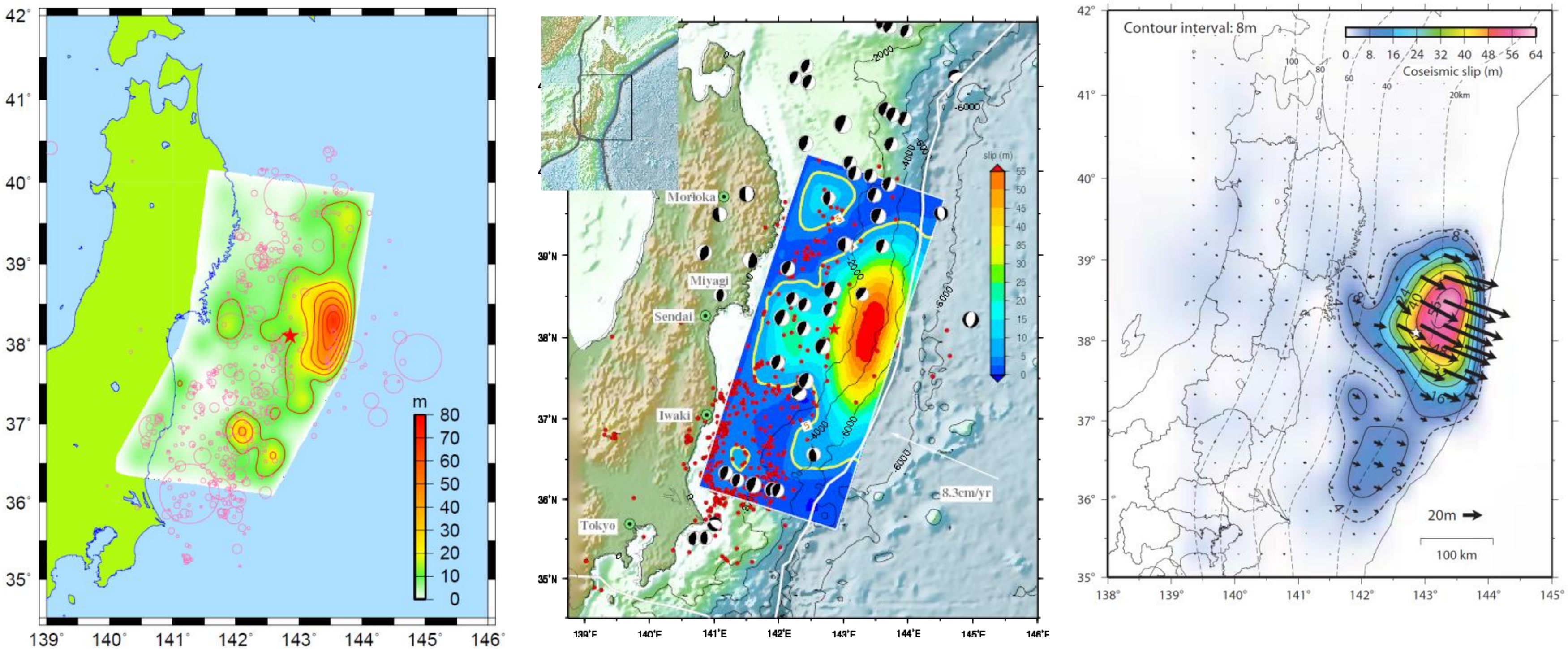


Fig. II-1-7 Schematic illustration for evaluating strong ground motion from fault model.



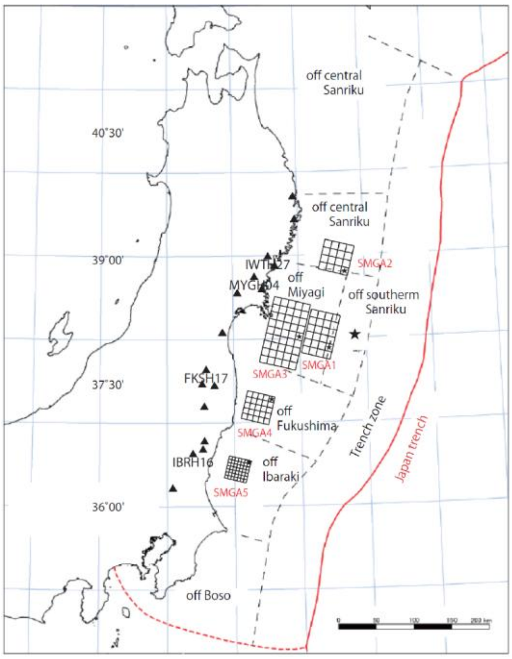
(a) JNES (b) Shao et al. (c) GSI and JCG

Fig. II-1-8 Slip distribution associating with main quake and aftershock distribution.

Left figure: result from source inversion using strong motion records with period range of 10 to125 seconds by Japan Nuclear Energy Safety Organization (JNES).

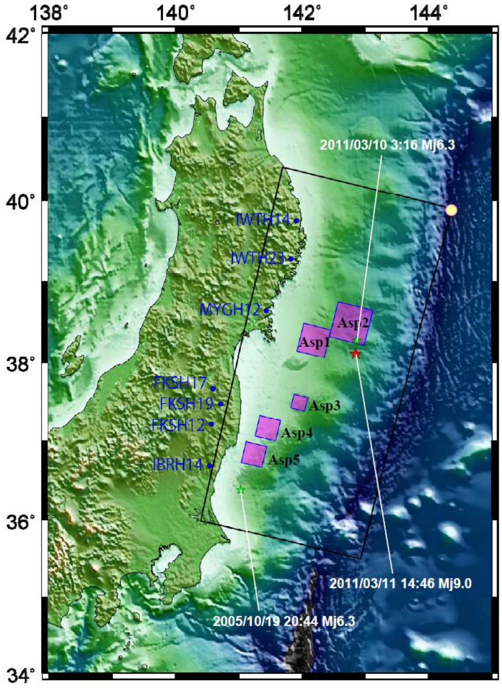
Middle figure: result from source inversion using teleseismic records.

Right figure: result estimated from GPS records collected at land and crustal movement records at ocean bottom operated by Geospatial Information Authority of Japan (GSI) and the Japan Coast Guard (JCG).



Irikura Model

	Moment (Nm)	Stress drop (MPa)	Mw	Area (km^2)
Asperity 1	2.31E+21	41.3	8.2	62.4×41.6
Asperity 2	7.05E+20	23.6	7.8	41.6×41.6
Asperity 3	4.34E+21	29.5	8.4	93.6×52.0
Asperity 4	3.83E+20	16.4	7.7	38.5×38.5
Asperity 5	3.99E+20	26.0	7.7	33.6×33.6
Total	8.14E+21		8.5	



Kamae Model

		Stress drop (MPa)	Mw	Area (km^2)
Asperity 1	4.93E+20	18.9	7.7	40×40
Asperity 2	1.10E+21	21.6	8.0	50×50
Asperity 3	8.30E+19	27.0	7.2	20×20
Asperity 4	1.19E+20	10.8	7.3	30×30
Asperity 5	2.58E+20	23.1	7.5	30×30
Total	2.05E+21		8.1	

Fig. II-1-9 Source models illuminating strong ground motion.
Left figure: model proposed by Irikura and Kurahashi.
Right figure: model by proposed by Kawabe and Kamae.

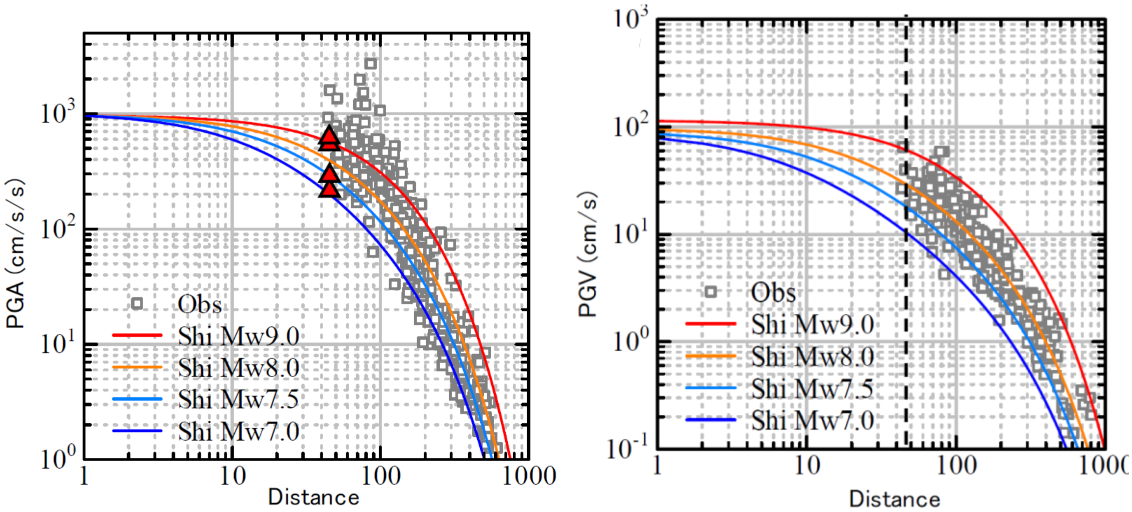


Fig. II-1-10 Comparison of observed data and attenuation relationship (Irikura and Kurahashi, 2011).
Left figure: peak ground acceleration.
Right figure: peak ground velocity.
Abscissa: shortest distance to fault (km).
□ : observed acceleration or velocity
Colored curves: predicted acceleration or velocity from attenuation relationship dependent on moment magnitude.

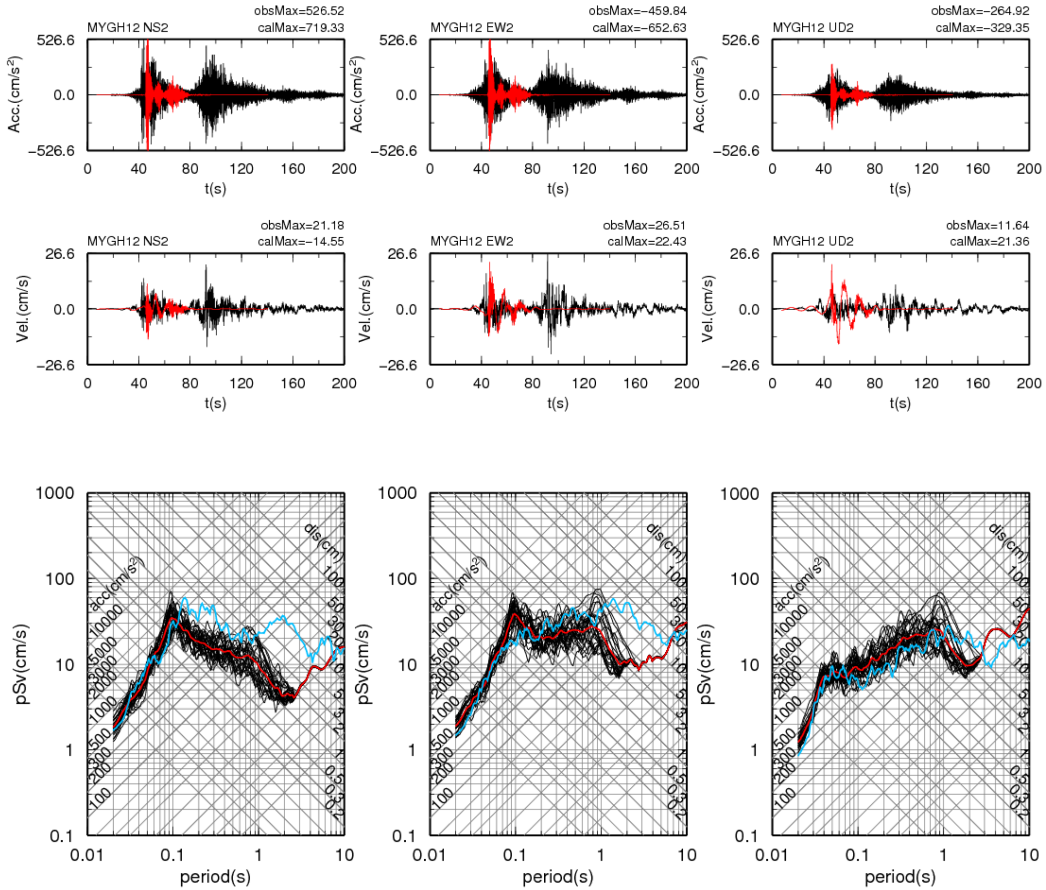


Fig. II-1-11 Comparison of waveforms at Shizugawa station (MYGH12).

Upper figure: black and red lines show observed acceleration of main quake and predicted accelerations from the scenario earthquake (Miyagiken-oki earthquake), respectively.

Lower figure: black lines and red line show predicted response spectra and average of them, respectively. Blue line shows observed response spectrum.

Left, middle and right columns: the north-south, east-west and vertical components, respectively.

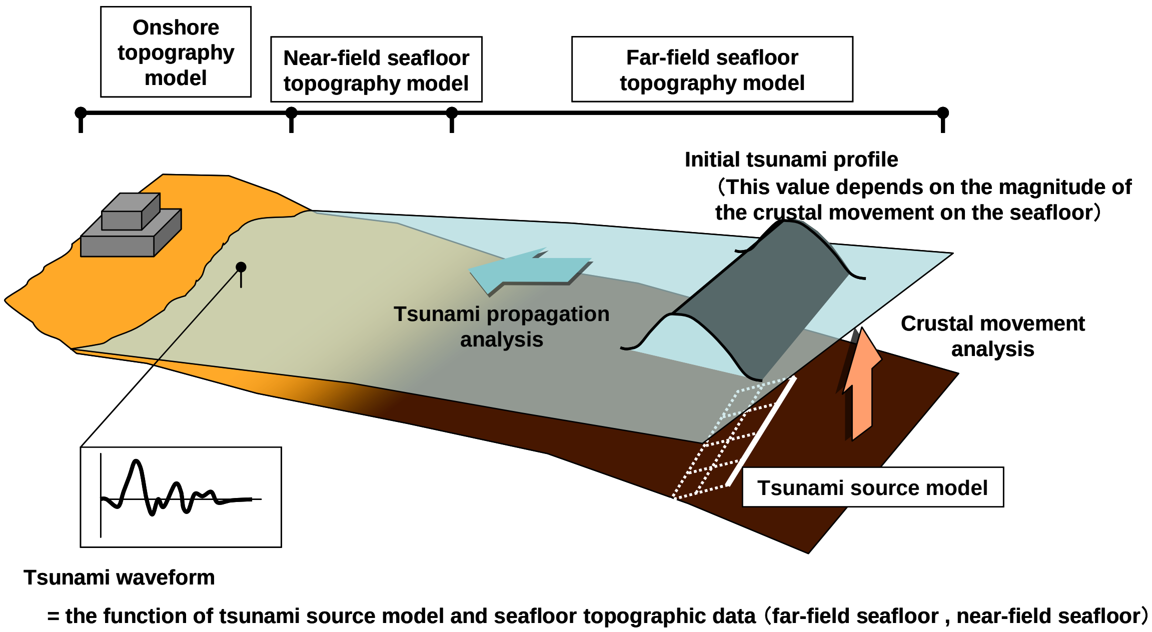
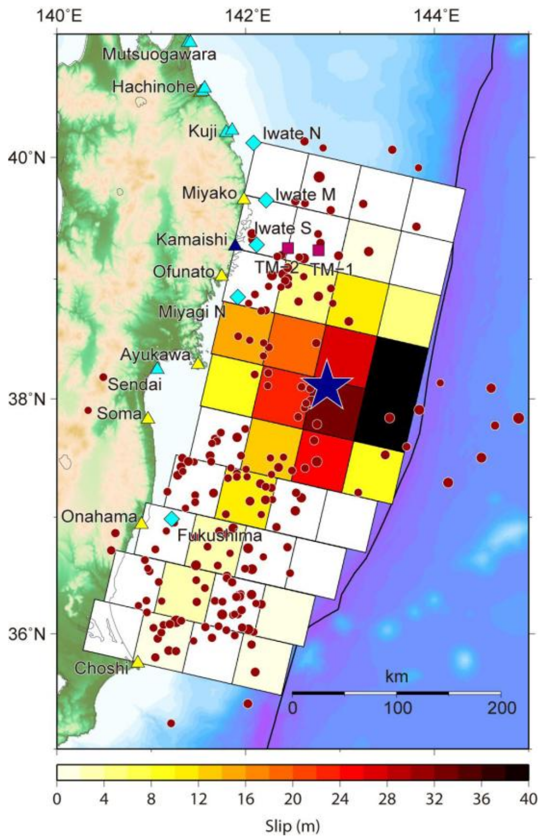
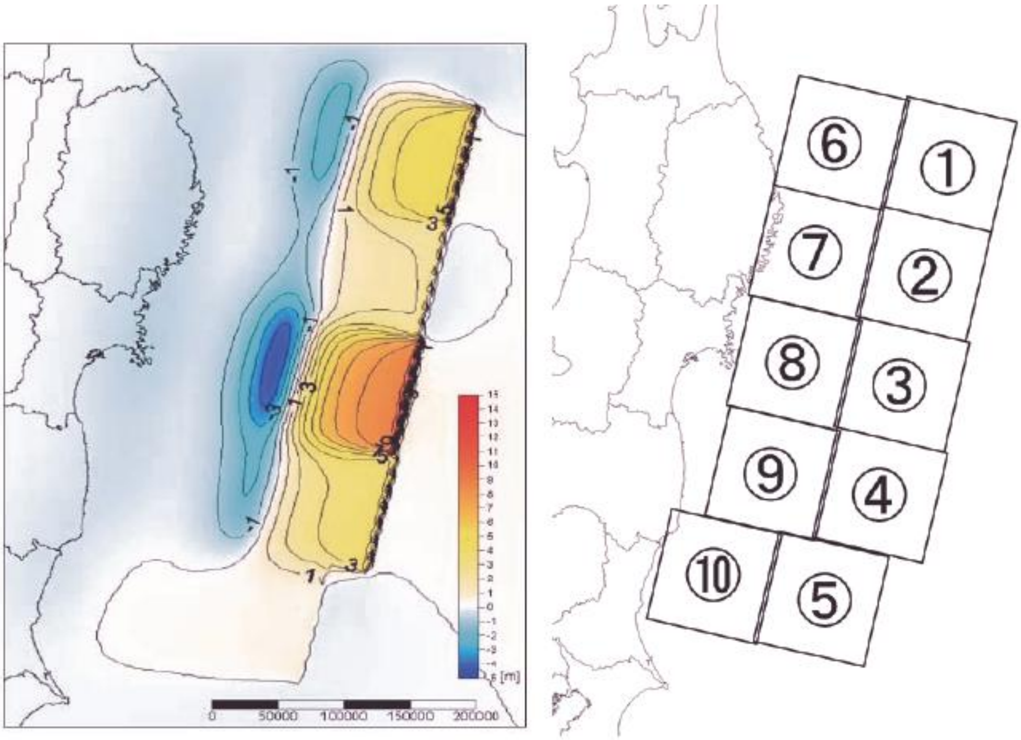


Fig. II-1-12 Schematic illustration for evaluating tsunami water level.



Reference: Tsunami source model (Ver. 4.2)(Fujii and Satake, 2011).
[Online]. http://iisee.kenken.go.jp/staff/fujii/OffTohokuPacific2011/tsunami_ja.html

Fig. II-1-13 Tsunami source model (ver. 4.2) from inversion method by Fujii and Satake.



Reference: Tsunami simulation for the Tohoku Dustrict-Off the Pacific Ocean Earthquake (Tohoku University model)
[Online]. http://www.tsunami.civil.tohoku.ac.jp/hokusai3/

Fig. II-1-14 Tsunami source model (ver. 1.0) from forward method by Tohoku University. (Initial tsunami profile and segment location)

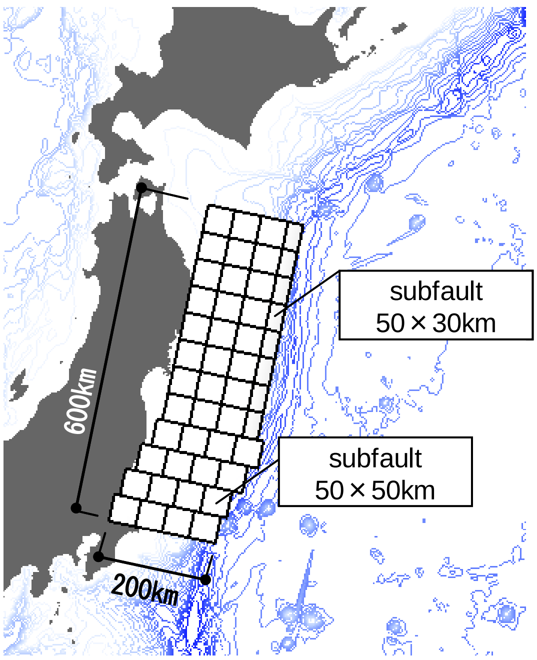
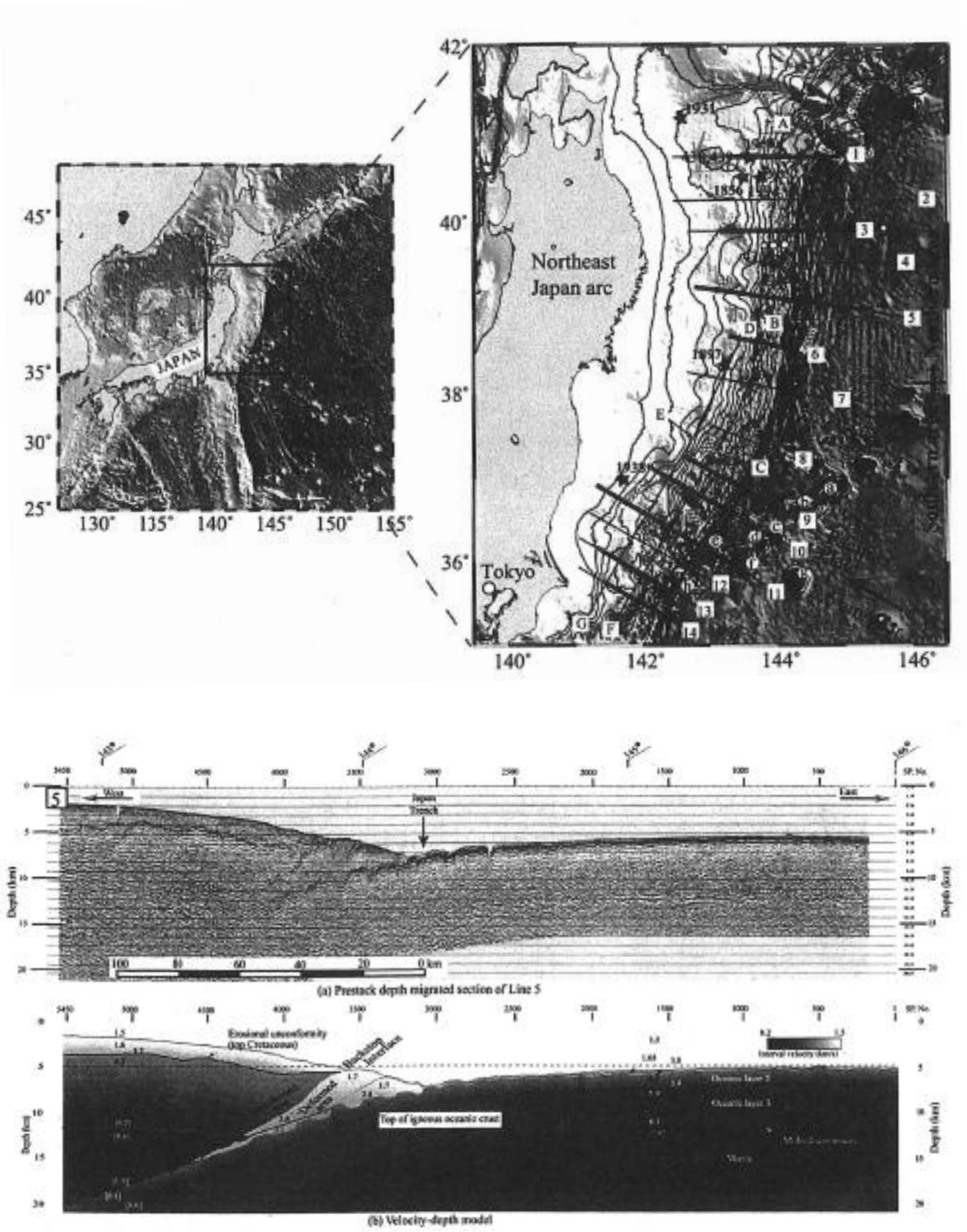


Fig. II-1-15 Locations of subfaults in tsunami source model of JNES.



Reference: Tsuru et al., Along-arc structural variation of the plate boundary at the Japan Trench margin: Implication of interplate coupling, Journal of Geophysical Research, Vol. 107, No. B12, 2357, 2002.

Fig. II-1-16 Shallow splay fault along the Japan Trench.

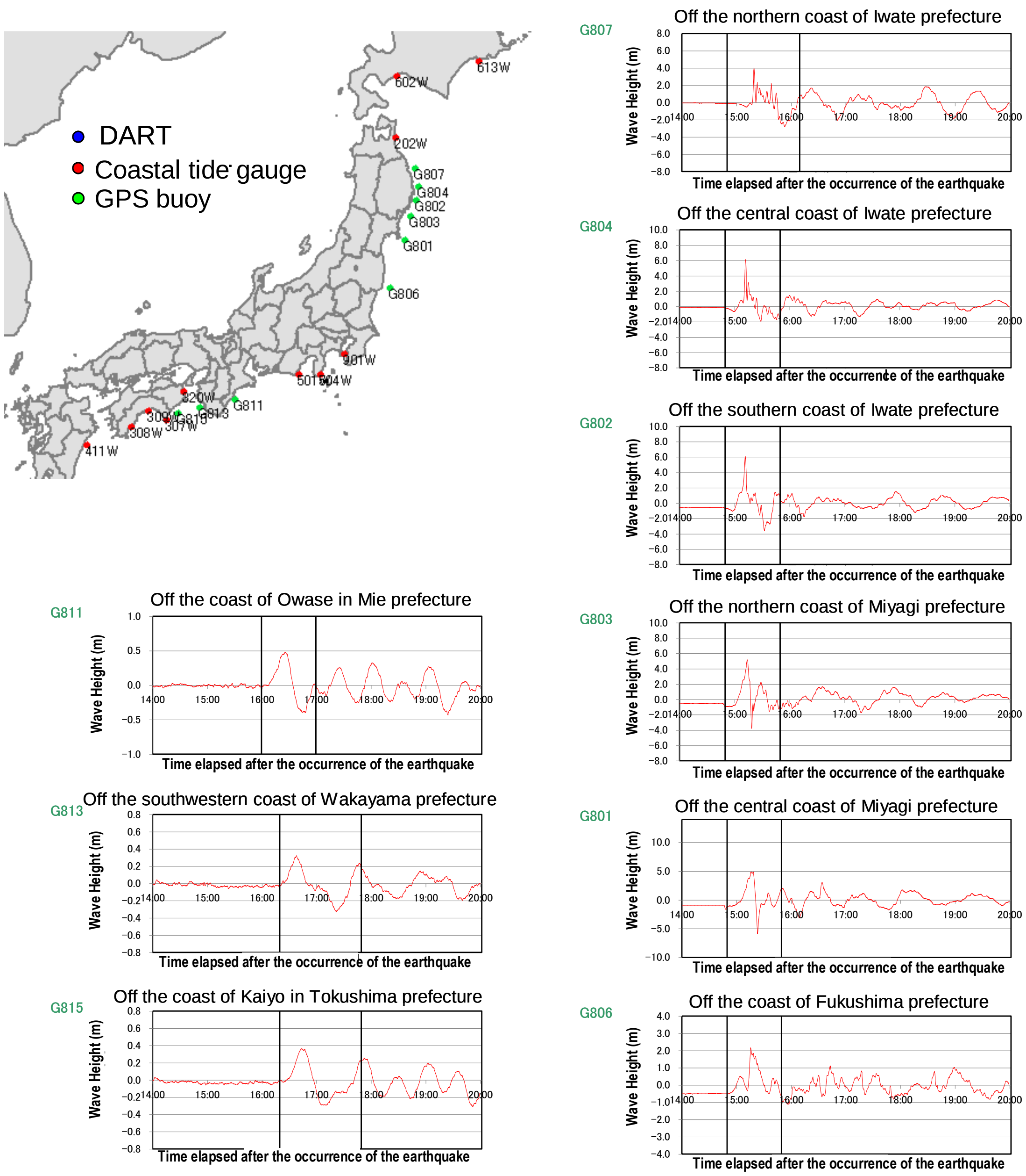


Fig. II-1-17 (a)　Locations of GPS buoys and observed tsunami waveforms.

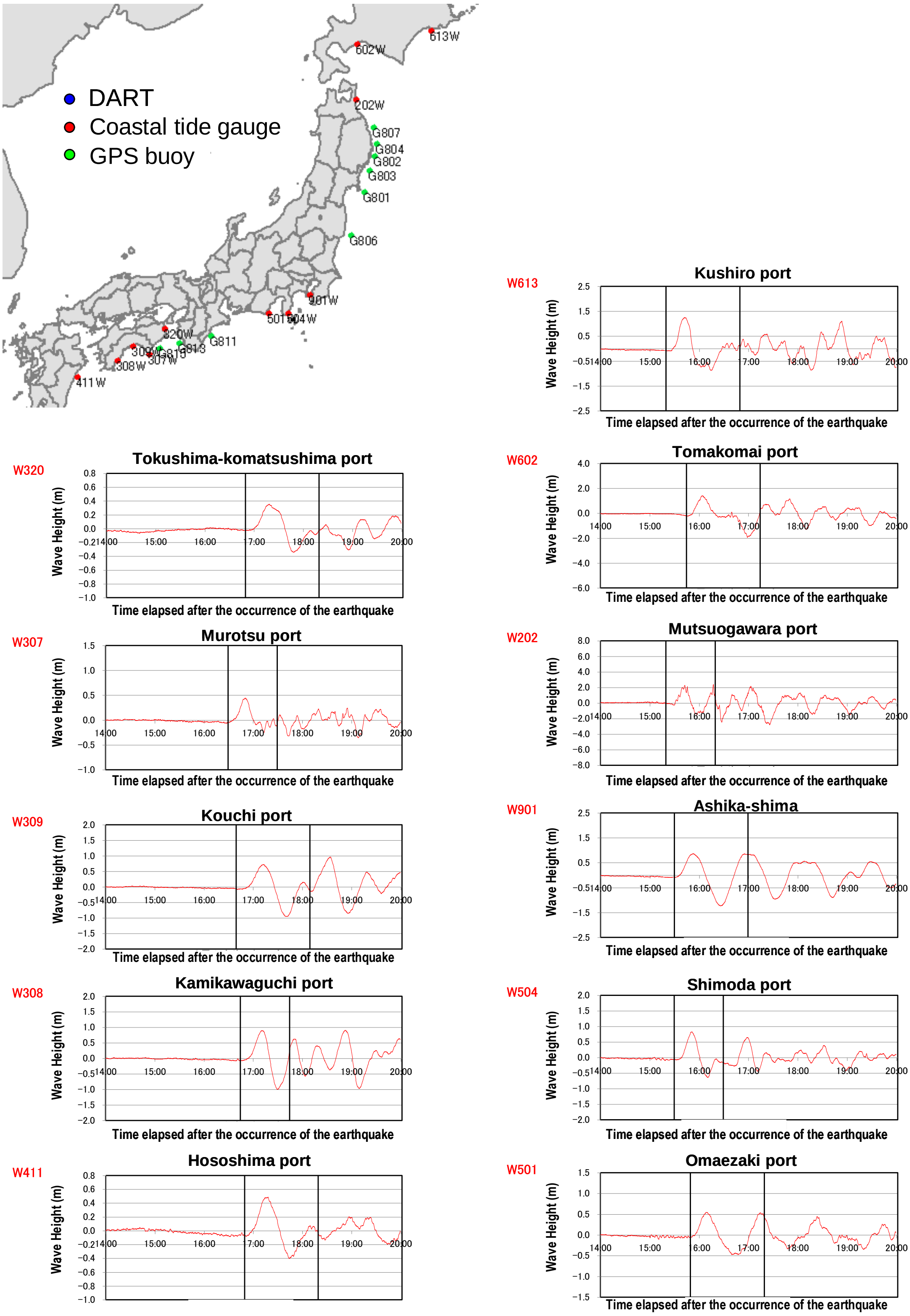


Fig. II-1-17 (b) Locations of coastal tide gauges and observed tsunami waveforms.

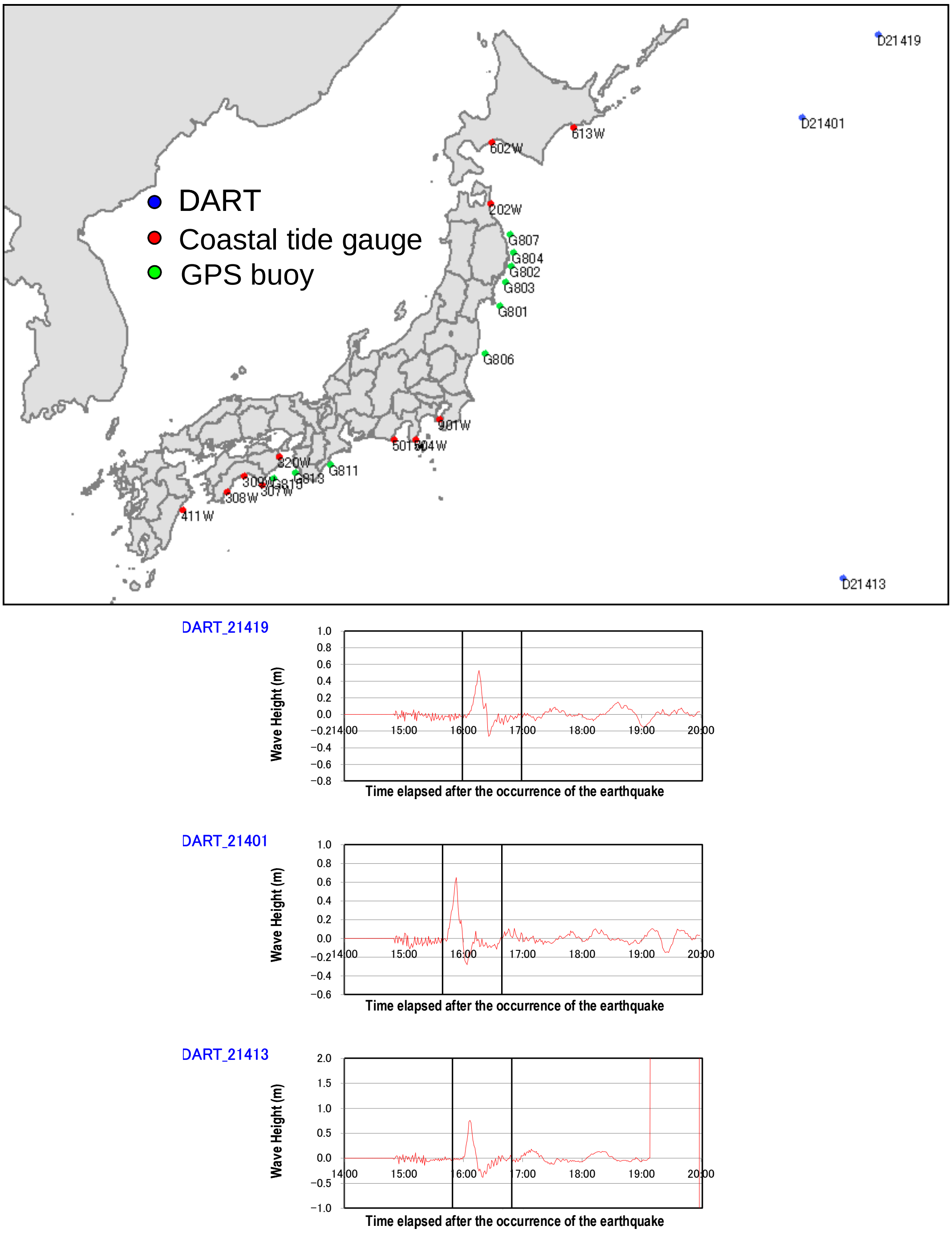


Fig. II-1-17 (c) Locations of Deep ocean Assessment and Reporting of Tsunami (DART) operated by NOAA and observed tsunami waveforms.

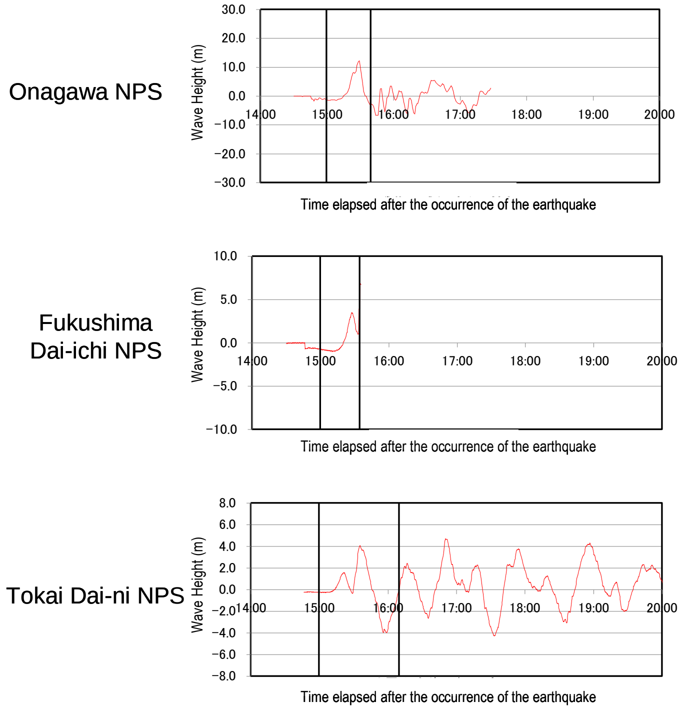
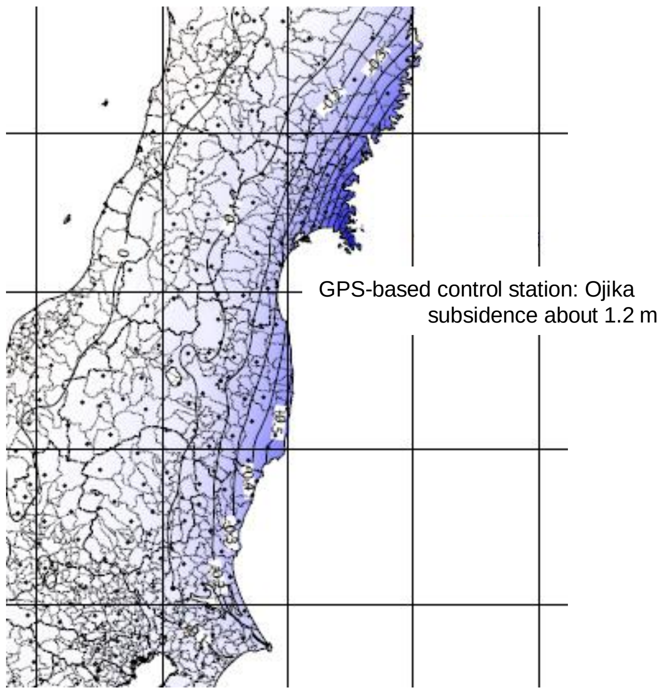
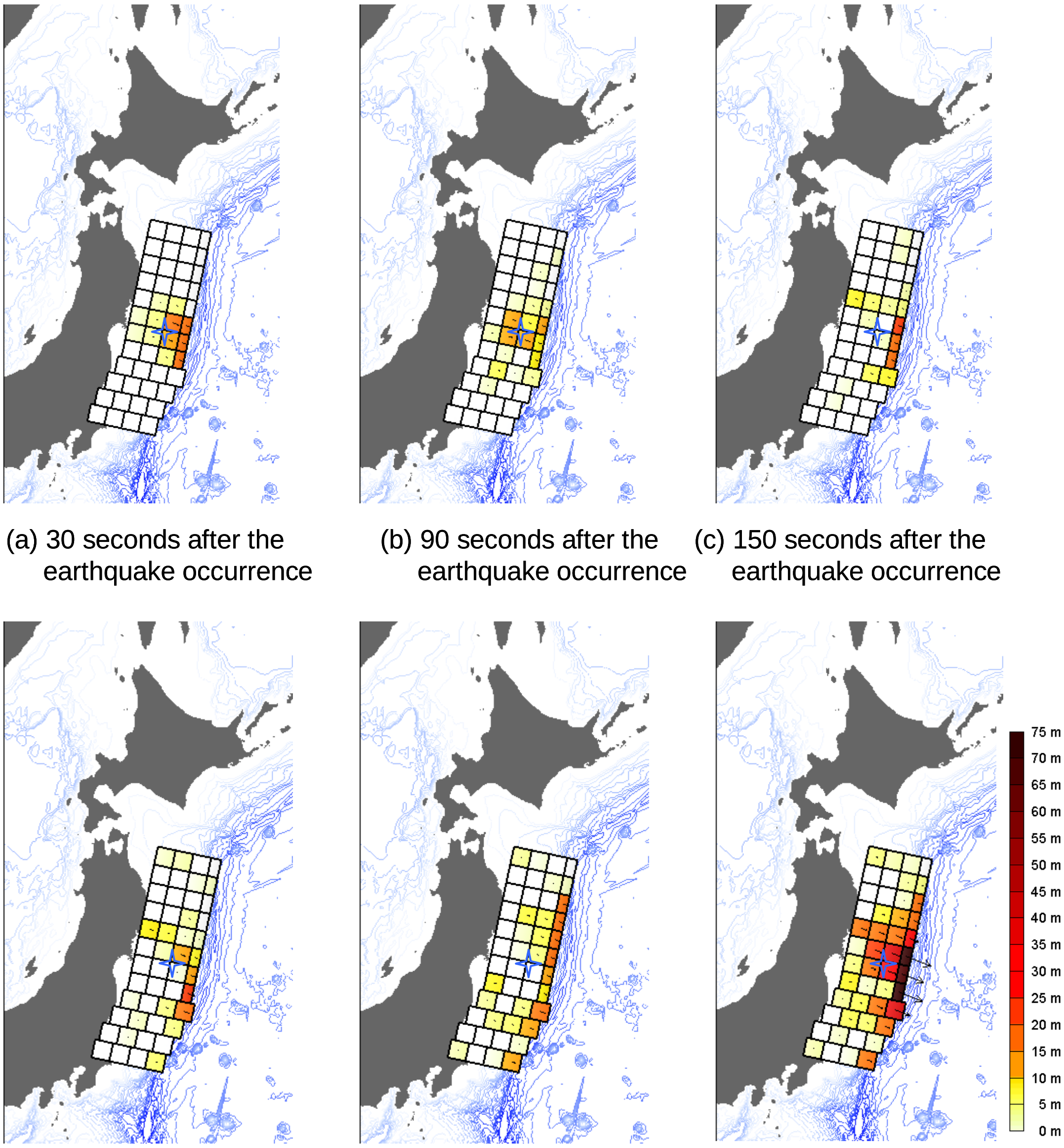


Fig. II-1-18 Tsunami waveforms observed at Onagawa NPS, Fukushima Dai-ichi NPS, and Tokai Dai-ni NPS.



Reference: Crustal movement based on GPS continius records (Geospatial Information Authority of Japan)
[Online] http://www.gsi.go.jp/chibankansi/chikakukansi40005.html

Fig. II-1-19 Amount of crustal movement (vertical displacement) based on GPS observation by Geospatial Information Authority of Japan.



(a) 30 seconds after the earthquake occurrence

(b) 90 seconds after the earthquake occurrence

(c) 150 seconds after the earthquake occurrence

(d) 210 seconds after the earthquake occurrence

(e) 270 seconds after the earthquake occurrence

(f) Aggregate slips

Fig. II-1-20 Analysis results using tsunami source model of JNES: trends in distribution of slips (shown by (a) to (e)) and the aggregate slips (shown by (f)).

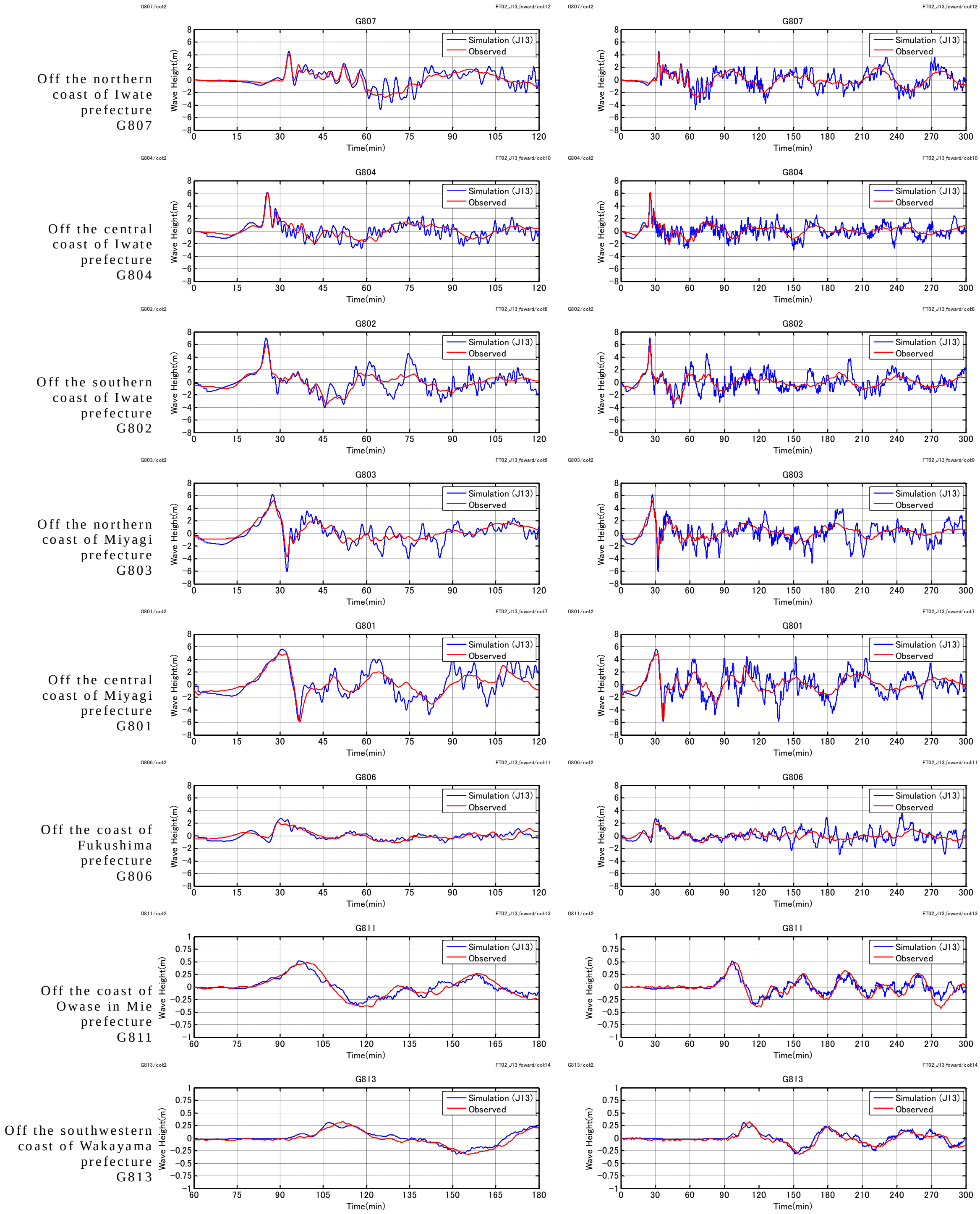


Fig. II-1-21 Comparison of observed tsunami waveforms by GPS buoys (red line) and simulated tsunami waveforms based on tsunami source model by JNES (blue line). (the left column shows the data for two hours; the right column shows the data for five hours)

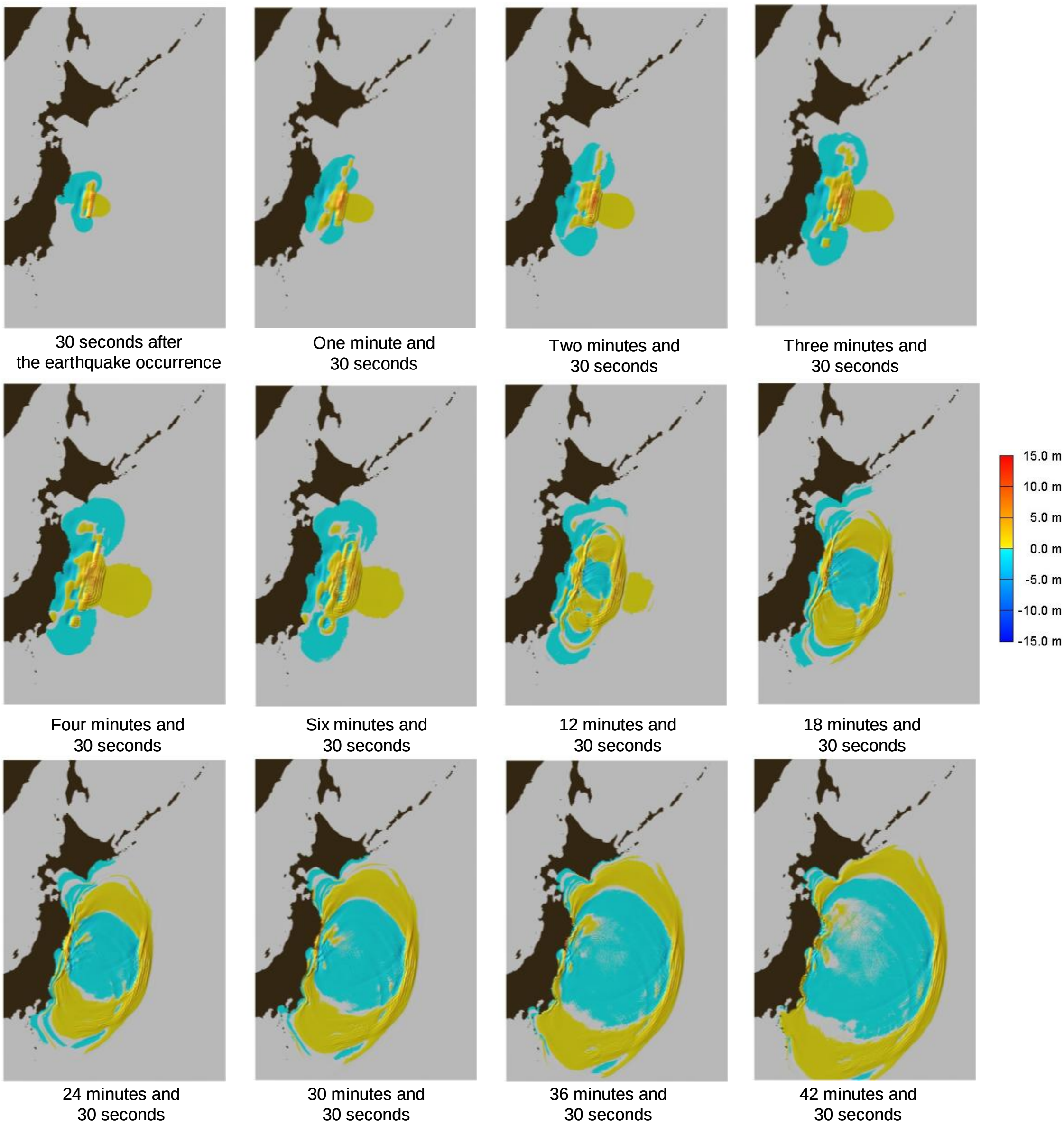


Fig. II-1-22 Snap shot of tsunami propagation based on tsunami source model by JNES.
(Below each diagram, the time elapsed since 14:46, the minute the earthquake struck, is noted. The tsunami arrived Fukushima Dai-ichi NPS approximately 36 minutes later.)

Off the northern coast of Iwate prefecture G807

Off the central coast of Iwate prefecture G804

Off the southern coast of Iwate prefecture G802

Off the northern coast of Miyagi prefecture G803

Off the central coast of Miyagi prefecture G801

Off the coast of Fukushima prefecture G806

Off the coast of Owase in Mie prefecture G811

Off the southwestern coast of Wakayama prefecture G813

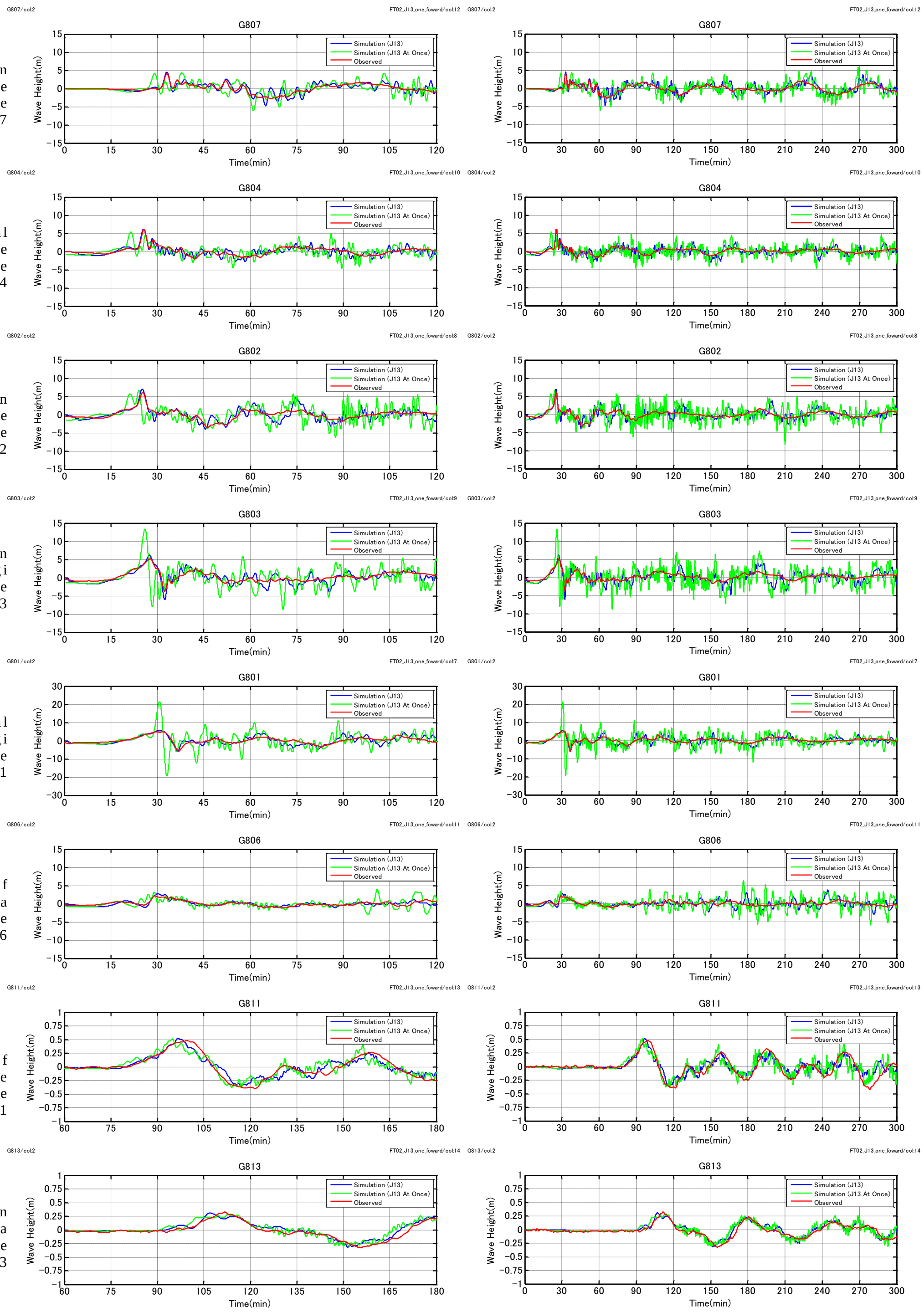


Fig. II-1-23 Effect of rupture start time and source duration time in tsunami source model on simulated tsunami waveform (the left column shows the data for two hours; the right column shows the data for five hours).

(red line: observed tsunami waveform, blue line: expected tsunami waveform based on tsunami source model takes into consideration the difference in rupture start time and the duration time, green line: expected tsunami waveform based on tsunami source model establishes the aggregate slips all at once.)

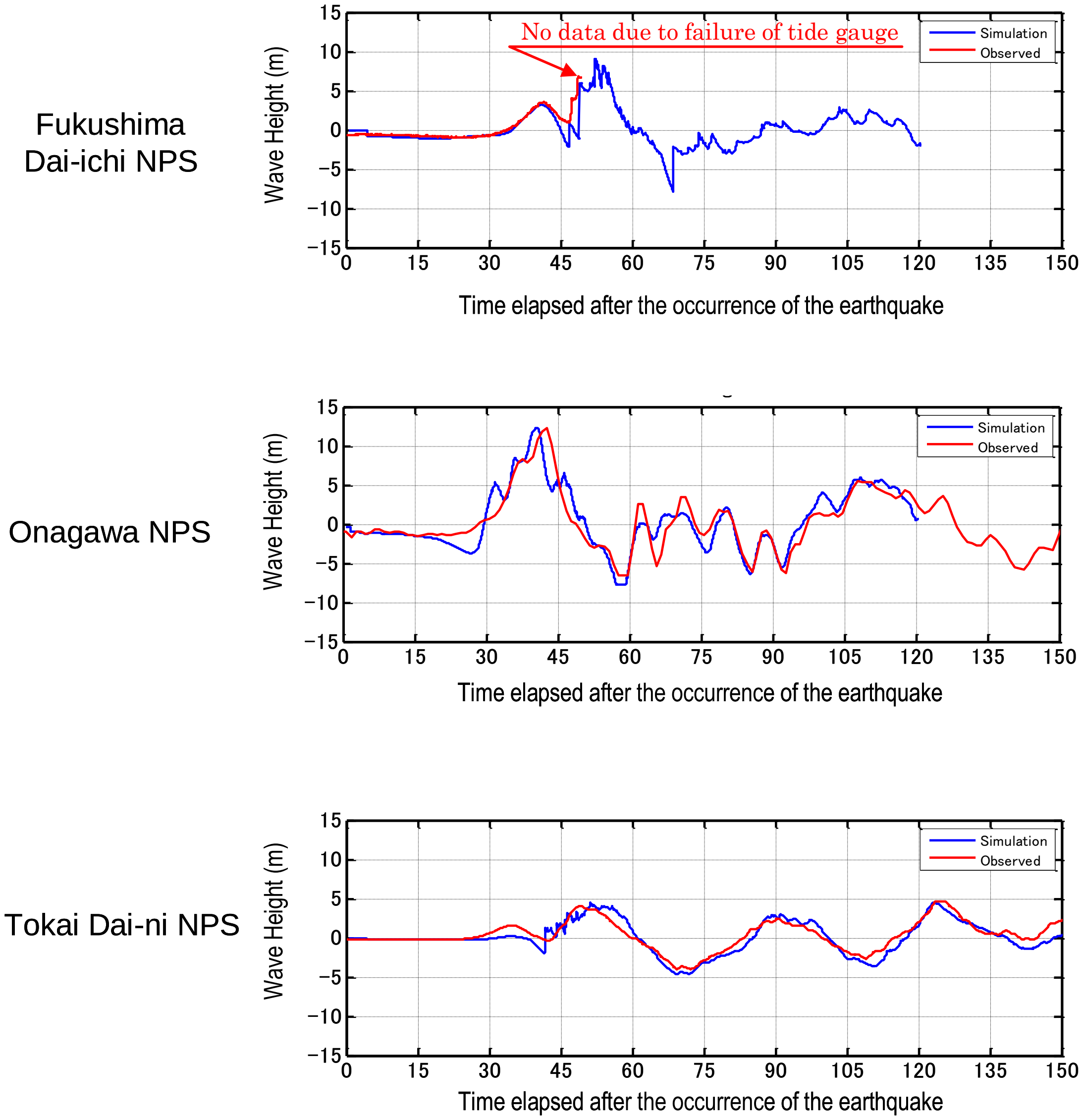


Fig. II-1-24 Comparison of simulated tsunami waveform (blue line) and observed one (red line) at Fukushima Dai-ichi NPS, Onagawa NPS and Tokai Dai-ni NPS. (No data at Fukushima Dai-ni NPS due to failure of tide gauge.)

2. Situation of the accident at the Fukushima NPSs, etc.

(1) New findings regarding the occurrence and development of the accident at the Fukushima Dai-ichi NPS

1) Evaluation of impact by the earthquake on buildings and structures, and equipment and piping systems, which are significant to seismic safety

a. Summary of observed results in the June Report

Impact evaluation was not carried out for the purpose of the June Report, which described the seismic ground motions observed at the Fukushima Dai-ichi nuclear power station (NPS), comparison to the standard seismic ground motion Ss, etc. They are summarized as follows:

Of the seismic records observed at the Fukushima Dai-ichi NPS (obtained at 29 of installed 53 seismometers), a list of peak ground acceleration (PGA) values for the observed ground motions in three components of two horizontal (east-west and north-south) and one vertical directions on the base mat of the reactor buildings is shown in Table II-2-1. The horizontal PGA was 550 Gal (east-west) observed at Unit 2, and the vertical PGA was 302 Gal observed at Unit 2. Also shown in the Table are the maximum acceleration response spectra to the Ss at locations in which seismometers were installed on the base mat of the reactor buildings. The east-west PGAs observed at Units 2, 3 and 5 exceeded the maximum acceleration response spectra for the Ss, respectively. In addition, Figure II-2-1(a) shows the east-west acceleration time history at Unit 2, and Figure II-2-1(b) shows a comparison between the observed response spectra and the response spectra for the Ss on the base mat of the reactor buildings at Units 2, 3 and 5. From this Figure, it can be seen that the observed response spectra at Units 2, 3 and 5 exceeded the response spectra for the Ss on the base mat level, in the periodic band between approximately 0.2 and 0.3 sec.

In addition, the maximum acceleration response spectra of Units other than the ones mentioned above, which are Unit 1, 4 and 6, are smaller than for response to DBGM Ss. However, comparing with the response spectra, there exist periodic bands which slightly exceeds or is highly close to the value of the response spectra for the Ss on the base mat of the buildings.

b. Findings from impact evaluation

(i) Reactor buildings

For the purpose of an earthquake response analysis of the reactor buildings following 2011 Tohoku District-Off the Pacific Ocean Earthquake, Tokyo Electric Power Co. Inc. (TEPCO), with a view to verifying the status of the buildings during the event, conducted an earthquake response analysis using the observation records obtained on the base mat of the buildings. Analysis models for Units 1 to 6 are shown in Figures II-2-2 to II-2-7.

The earthquake response analysis found that the maximum shear strain of the seismic wall at each Unit was: 0.14×10^{-3} (north-south, 1st floor) at Unit 1; 0.43×10^{-3} (east-west, 5th floor) at Unit 2; 0.17×10^{-3} (east-west, 5th floor) at Unit 3; 0.15×10^{-3} (east-west, 5th floor) at Unit 4; 0.36×10^{-3} (east-west, 5th floor) at Unit 5; and 0.16×10^{-3} (east-west, 4th floor) at Unit 6, and that the stress and strain of all seismic walls, except the east-west wall on the 5th floor at Unit 2 and the east-west walls on the crane floor and the 5th floor at Unit 5, was below the first knee point on the skeleton curve (the condition of reactor buildings able to keep safety function) (Figures II-2-8 to II-2-13).

(ii) Components and piping systems significant to seismic safety

TEPCO conducted an earthquake response analysis of large components such as reactors, based on the observed records of the Tohoku District-Off the Pacific Ocean Earthquake, and the results obtained such as seismic load were compared, for Units 1 to 6, to those indexes such as seismic load provided by the seismic safety assessment using the defined the Ss. Models of large equipment coupled earthquake response analysis for Units 1 to 6 are shown in Figures II-2-14 to II-2-19.

Based on the comparison results, according to TEPCO, it was found that for Units 1 to 3, and 5, some of those indexes such as seismic load by the earthquake exceeded the ones from the seismic safety assessment. However, a seismic assessment of major components that have important safety functions relevant to "Shutdown" and "Cool down" of reactors, and "Containment" of radioactive materials was performed, and found that the calculated stress, etc. were below the criteria (Tables II-2-2 to II-2-7). For Units 4 and 6, it was found that those indexes such as seismic load by the earthquake, except some peak floor response spectra, were below the ones from the seismic safety assessment.

And also, a seismic assessment of the piping systems using floor response spectra was performed, for Units 1 to 6, and found that the calculated stress was below the criteria (Tables II-2-8 to II-2-13).

Based on these findings, TEPCO presumes that major components that have important safety functions were supposedly in conditions that allow safety functions to be maintained during and immediately after the earthquake.

c. Future efforts

TEPCO's evaluation results and analysis of plant data above, etc. indicate that the accident, which had serious consequences, was supposedly caused by the resulting tsunami, not by the earthquake. However, it is important for the government to conduct the same kind of detailed review of seismic safety evaluation for buildings, equipment and piping, etc. as was conducted at the Kashiwazaki Kariwa NPS after Chuetsu-oki Earthquake occurred. Therefore, Nuclear and Industrial Safety Agency (NISA) will be investigating the cause of the accident based on views and opinions of experts, while carrying out proper evaluation by making use of not only the analysis data but also on-site surveys (in the case of restricted admittance due to high-level radioactivity, surveys undertaken once lifted).

In addition, the effects of tsunami waves (impact force) on structures should be fully examined, so that they can be included in countermeasures against tsunami.

Table II-2-1 Maximum Acceleration observed at the Reactor Building Base Mat of Fukushima Dai-ichi NPS

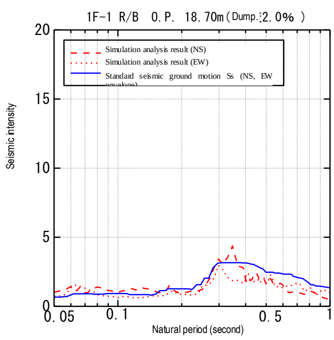
Loc. of Seismometer (at the reactor building base mat)		Observed data Max. acceleration (gal)			Max. response acceleration (gal) of the standard seismic ground motion Ss		
		NS	EW	UD	NS	EW	UD
Fukushima Dai-ichi	Unit 1	460	447	258	487	489	412
	Unit 2	348	550	302	441	438	420
	Unit 3	322	507	231	449	441	429
	Unit 4	281	319	200	447	445	422
	Unit 5	311	548	256	452	452	427
	Unit 6	298	444	244	445	448	415

Table II-2-2 Overview of Impact Evaluation on Equipment and Piping Systems important for Seismic Safety (Fukushima Dai-ichi NPS, Unit 1)

Equipment, etc.		Seismic response load	Standard seismic ground motion Ss	Simulation analysis result	Seismic safety evaluation result
Seismic load, etc.	RPV base	Shear force (kN)	4730	6110	Reactor Pressure Vessel (RPV) (basement bolt) Calculated value: 93 MPa Evaluation criteria value: 222 MPa
		Moment (kN・m)	45900	62200	
		Axial force (kN)	5250	3890	
	PCV base	Shear force (kN)	4270	5080	Primary Containment Vessel (PCV) (Drywell) Calculated value: 98 MPa Evaluation criteria value: 411 MPa
		Moment (kN・m)	55900	64200	
		Axial force (kN)	2070	1560	
	Core shroud base	Shear force (kN)	3060	3370	Core support structures (Shroud support) Calculated value: 103 MPa Evaluation criteria value: 196 MPa
		Moment (kN・m)	15300	16600	
		Axial force (kN)	1020	792	
	Fuel assembly	Relative displacement (mm)	21.2	26.4	Control rod (insertability) Evaluation criteria value: 40.0 mm
Seismic intensity for evaluation	Fuel exchange floor	Seismic intensity (horizontal) (G)	0.96	1.29	Reactor shutdown cooling system pump (basement bolt) Calculated value: 8 MPa Evaluation criteria value: 127 MPa
		Seismic intensity (vertical) (G)	0.58	0.54	
	Base mat	Seismic intensity (horizontal) (G)	0.60	0.57	
		Seismic intensity (vertical) (G)	0.51	0.32	

Floor response spectra (reactor building)

<Reactor building (O.P. 18.70 m)>



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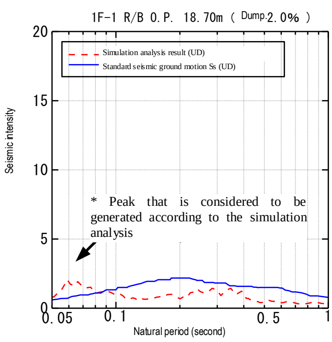
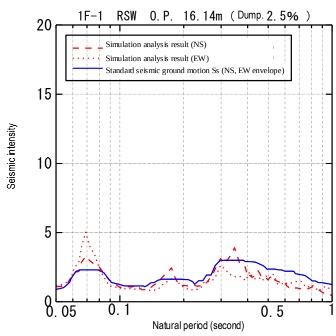


(Vertical)

Floor response spectra (reactor shielding wall)

<Reactor shielding wall (O.P. 16.14 m)>



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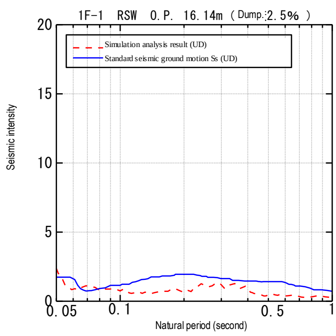


(Vertical)

Seismic safety evaluation result:

Main steam system piping
Calculated value: 269 MPa
Evaluation criteria value: 374 MPa

Reactor shutdown cooling system piping
Calculated value: 228 MPa
Evaluation criteria value: 414 MPa

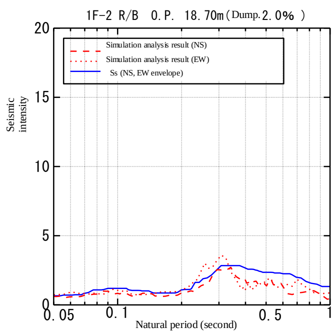
Table II-2-3 Overview of Impact Evaluation on Equipment and Piping Systems important for Seismic Safety

(Fukushima Dai-ichi NPS, Unit 2)

Equipment, etc.		Seismic response load		Standard seismic ground motion Ss	Simulation analysis result	Seismic safety evaluation result
Seismic load, etc.	RPV base	Shear force	(kN)	4960	5110	Reactor Pressure Vessel (RPV) (basement bolt) Calculated value: 29 MPa Evaluation criteria value: 222 MPa
		Moment	(kN・m)	22500	25600	
		Axial force	(kN)	5710	4110	
	PCV base	Shear force	(kN)	7270	8290	Primary Containment Vessel (PCV) (Drywell) Calculated value: 87 MPa Evaluation criteria value: 278 MPa
		Moment	(kN・m)	124000	153000	
		Axial force	(kN)	3110	2350	
	Core shroud base	Shear force	(kN)	2590	3950	Core support structures (Shroud support) Calculated value: 122 MPa Evaluation criteria value: 300 MPa
		Moment	(kN・m)	13800	21100	
		Axial force	(kN)	760	579	
	Fuel assembly	Relative displacement	(mm)	16.5	33.2	Control rod (insertability) Evaluation criteria value: 40.0 mm
Seismic intensity for evaluation	Fuel exchange floor	Seismic intensity (horizontal)	(G)	0.97	1.21	Residual Heat Removal System (RHR) pump (Motor installation bolt) Calculated value: 45 MPa Evaluation criteria value: 185 MPa
		Seismic intensity (vertical)	(G)	0.56	0.70	
	Base mat	Seismic intensity (horizontal)	(G)	0.54	0.68	
		Seismic intensity (vertical)	(G)	0.52	0.37	

Floor response spectra (reactor building)

<Intermediate story (O.P. 18.70 m)>



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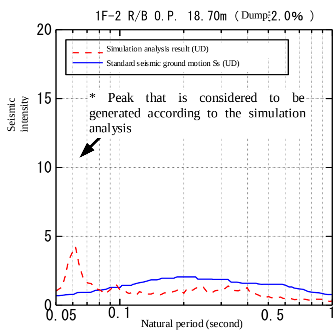


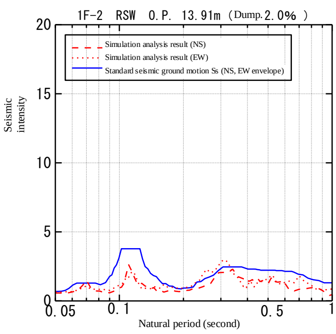
(Vertical)

Main steam system piping
Calculated value: 208 MPa
Evaluation criteria value: 360 MPa

Residual Heat Removal System (RHR) piping
Calculated value: 87 MPa
Evaluation criteria value: 315 MPa

Floor response spectra (reactor shielding wall)

<Reactor shielding wall base (O.P. 13.91 m)>



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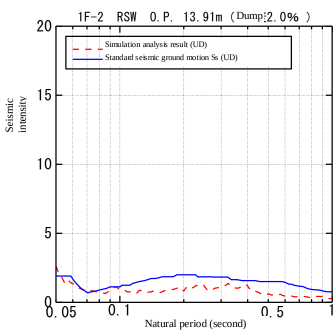


(Vertical)

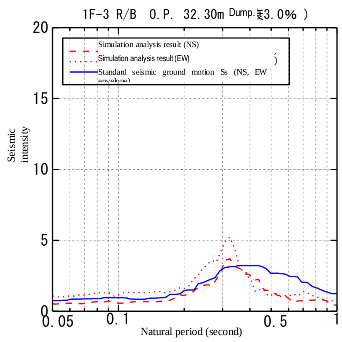
Table II-2-4 Overview of Impact Evaluation on Equipment and Piping Systems important for Seismic Safety

(Fukushima Dai-ichi NPS, Unit 3)

Equipment, etc.		Seismic response load	Standard seismic ground motion Ss	Simulation analysis result	Seismic safety evaluation result
Seismic load, etc.	RPV base	Shear force (kN)	4970	5750	Reactor Pressure Vessel (RPV) (basement bolt) Calculated value: 50 MPa Evaluation criteria value: 222 MPa
		Moment (kN・m)	30400	41700	
		Axial force (kN)	5780	4900	
	PCV base	Shear force (kN)	7070	8150	Primary Containment Vessel (PCV) (Drywell) Calculated value: 158 MPa Evaluation criteria value: 278 MPa
		Moment (kN・m)	123000	153000	
		Axial force (kN)	2930	2080	
	Core shroud base	Shear force (kN)	2440	3010	Core support structures (Shroud support) Calculated value: 100 MPa Evaluation criteria value: 300 MPa
		Moment (kN・m)	13600	16600	
		Axial force (kN)	783	681	
	Fuel assembly	Relative displacement (mm)	14.8	24.1	Control rod (insertability) Evaluation criteria value: 40.0 mm
Seismic intensity for evaluation	Fuel exchange floor	Seismic intensity (horizontal) (G)	0.95	1.34	Residual Heat Removal System (RHR) pump (Motor installation bolt) Calculated value: 42 MPa Evaluation criteria value: 185 MPa
		Seismic intensity (vertical) (G)	0.57	0.81	
	Base mat	Seismic intensity (horizontal) (G)	0.55	0.61	
		Seismic intensity (vertical) (G)	0.53	0.29	

Floor response spectra (reactor building)

<Reactor building (O.P. 32.30 m)>



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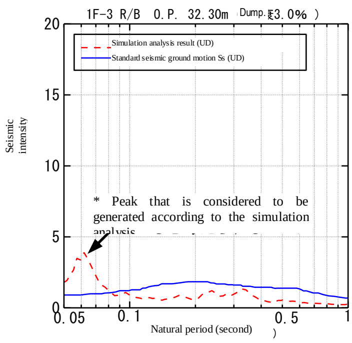


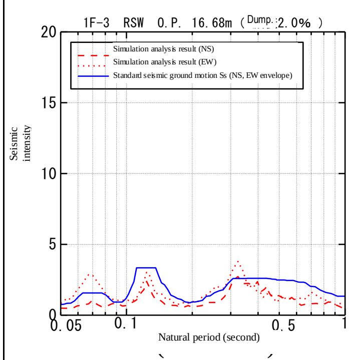
(Vertical)

Main steam system piping
Calculated value: 151 MPa
Evaluation criteria value: 378 MPa

Residual Heat Removal System (RHR) piping
Calculated value: 269 MPa
Evaluation criteria value: 363 MPa

Floor response spectra (reactor shielding wall)

<Reactor shielding wall (O.P. 16.68 m)>



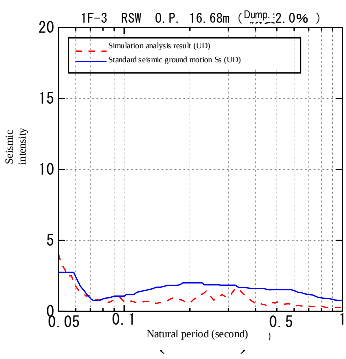


Table II-2-5 Overview of Impact Evaluation on Equipment and Piping Systems important for Seismic Safety

(Fukushima Dai-ichi NPS, Unit 4)

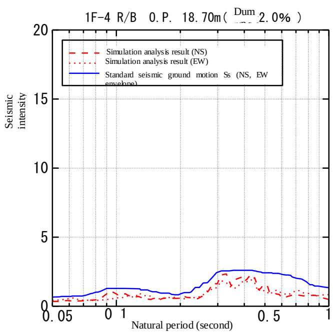
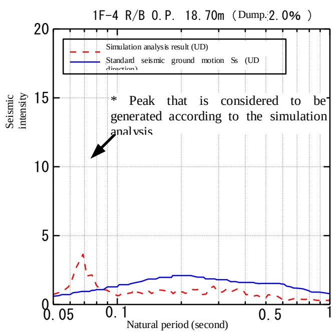
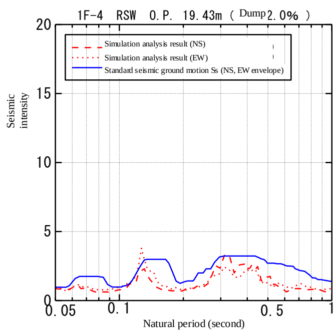
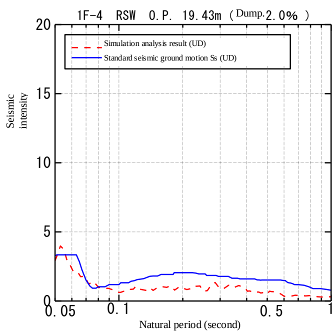
Equipment, etc.		Seismic response load		Standard seismic ground motion Ss	Simulation analysis result	Seismic safety evaluation result
Seismic load, etc.	RPV base	Shear force	(kN)	4790	4000	Reactor Pressure Vessel (RPV) (basement bolt) **Evaluation is not required because the load is below that of standard seismic ground motion Ss**
		Moment	(kN・m)	38900	28000	
		Axial force	(kN)	6660	6020	
	PCV base	Shear force	(kN)	6840	4910	Primary Containment Vessel (PCV) (Drywell) **Evaluation is not required because the load is below that of standard seismic ground motion Ss**
		Moment	(kN・m)	113000	79900	
		Axial force	(kN)	2460	1170	
	Core shroud base	Shear force	(kN)	The core shroud is not installed because replacement construction of the core shroud was in progress at the time of the earthquake		－
		Moment	(kN・m)			
		Axial force	(kN)			
	Fuel assembly	Relative displacement	(mm)	All fuel assemblies were extracted because the periodic inspection was in progress at the time of the earthquake		－
Seismic intensity for evaluation	Fuel exchange floor	Seismic intensity (horizontal)	(G)	0.96	0.68	Residual Heat Removal System (RHR) pump (basement bolt) **Evaluation is not required because the load is below that of standard seismic ground motion Ss**
		Seismic intensity (vertical)	(G)	0.58	0.71	
	Base mat	Seismic intensity (horizontal)	(G)	0.55	0.39	
		Seismic intensity (vertical)	(G)	0.52	0.25	
Floor response spectra (reactor building)	<Intermediate story (O.P. 18.70 m)>  (Horizontal)  (Vertical)					Main steam system piping **Evaluation is not required because the system is currently isolated as a safety measure during shroud replacement construction** Residual Heat Removal System (RHR) piping Calculated value: 124 MPa Evaluation criteria value: 335 MPa
Floor response spectra (reactor shielding wall)	<Reactor shielding wall center (O.P. 19.43 m)>  (Horizontal)  (Vertical)					

Table II-2-6 Overview of Impact Evaluation on Equipment and Piping Systems important for Seismic Safety

(Fukushima Dai-ichi NPS, Unit 5)

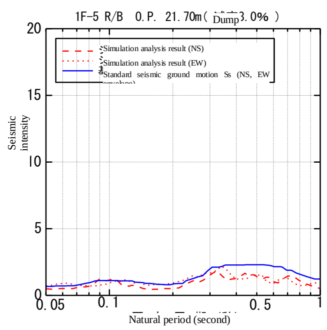
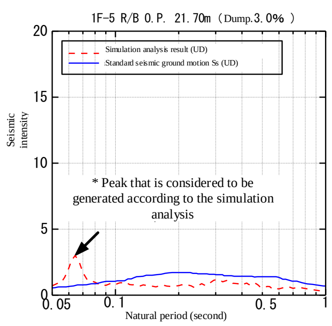
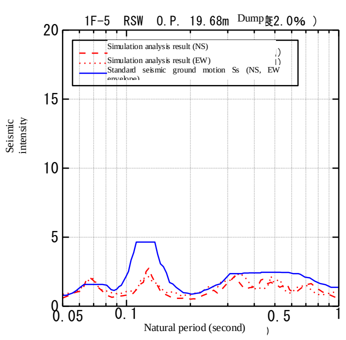
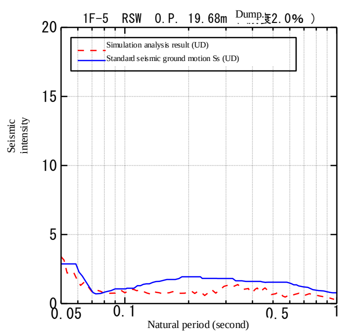
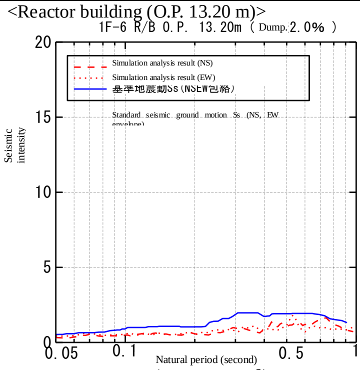
Equipment, etc.		Seismic response load		Standard seismic ground motion Ss	Simulation analysis result	Seismic safety evaluation result
Seismic load, etc.	RPV base	Shear force	(kN)	5200	6830	Reactor Pressure Vessel (RPV) (basement bolt) Calculated value: 53 MPa Evaluation criteria value: 222 MPa
		Moment	(kN・m)	32200	43500	
		Axial force	(kN)	5940	5060	
	PCV base	Shear force	(kN)	8290	8830	Primary Containment Vessel (PCV) (Drywell) **Functionality of the PCV boundaries does not need to be maintained because the containment have been opened**
		Moment	(kN・m)	150000	169000	
		Axial force	(kN)	3320	1820	
	Core shroud base	Shear force	(kN)	2640	2820	Core support structures (Shroud support) Calculated value: 84 MPa Evaluation criteria value: 300 MPa
		Moment	(kN・m)	16600	15700	
		Axial force	(kN)	754	842	
	Fuel assembly	Relative displacement	(mm)	All control rods were inserted because the periodic inspection was in progress at the tine of the earthquake		—
Seismic intensity for evaluation	Fuel exchange floor	Seismic intensity (horizontal)	(G)	0.94	1.17	Residual Heat Removal System (RHR) pump (Motor installation bolt) Calculated value: 44 MPa Evaluation criteria value: 185 MPa
		Seismic intensity (vertical)	(G)	0.55	0.68	
	Base mat	Seismic intensity (horizontal)	(G)	0.56	0.67	
		Seismic intensity (vertical)	(G)	0.53	0.32	
Floor response spectra (reactor building)	<Intermediate story (O.P. 21.70 m)>  (Horizontal)		 (Vertical)			Main steam system piping Calculated value: 244 MPa Evaluation criteria value: 417 MPa Residual Heat Removal System (RHR) piping Calculated value: 189 MPa Evaluation criteria value: 364 MPa
Floor response spectra (reactor shielding wall)	<Reactor shielding wall (O.P. 19.68 m)>  (Horizontal)		 (Vertical)			

Table II-2-7 Overview of Impact Evaluation on Equipment and Piping Systems important for Seismic Safety

(Fukushima Dai-ichi NPS, Unit 6)

<table>
<tr><th colspan="2">Equipment, etc.</th><th colspan="2">Seismic response load</th><th>Standard seismic ground motion Ss</th><th>Simulation analysis result</th><th>Seismic safety evaluation result</th></tr>
<tr><td rowspan="10">Seismic load, etc.</td><td rowspan="3">RPV base</td><td>Shear force</td><td>(kN)</td><td>5260</td><td>3950</td><td rowspan="3">Reactor Pressure Vessel (RPV) (basement bolt)
Evaluation is not required because the load is below that of standard seismic ground motion Ss</td></tr>
<tr><td>Moment</td><td>(kN・m)</td><td>18500</td><td>11700</td></tr>
<tr><td>Axial force</td><td>(kN)</td><td>9470</td><td>5930</td></tr>
<tr><td rowspan="3">PCV base</td><td>Shear force</td><td>(kN)</td><td>21400</td><td>17700</td><td rowspan="3">Primary Containment Vessel (PCV)
(Drywell)
Functionality of the PCV boundaries does not need to be maintained because the containment have been opened</td></tr>
<tr><td>Moment</td><td>(kN・m)</td><td>403000</td><td>314000</td></tr>
<tr><td>Axial force</td><td>(kN)</td><td>5570</td><td>3200</td></tr>
<tr><td rowspan="3">Core shroud base</td><td>Shear force</td><td>(kN)</td><td>6110</td><td>3880</td><td rowspan="3">Core support structures
(Shroud support)
Evaluation is not required because the load is below that of standard seismic ground motion Ss</td></tr>
<tr><td>Moment</td><td>(kN・m)</td><td>36000</td><td>23800</td></tr>
<tr><td>Axial force</td><td>(kN)</td><td>1190</td><td>882</td></tr>
<tr><td>Fuel assembly</td><td>Relative displacement</td><td>(mm)</td><td colspan="2">All control rods were inserted because the periodic inspection was in progress at the time of the earthquake</td><td>—</td></tr>
<tr><td rowspan="4">Seismic intensity for evaluation</td><td rowspan="2">Fuel exchange floor</td><td>Seismic intensity (horizontal)</td><td>(G)</td><td>1.14</td><td>0.71</td><td rowspan="4">Residual Heat Removal System (RHR) pump
(Motor installation bolt)
Evaluation is not required because the load is below that of standard seismic ground motion Ss</td></tr>
<tr><td>Seismic intensity (vertical)</td><td>(G)</td><td>0.67</td><td>0.41</td></tr>
<tr><td rowspan="2">Base mat</td><td>Seismic intensity (horizontal)</td><td>(G)</td><td>0.55</td><td>0.53</td></tr>
<tr><td>Seismic intensity (vertical)</td><td>(G)</td><td>0.51</td><td>0.20</td></tr>
<tr><td>Floor response spectra (reactor building)</td><td colspan="5"><Reactor building (O.P. 13.20 m)>

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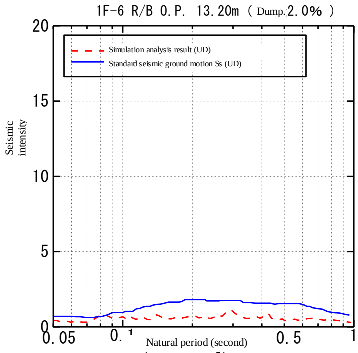
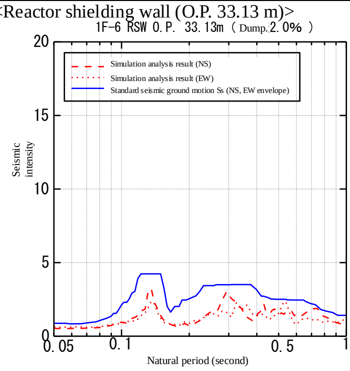
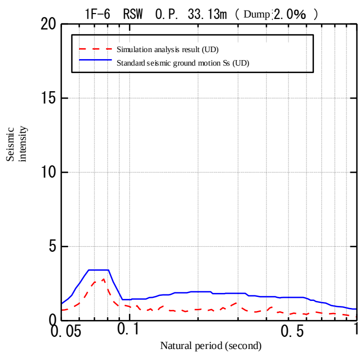

(Vertical)</td><td rowspan="2">Main steam system piping
Calculated value: 211 MPa
Evaluation criteria value: 375 MPa

Residual Heat Removal System (RHR) piping
Calculated value: 88 MPa
Evaluation criteria value: 335 MPa</td></tr>
<tr><td>Floor response spectra (reactor shielding wall)</td><td colspan="5"><Reactor shielding wall (O.P. 33.13 m)>

(Horizontal)

(Vertical)</td></tr>
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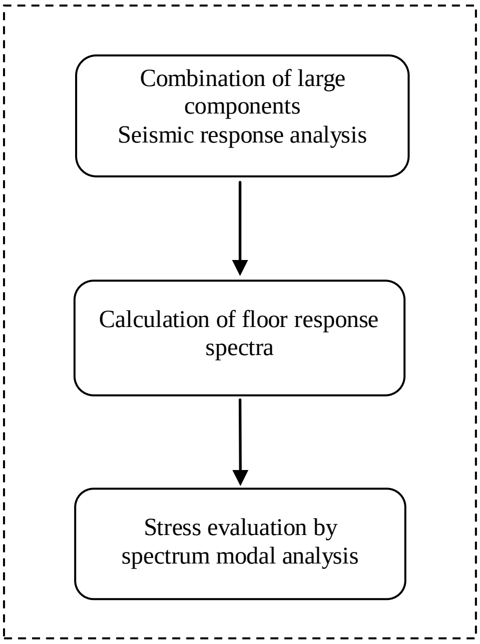
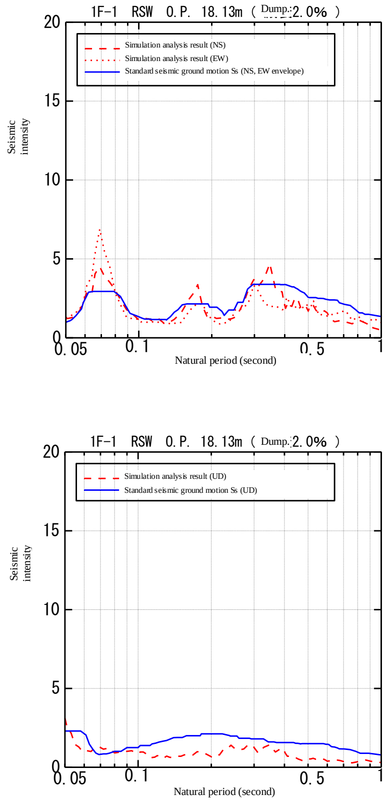
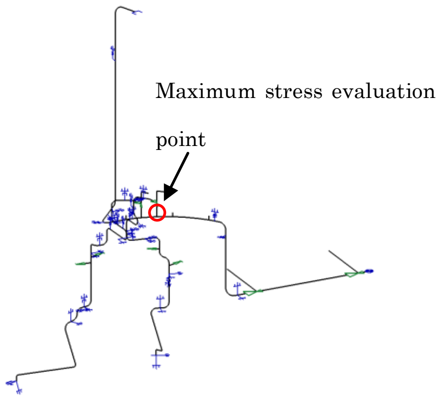


Scheme of Evaluation



Floor Response Spectra



* Schematic Diagram for showing Inputs to Anchors and Supports (Shown as Blue Symbols in Diagram)

Main Steam System Piping Model

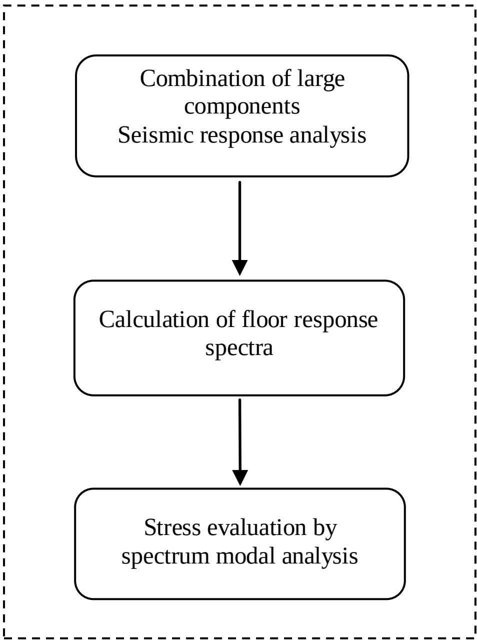
Results of Structural Strength Evaluation

Equipment concerned	Evaluated portion	Standard seismic ground motion Ss				This earthquake			
		Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique	Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique
Main steam system piping	Main body of piping	Primary	287*	374	Details	Primary	269*	374	Details

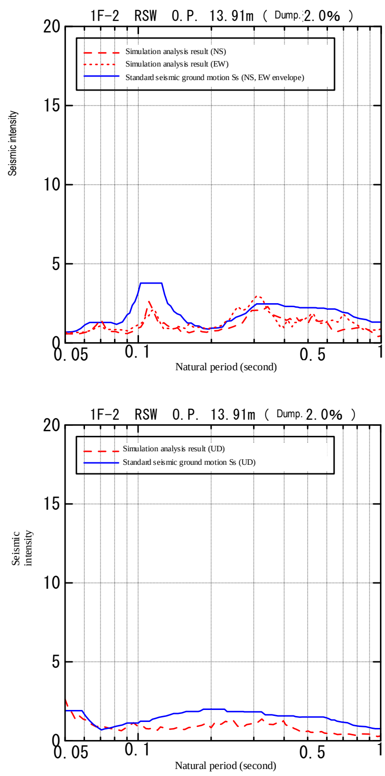
*: The horizontal floor response spectra of this earthquake is greater than that of standard seismic ground motion Ss in part of the periodic band, whereas the vertical floor response spectra of this earthquake is generally less than that of standard seismic ground motion Ss. Accordingly, it is thought that the calculated values for this earthquake were less than those of standard seismic ground

Table II-2-8 Outline of Seismic Evaluation (Example of Main Steam System Piping)

(Fukushima Dai-ichi NPS, Unit 1)



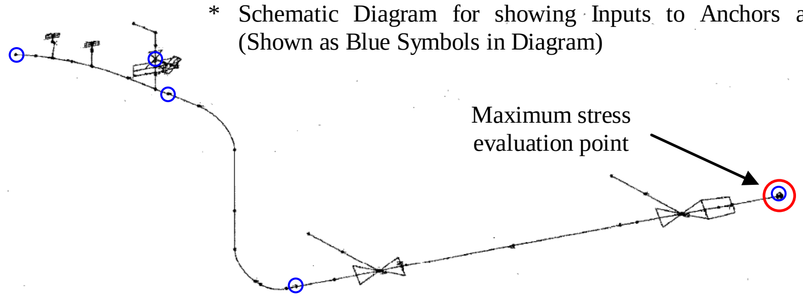
Scheme of Evaluation



Floor Response Spectra

The floor response spectra of this earthquake are generally less than those of standard seismic ground motion Ss. It is in part of the periodic band that the floor response spectra of this earthquake are greater than those of standard seismic ground motion Ss.

* Schematic Diagram for showing Inputs to Anchors and Supports (Shown as Blue Symbols in Diagram)



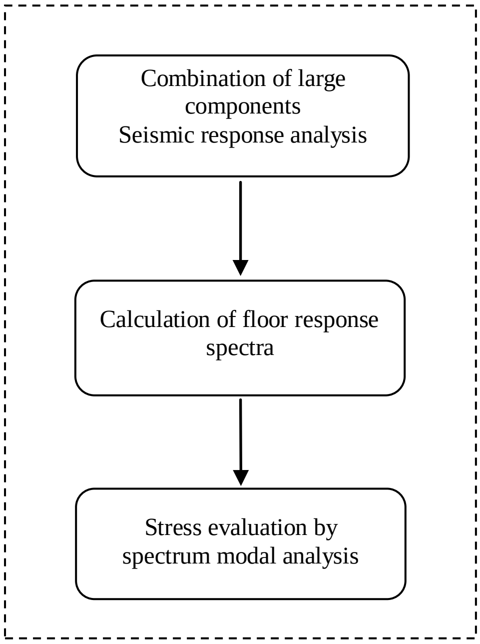
Main Steam System Piping Model (Partial View)

Results of Structural Strength Evaluation

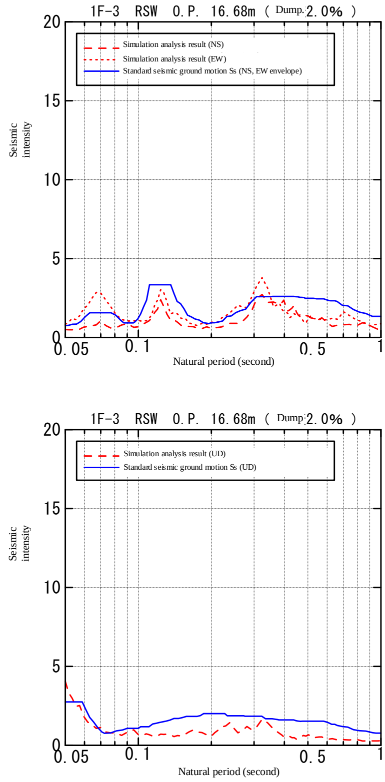
Equipment concerned	Evaluated portion	Standard seismic ground motion Ss				This earthquake			
		Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique	Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique
Main steam system piping	Main body of piping	Primary	288	360	Details	Primary	208	360	Details

Table II-2-9 Outline of Seismic Evaluation (Example of Main Steam System Piping)

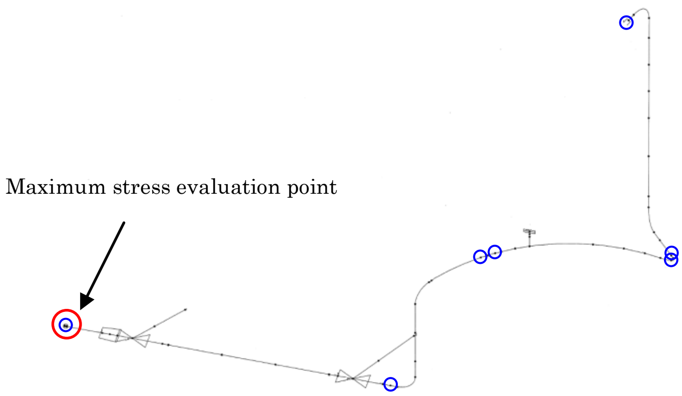
(Fukushima Dai-ichi NPS, Unit 2)



Scheme of Evaluation



Floor Response Spectra



* Schematic Diagram for showing Inputs to Anchors and Supports (Shown as Blue Symbols in Diagram)

Main Steam System Piping Model (Partial View)

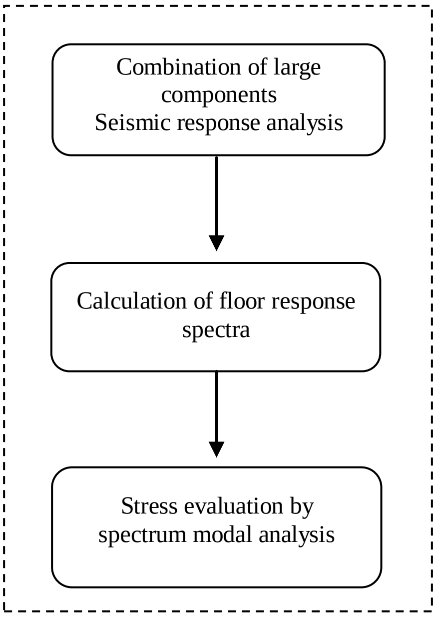
Results of Structural Strength Evaluation

Equipment concerned	Evaluated portion	Standard seismic ground motion Ss				This earthquake			
		Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique	Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique
Main steam system piping	Main body of piping	Primary	183	417*	Details	Primary	151	378*	Details

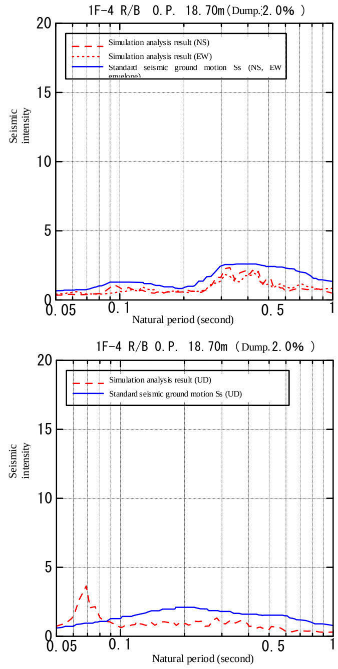
*: The evaluation reference value for standard seismic ground motion Ss and that for this earthquake are different from each other because piping materials at their maximum stress evaluation points (locations with a minimum seismic margin) are different.

Table II-2-10 Outline of Seismic Evaluation (Example of Main Steam System Piping)

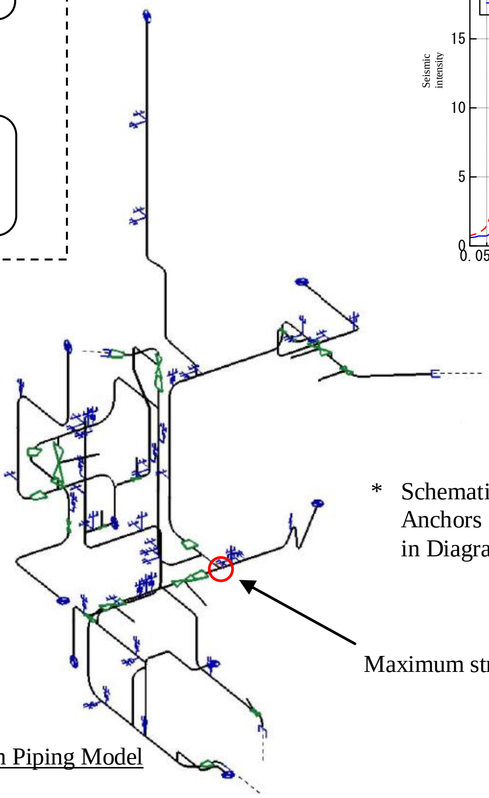
(Fukushima Dai-ichi NPS, Unit 3)



Scheme of Evaluation



Floor Response Spectra



* Schematic Diagram for showing Inputs to Anchors and Supports (Shown as Blue Symbols in Diagram)

Maximum stress evaluation point

Residual Heat Removal System Piping Model

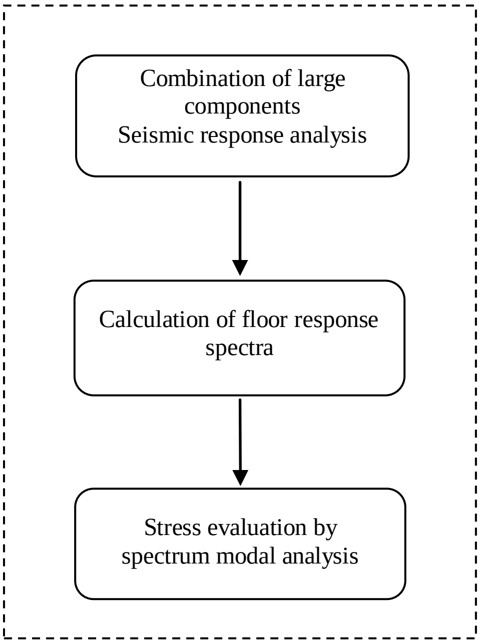
Results of Structural Strength Evaluation

Equipment concerned	Evaluated portion	Standard seismic ground motion Ss				This earthquake			
		Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique	Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique
Main steam system piping	Main body of piping	Primary	137*	335*	Details	Primary	124*	335*	Details

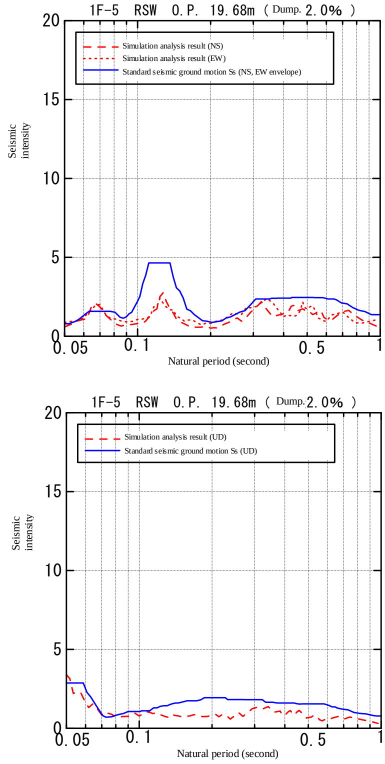
* The portion that was evaluated in the interim report had not been operating due to a safety measure at this earthquake, so that this evaluation was carried out for a different piping model. Accordingly, this comparison of evaluation results is only for reference.

Table. II-2-11 Outline of Seismic Evaluation (Example of Residual Heat Removal System Piping)

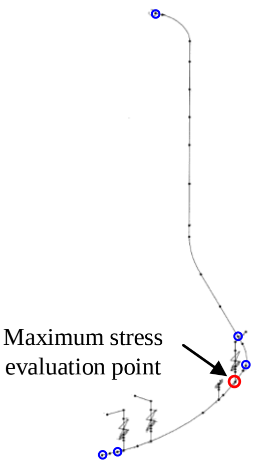
(Fukushima Dai-ichi NPS, Unit 4)



Scheme of Evaluation



Floor Response Spectra



Main Steam System Piping Model (Partial View)

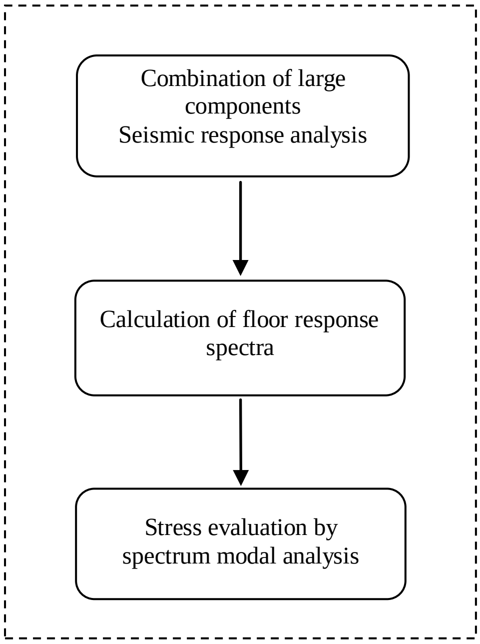
* Schematic Diagram for showing Inputs to Anchors and Supports (Shown as Blue Symbols in Diagram)

Results of Structural Strength Evaluation

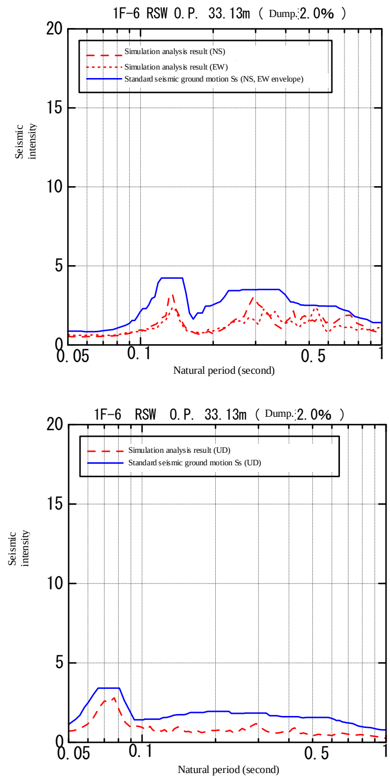
Equipment concerned	Evaluated portion	Standard seismic ground motion Ss				This earthquake			
		Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique	Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique
Main steam system piping	Main body of piping	Primary	356	417	Details	Primary	244	417	Details

Table II-2-12 Outline of Seismic Evaluation (Example of Main Steam System Piping)

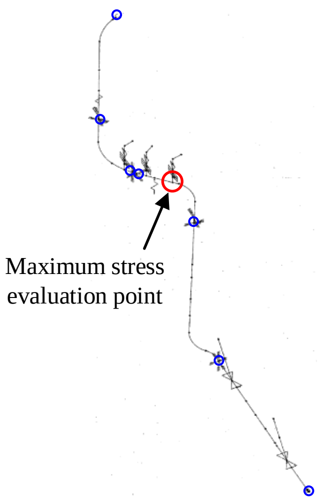
(Fukushima Dai-ichi NPS, Unit 5)



Scheme of Evaluation



Floor Response Spectra



* Schematic Diagram for showing Inputs to Anchors and Supports (Shown as Blue Symbols in Diagram)

Main Steam System Piping Model (Partial View)

Results of Structural Strength Evaluation

Equipment concerned	Evaluated portion	Standard seismic ground motion Ss				This earthquake			
		Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique	Stress classification	Calculated value (MPa)	Evaluation criteria value (MPa)	Evaluation technique
Main steam system piping	Main body of piping	Primary	292	375	Details	Primary	211	375	Details

Table II-2-13 Outline of Seismic Evaluation (Example of Main Steam System Piping)

(Fukushima Dai-ichi NPS, Unit 6)

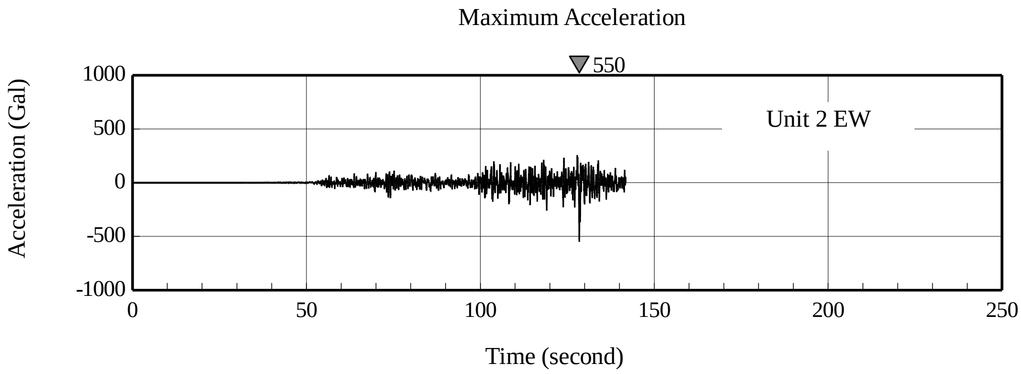


Figure II-2-1(a) Acceleration data observed at the Reactor Building Base Mat of Fukushima Dai-ichi NPS

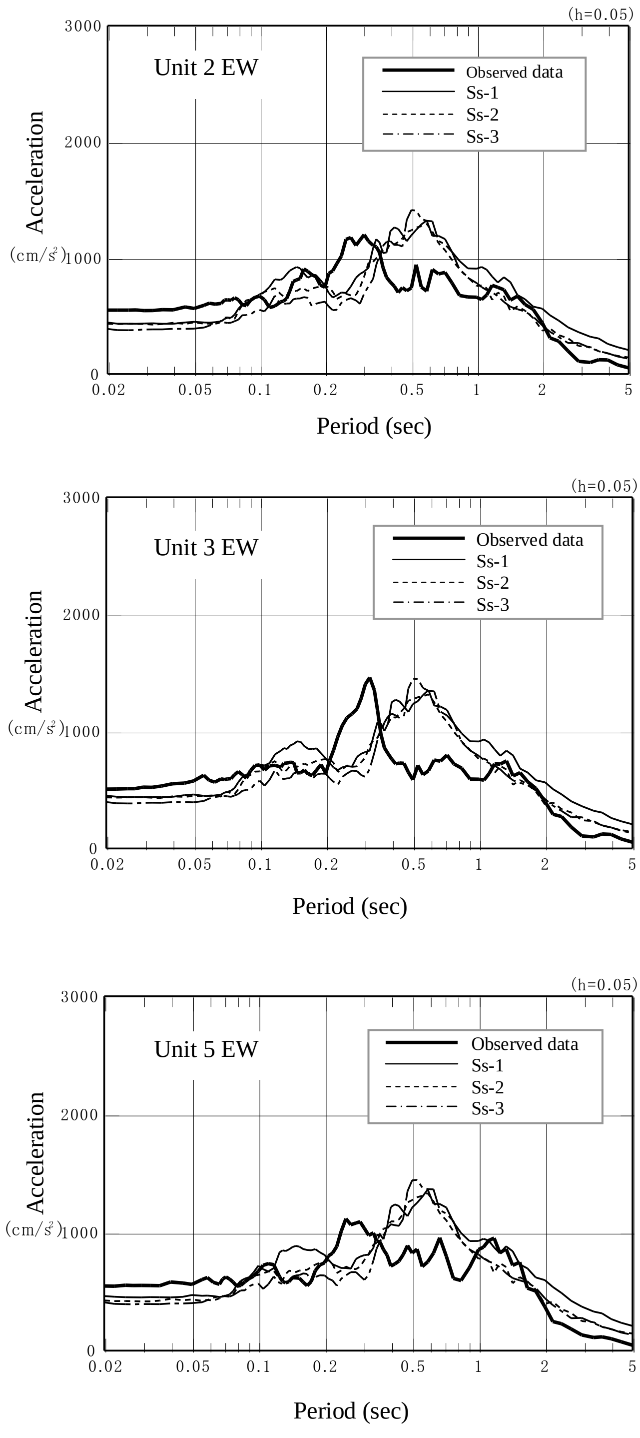


Figure II-2-1(b) Response Spectra at the Reactor Building Base Mat of Fukushima Dai-ichi NPS

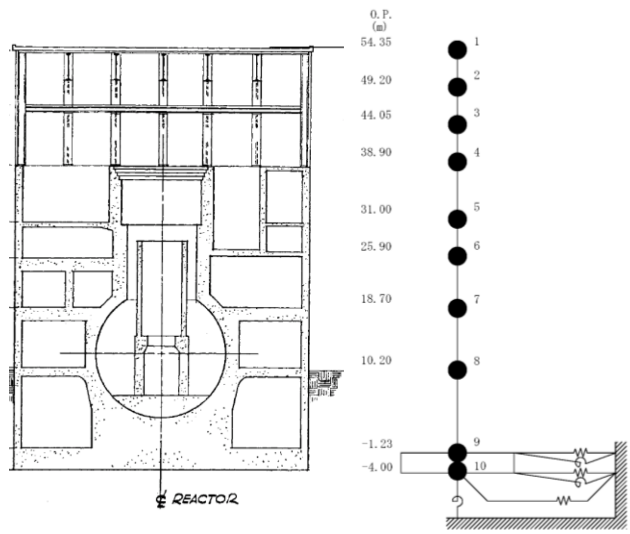


Figure II-2-2 Model of Reactor Building (Fukushima Dai-ichi NPS, Unit 1)

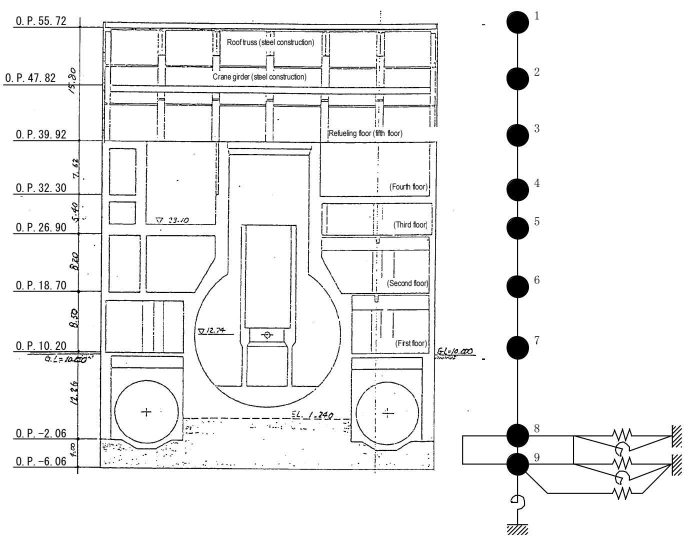


Figure II-2-3 Model of Reactor Building (Fukushima Dai-ichi NPS, Unit 2)

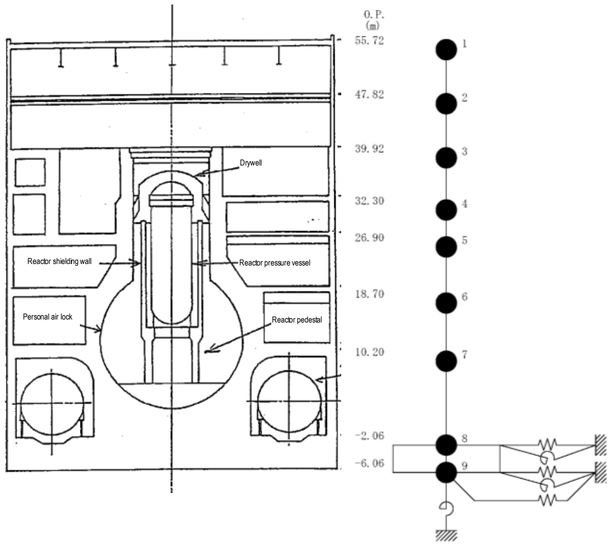


Figure II-2-4 Model of Reactor Building (Fukushima Dai-ichi NPS, Unit 3)

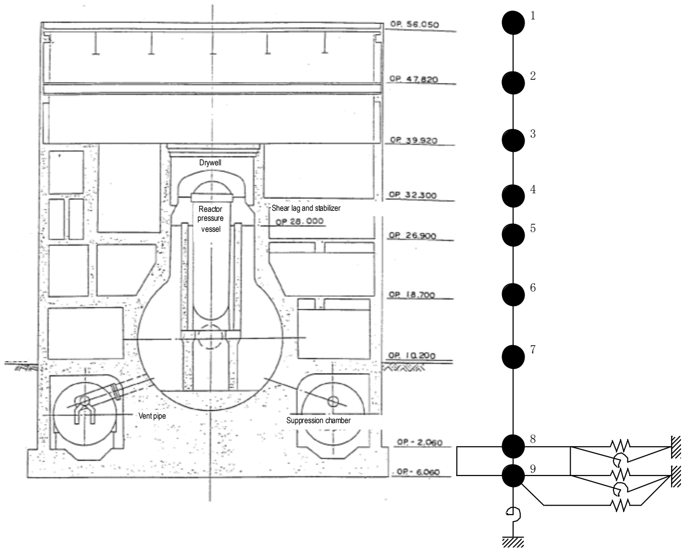


Figure II-2-5 Model of Reactor Building (Fukushima Dai-ichi NPS, Unit 4)

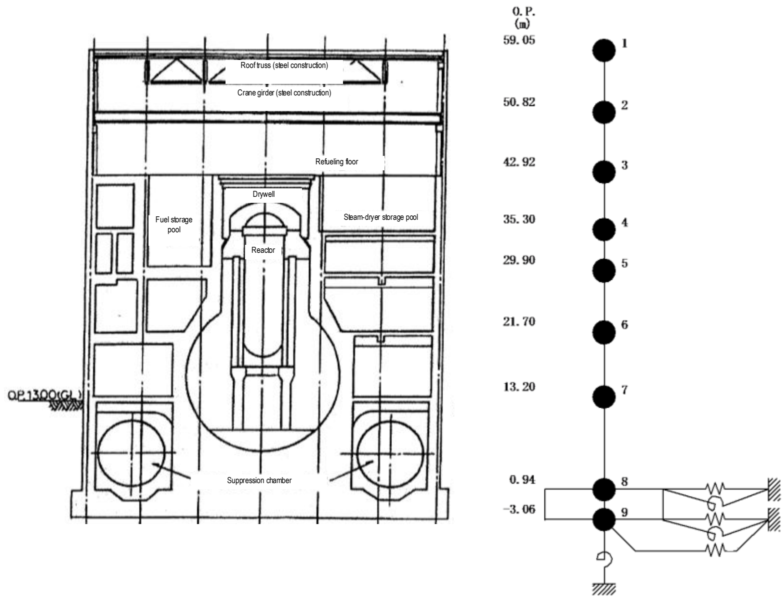


Figure II-2-6 Model of Reactor Building (Fukushima Dai-ichi NPS, Unit 5)

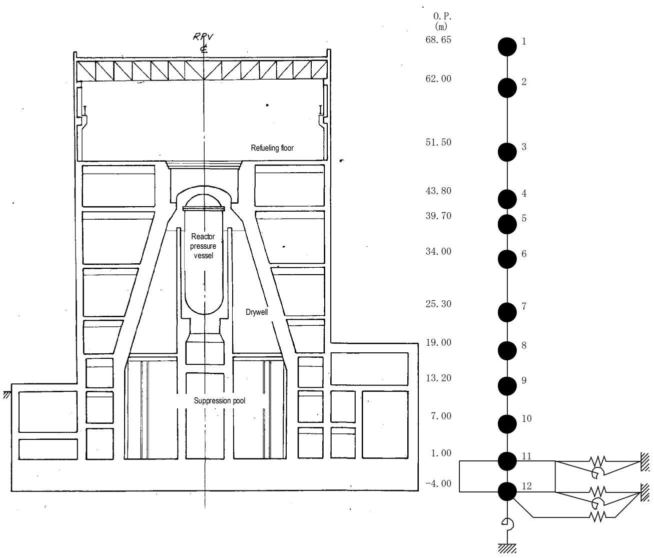


Figure II-2-7 Model of Reactor Building (Fukushima Dai-ichi NPS, Unit 6)

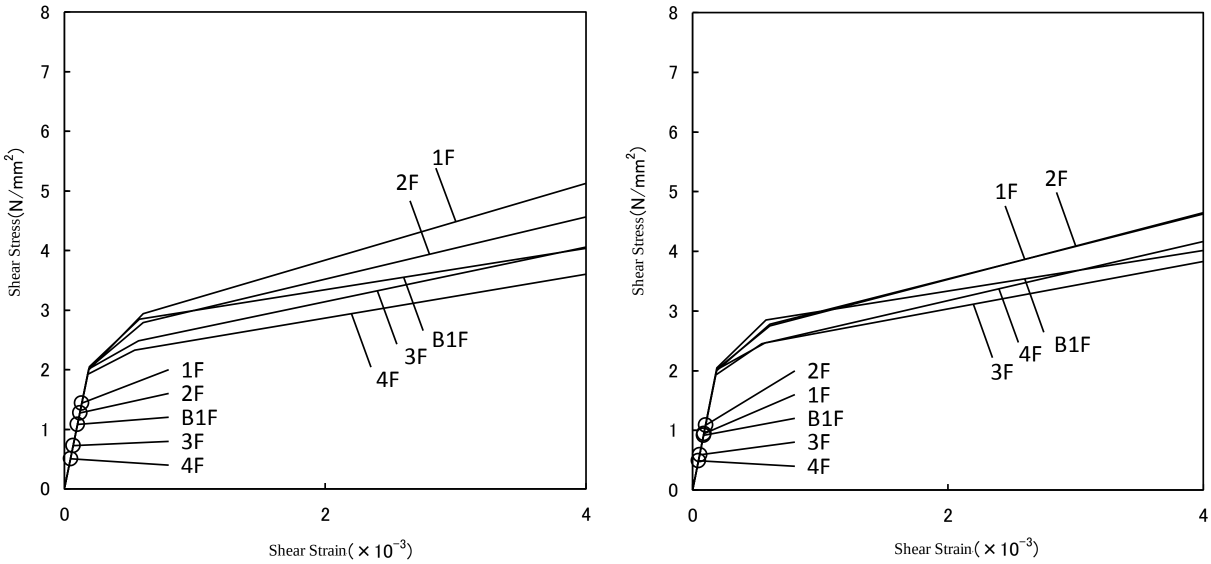


Figure II-2-8 Shear Strain on Seismic Wall (Left: NS Direction, Right: EW Direction)
(Fukushima Dai-ichi NPS, Unit 1)

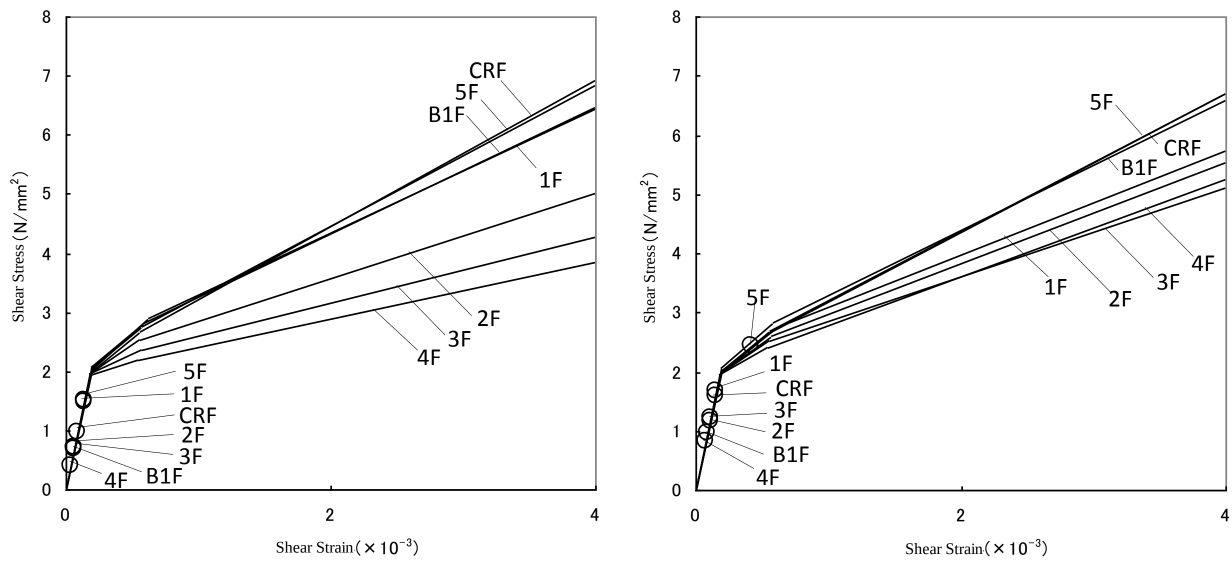


Figure II-2-9 Shear Strain on Seismic Wall (Left: NS Direction, Right: EW Direction)
(Fukushima Dai-ichi NPS, Unit 2)

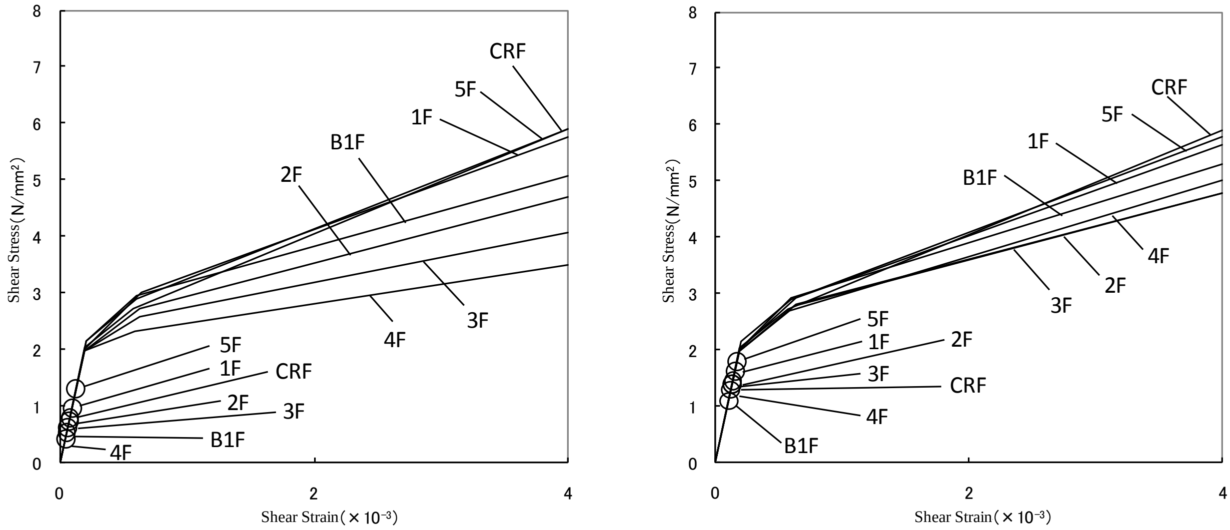


Figure II-2-10 Shear Strain on Seismic Wall (Left: NS Direction, Right: EW Direction)

(Fukushima Dai-ichi NPS, Unit 3)

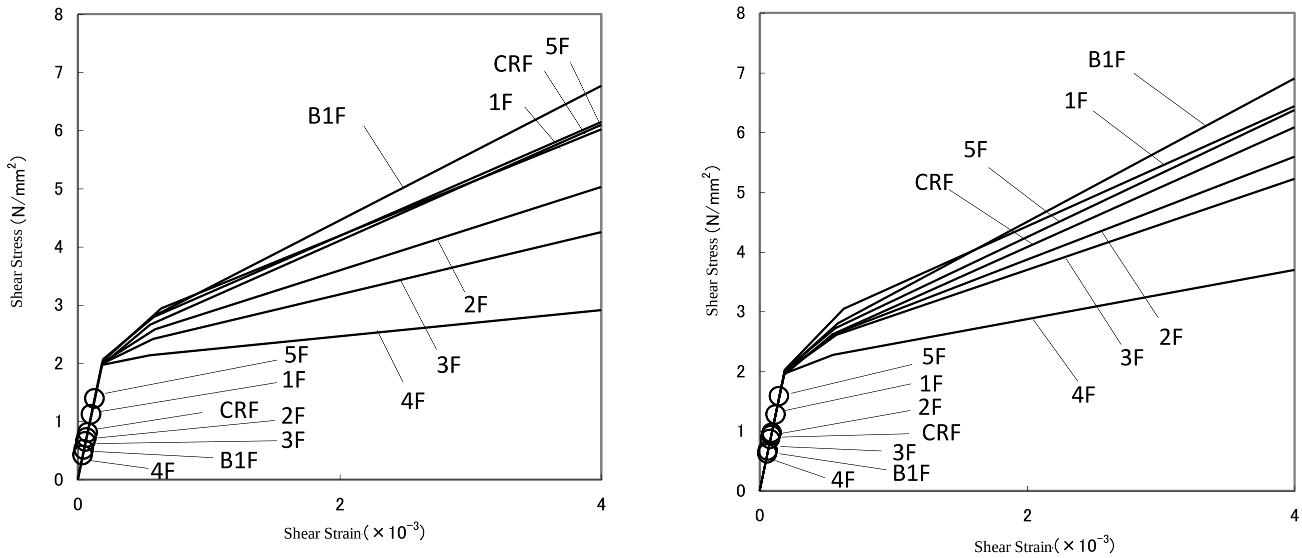


Figure II-2-11 Shear Strain on Seismic Wall (Left: NS Direction, Right: EW Direction)

(Fukushima Dai-ichi NPS, Unit 4)

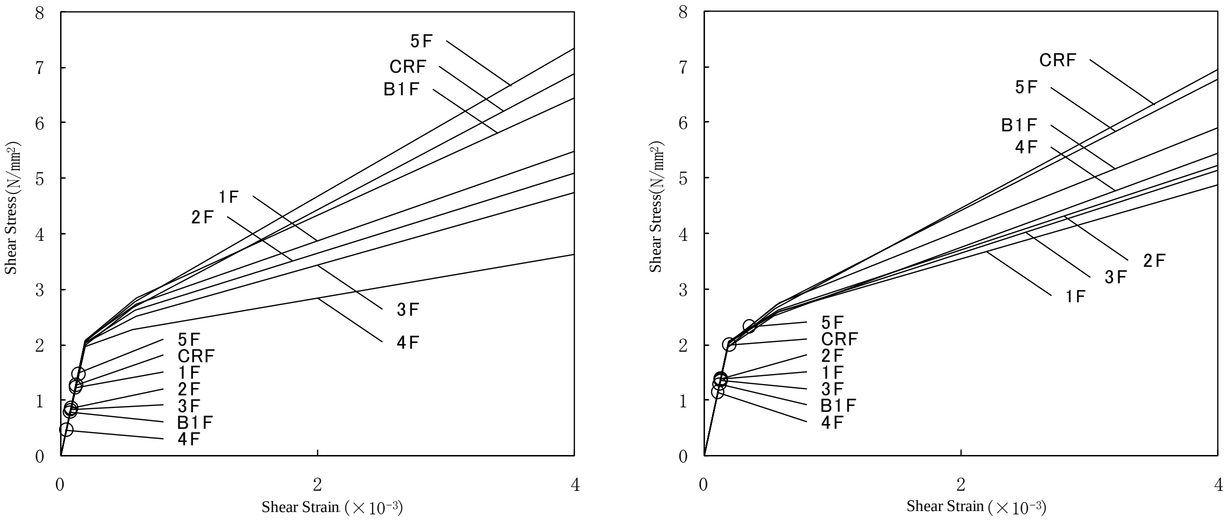


Figure II-2-12 Shear Strain on Seismic Wall (Left: NS Direction, Right: EW Direction)

(Fukushima Dai-ichi NPS, Unit 5)

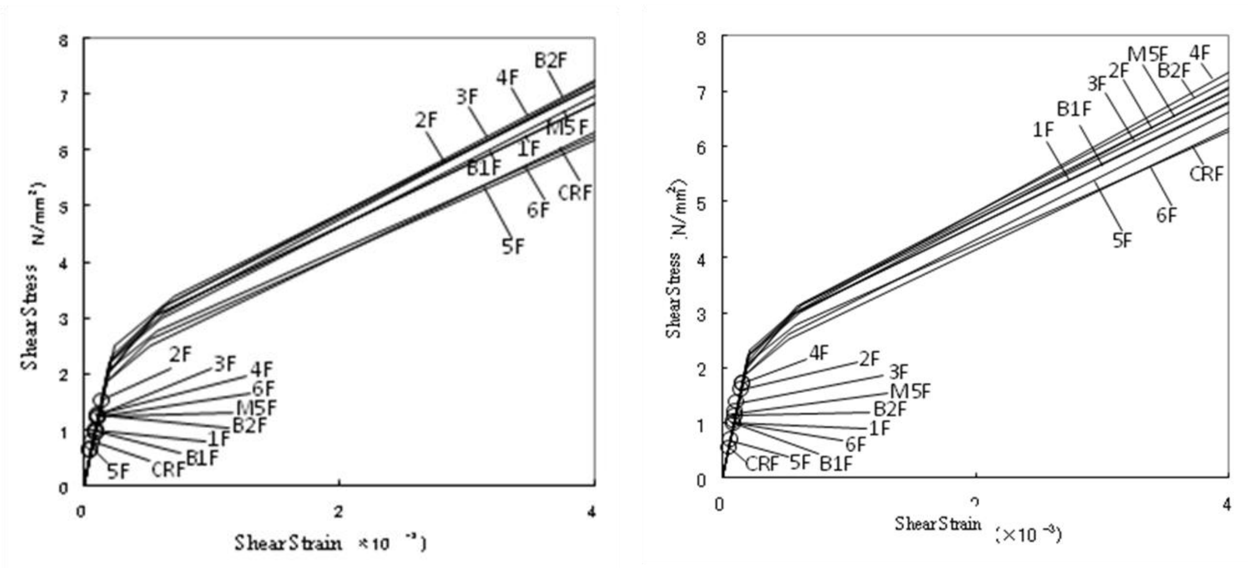


Figure II-2-13 Shear Strain on Seismic Wall (Left: NS Direction, Right: EW Direction)

(Fukushima Dai-ichi NPS, Unit 6)

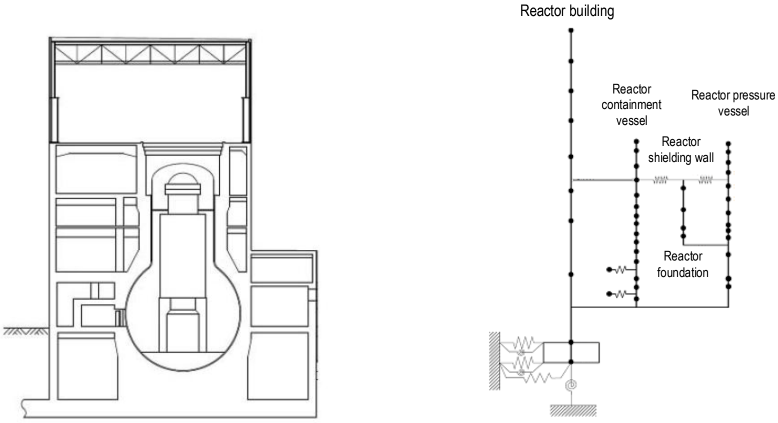


Figure II-2-14 Example of Model for Building-Large Equipment Interaction Response Analysis (Fukushima Dai-ichi NPS, Unit 1)

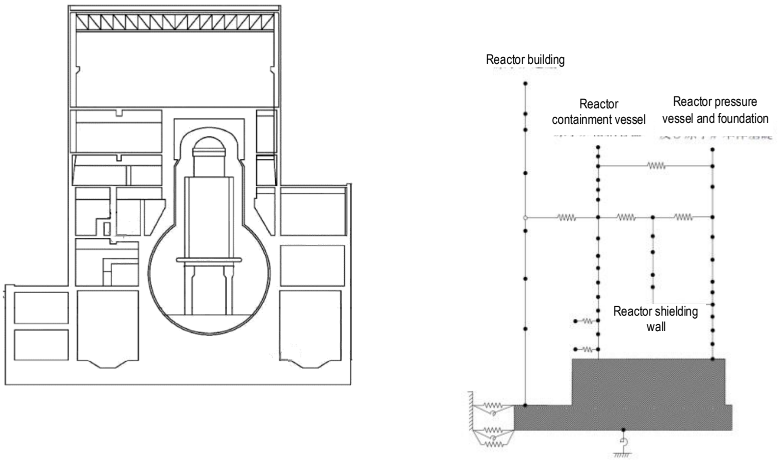


Figure II-2-15 Example of Model for Building-Large Equipment Interaction Response Analysis (Fukushima Dai-ichi NPS, Unit 2)

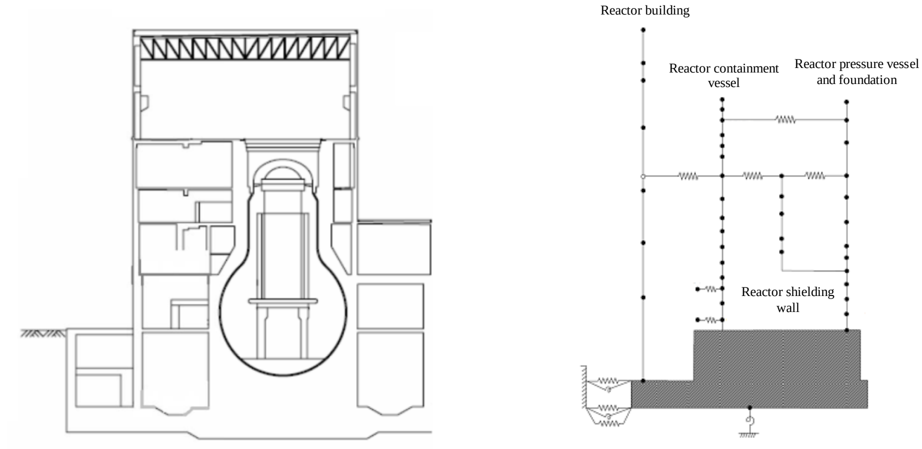


Figure II-2-16 Example of Model for Building-Large Equipment Interaction Response Analysis (Fukushima Dai-ichi NPS, Unit 3)

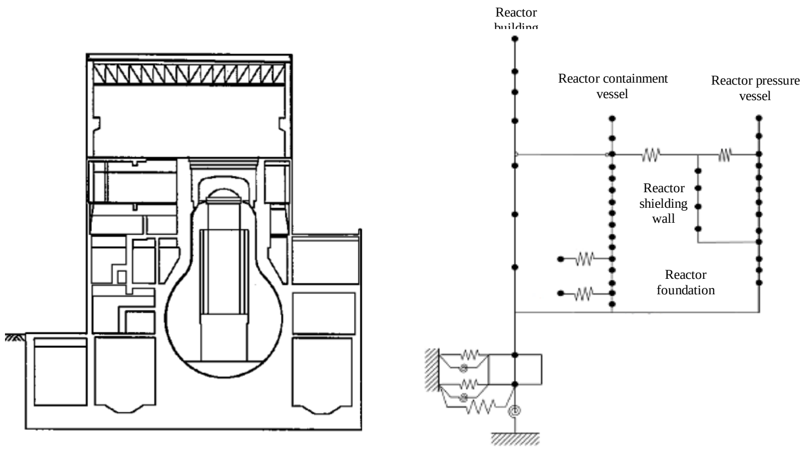


Figure II-2-17 Example of Model for Building-Large Equipment Interaction Response Analysis (Fukushima Dai-ichi NPS, Unit 4)

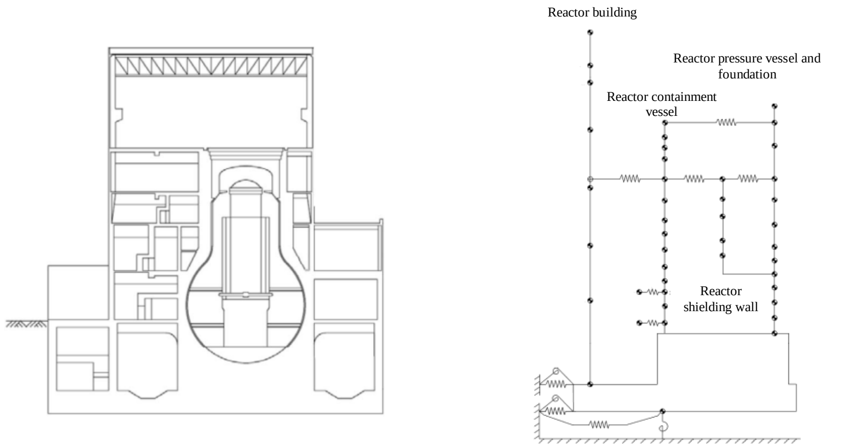


Figure II-2-18 Example of Model for Building-Large Equipment Interaction Response Analysis (Fukushima Dai-ichi NPS, Unit 5)

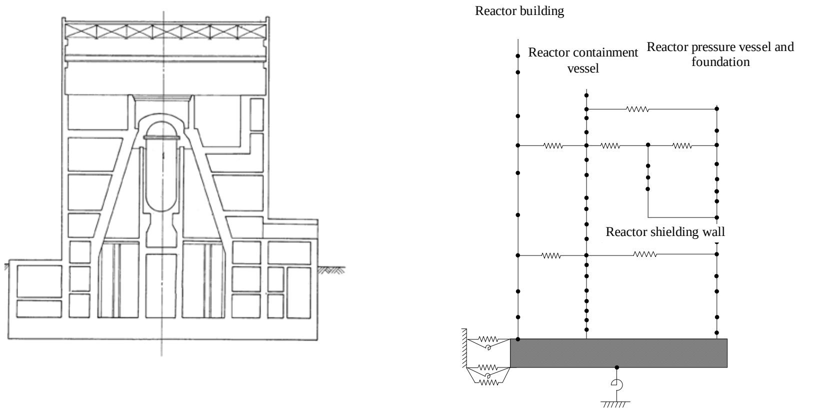


Figure II-2-19 Example of Model for Building-Large Equipment Interaction Response Analysis (Fukushima Dai-ichi NPS, Unit 6)

2) Status of inundation by tsunami

a. Outline of the June Report

In the June Report, as matters related to tsunami, tidal level observation system and observed records, comparison between design basis tsunami height and observed tsunami height, and probabilistic tsunami hazard assessment and exceedance probability of design basis tsunami height were summarized. The outline is shown as follow.

According to the tide gauge installed in a point where about 13 m depth of water outside port, the initial major tsunami arrived at around 15:27 (41 minutes later of main shock occurrence) whose height was approximately 4 m height. Though the next major tsunami was the one that arrived at 15:35, the water level is unknown due to the damage of the tide gauge. The maximum scale of the gauge is 7.5 m.

The site height of the Fukushima Dai-ichi NPS is O.P. +10 m (O.P.: Onahama port base tide level for construction) at Units 1 to 4, and O.P. +13 m at Units 5 and 6. At the Fukushima Dai-ichi NPS, tsunami rushed from the offshore area in front of the site, and most parts of the site where main buildings were placed was flooded. The inundation height based on the results of the trace investigation at flooding conducted by TEPCO is shown in Figure II-2-20. The inundation height of the ocean-side area such as reactor buildings and turbine buildings of Units 1 to 4, etc. is O.P. approximately +14 to 15 m at points H to K in the Figure. Experts estimate that the tsunami height caused by this earthquake is more than 10 m from the picture showing the overflow status of tsunami seawall (10 m) released by TEPCO. It is hence assumed that tsunami height at the seawater pump is more than 10 m.

As for the relationship between the designed basis tsunami height and observed tsunami height, as shown in Figure II-2-21, in the application document for establishment permit, subject tsunami source is Chile earthquake (M9.5, 1960) and the design basis tsunami water level is O.P. +3.1 m. In 2002, based on the "Tsunami Assessment Method for Nuclear Power Plants in Japan (2002)" of the Tsunami Evaluation Subcommittee, the Nuclear Civil Engineering Committee, Japan Society of Civil Engineers [II2-1], TEPCO evaluated the tsunami height of each unit as O.P. +5.4 m to O.P. +5.7 m.

In 2009, NISA requested operators to take into account the Jogan earthquake in AD 869 for evaluating design basis tsunami height when new knowledge on the tsunami of the Jogan earthquake is obtained.

Regarding probabilistic tsunami hazard evaluation and exceedance probability of design basis tsunami height, the Tsunami Evaluation Subcommittee of Japan Society of Civil Engineers is at work on consideration about probabilistic tsunami hazard analysis method. As a part of the consideration, the tsunami hazard assessment method and a result of the trial assessment of tsunami exceedance probability (Figure II-2-22) is already published [II2-2 to II2-4] but not yet completed. Other trial assessment of tsunami hazard is announced as well [II2-5].

Also, regarding damages related to tsunami, damages of the seawater system pump and the emergency power supply system were summarized in the June Report. The outline is shown as follow.

Regarding seawater system pump and emergency power supply system, as to the seawater pump facilities for components cooling (height: 5.6 to 6m) at the Fukushima Dai-ichi NPS, all units were flooded by tsunami as shown in Figure II-2-20. In addition, many of the Emergency Diesel Generators (Emergency DG) and distribution boards installed in the basement floor of the reactor buildings and the turbine buildings (height: 0 m to 5.8 m) were damaged by tsunami, and emergency power source supply was lost except in Unit 6. As for Unit 6, only one emergency DG out of three installed on the first floor of DG building kept its function, and emergency power supply was possible.

b. Matters found after June

○ Trial calculation of tsunami height by TEPCO

In 2008, TEPCO carried out a trial calculation of the tsunami height based on hypothesized tsunami source model in the area along the trench of off the coast of Fukushima Prefecture as well as the proposed tsunami source models based on a research paper on Jogan Earthquake Tsunami.

NSIA heard the explanation about both a result of the trial calculation by the proposed tsunami source model of the Jogan Earthquake Tsunami in September 2009 and, on March 7, 2011, a result of the calculation that “the trial calculation of tsunami height hypothesizing tsunami source model in the area along the trench of off the coast of Fukushima Prefecture" showed tsunami of 10 m or higher. TEPCO had requested Japan Society of Civil Engineers for deliberation in June 2009 in order to establish tsunami source model.

○ Reproduction calculation of tsunami

TEPCO carried out estimation, by numerical simulation, of tsunami source model explainable of inundation height, height of the run-up tsunami, inundation area, records of tide observation, and crustal movement in a broad area (Hokkaido to Chiba Prefecture) due to earthquake and tsunami this time. Estimated source model was magnitude (Mw) 9.1, the tsunami height at the point where tide gauge was installed was 13.1 m, and inundation height and inundation area in the site of the Fukushima Dai-ichi NPS are shown in Figure II-2-23 and Figure II-2-24, and actual behavior was almost simulated. As for amount of ground deformation, it measured the average ground subsidence level as about 0.66 m at the Fukushima Dai-ichi NPS, but this is a provisional value and is not reflect on inundation height.

○ Status of damage and inundation of buildings

In the investigation conducted by TEPCO, around major buildings in the site of O.P. +10 m and O.P. +13 m, almost all areas were estimated to be flooded due to the run-up of tsunami, but significant damage to the structure of main building, such as outer wall and pillars, etc. was not found.

In addition, due to inundation, some parts of the openings on the ground of main building (entrance of building, equipment hatch, and exhaust port) and the opening connected to trench and duct buried under the ground of the site (penetrations slots for cable and pipe) were estimated to be flooding routes into buildings, and it was found that, mainly in the east side (the sea side) of Units 1 to 4 of turbine building, parts of doors and shutters, etc. were damaged by tsunami. It is estimated that, in the inside of the buildings, wide range of the basement was flooded through passageway and stairs room. Location of the opening conceivable to be the flooding routes to the main building is shown in Figure II-2-25.

○ Status of damage and inundation of facilities

In investigation conducted by TEPCO, regarding emergency sea water cooling system facilities installed in exterior yard area, each of them remained at installed place after being damaged by tsunami, and no case was found that the main pump was flowing except pump which had been removed due to under inspection. However, damages of pumps as well as ancillary equipments due to strike of the collapsed crane for facility inspection and of floating objects, and incorporation of seawater into motor shaft lubricating oil were found.

Regarding direct main bus panel, those in Units 1, 2, and 4 were flooded but those in Units 3, 5, and 6 were not flooded. Status of damage of emergency power supply system by inundation is shown in Table II-2-14.

Table II-2-14 Influences of Inundation due to Tsunami on Emergency Power Distribution Panels (M/C, P/C), Emergency Diesel Generator Facilities (D/G) and DC Main Bus Panels at Fukushima Dai-ichi NPS

Facility	Line*1	Unit 1			Unit 2			Unit 3			Unit 4			Unit 5			Unit 6		
		Inundation	Condition after tsunami	Location	Inundation	Condition after tsunami	Location	Inundation	Condition after tsunami	Location	Inundation	Condition after tsunami	Location	Inundation	Condition after tsunami	Location	Inundation	Condition after tsunami	Location
Emergency power distribution panel (M/C)	C	YES	×	T/B 1FL O.P.+10.2m	YES	×	T/B B1FL O.P.+1.9m	YES	×	T/B B1FL O.P.-0.3m	YES	× *2	T/B B1FL O.P.+1.9m	YES	×	T/B B1FL O.P.+2.77m	NO	○	R/B B2FL O.P.+1m
	D	YES	×		YES	×		YES	×		YES	×		YES	×		NO	○	R/B B1FL O.P.+7m
	E(H)				YES	×	Cmn B1FL O.P.+2.7m				YES	×	Cmn B1FL O.P.+2.7m				NO	○	R/B 1FL O.P.+13.2m
Emergency power distribution panel (P/C)	C	YES	×	C/B B1FL O.P.+4.9m	YES	○	T/B 1FL O.P.+9m	YES	×	T/B B1FL O.P.-0.3m	YES	– *2	T/B 1FL O.P.+9m	YES	×	T/B B1FL O.P.+2.77m	NO	○	R/B B2FL O.P.+1m
	D	YES	×		YES	○		YES	×		YES	○		YES	×		NO	○	R/B B1FL O.P.+7m
	E				YES	×	Cmn B1FL O.P.+2.7m				YES	×	Cmn B1FL O.P.+2.7m				NO	○	DG Bldg.1FL O.P.+5.7m
Emergency diesel generator facility (D/G)	A	YES	×	T/B B1FL O.P.+4.9m	YES	×	T/B B1FL O.P.+1.9m	YES	×	T/B B1FL O.P.+1.9m	YES	× *2	T/B B1FL O.P.+1.9m	NO	×	T/B B1FL O.P.+4.9m	NO	×	R/B B1FL O.P.+5.8m
	B	YES	×	T/B B1FL O.P+.2m	NO	×	Cmn 1FL O.P.+10.2m	YES	×		NO	×	Cmn 1FL O.P.+10.2m	NO	×		NO	○	DG Bldg.1FL O.P.+13.2m
	H																NO	×	R/B B1FL O.P.+5.8m
DC main bus panel	A	YES	×	C/B B1FL O.P.+4.9m	YES	×	C/B B1FL O.P.+1.9m	NO	○	T/B MB1F O.P.+6.5m	YES	×	C/B B1FL O.P.+1.9m	NO	○	T/B MB1F O.P.+9.5m	NO	○	T/B MB1F O.P.+9.5m
	B	YES	×		YES	×		NO	○		YES	×		NO	○		NO	○	

Note: ○: Usable, ×: Unusable
T/B: Turbine Building, C/B: Control Building, Cmn: Common operation support facility
R/B: Reactor Building, DG building: Diesel Generator building
*1: M/C of Units 2 and 4 are in Train E and M/C of Unit 6 is in Train H.
*2: M/C (4C) and D/G (4A) are under inspection/repair. P/C (4C) is under replacement.

: Inundated

: Unusable due to inundated main/ancillary equipment

: Cannot be energized due to failed power source. M/C (6C, 6H) cannot be energized as D/G (6A, 6H) is unavailable.

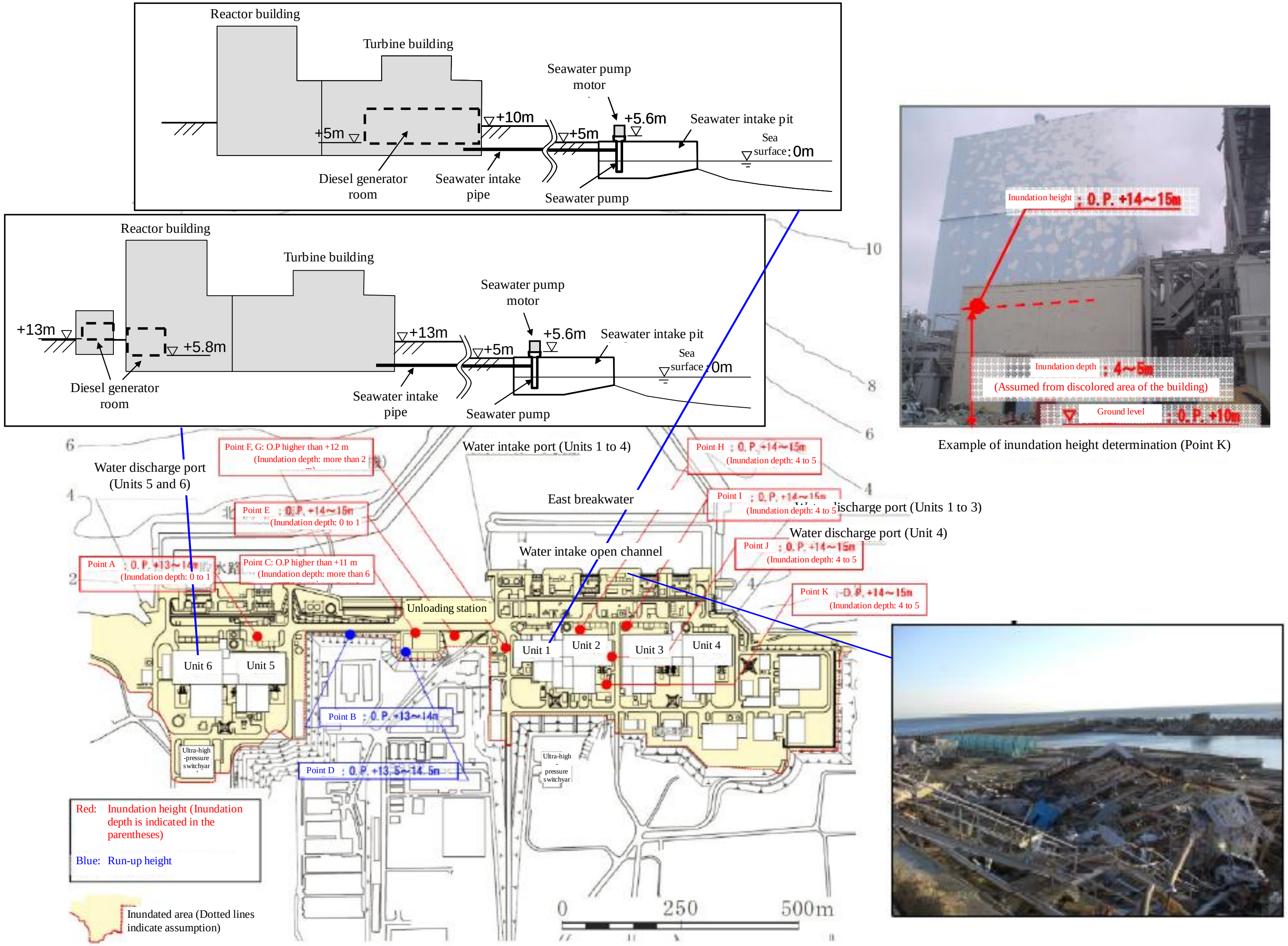


Figure II-2-20 Damage of Fukushima Dai-ichi NPS due to the Tsunami

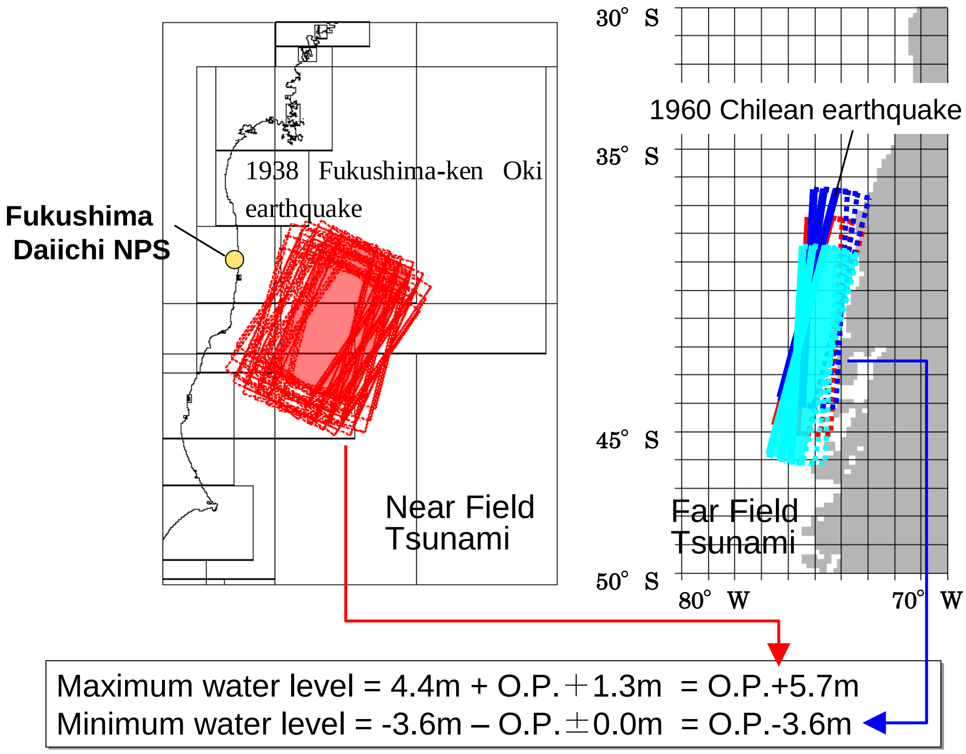
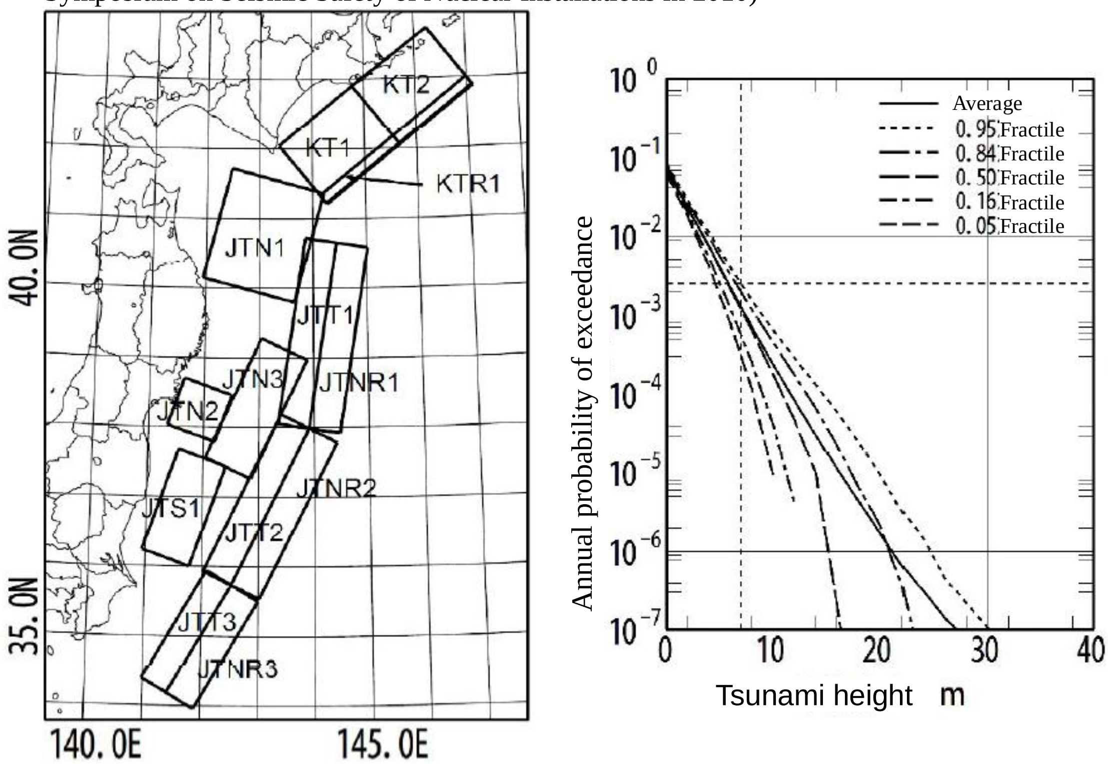


Figure II-2-21 Design Tsunami Level Evaluated by TEPCO for Fukushima Dai-ichi NPS

(Reference: Takao/TEPCO; Presentation material at the 1st Kashiwazaki International Symposium on Seismic Safety of Nuclear Installations in 2010)



[Reference III 2-6] Reports of Japan Society of Civil Engineering, the Tsunami Evaluation Subcommittee, the Nuclear Civil Engineering Committee

Figure II-2-22 Evaluation Results of Tsunami Hazard Curves Based on Near-and Far-field Tsunami Sources for Yamada Village, Iwate Pref., the Nuclear Civil Engineering Committee

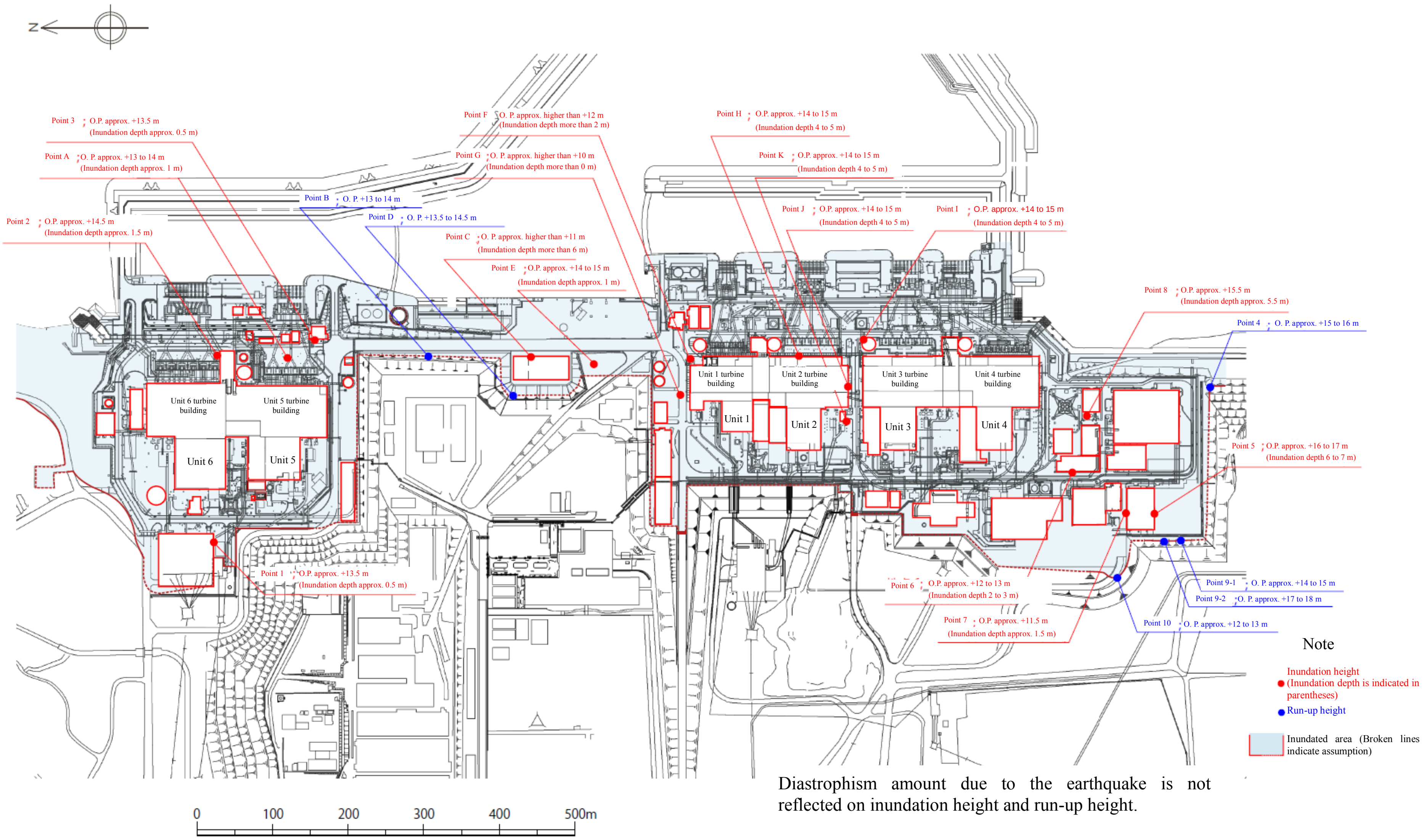
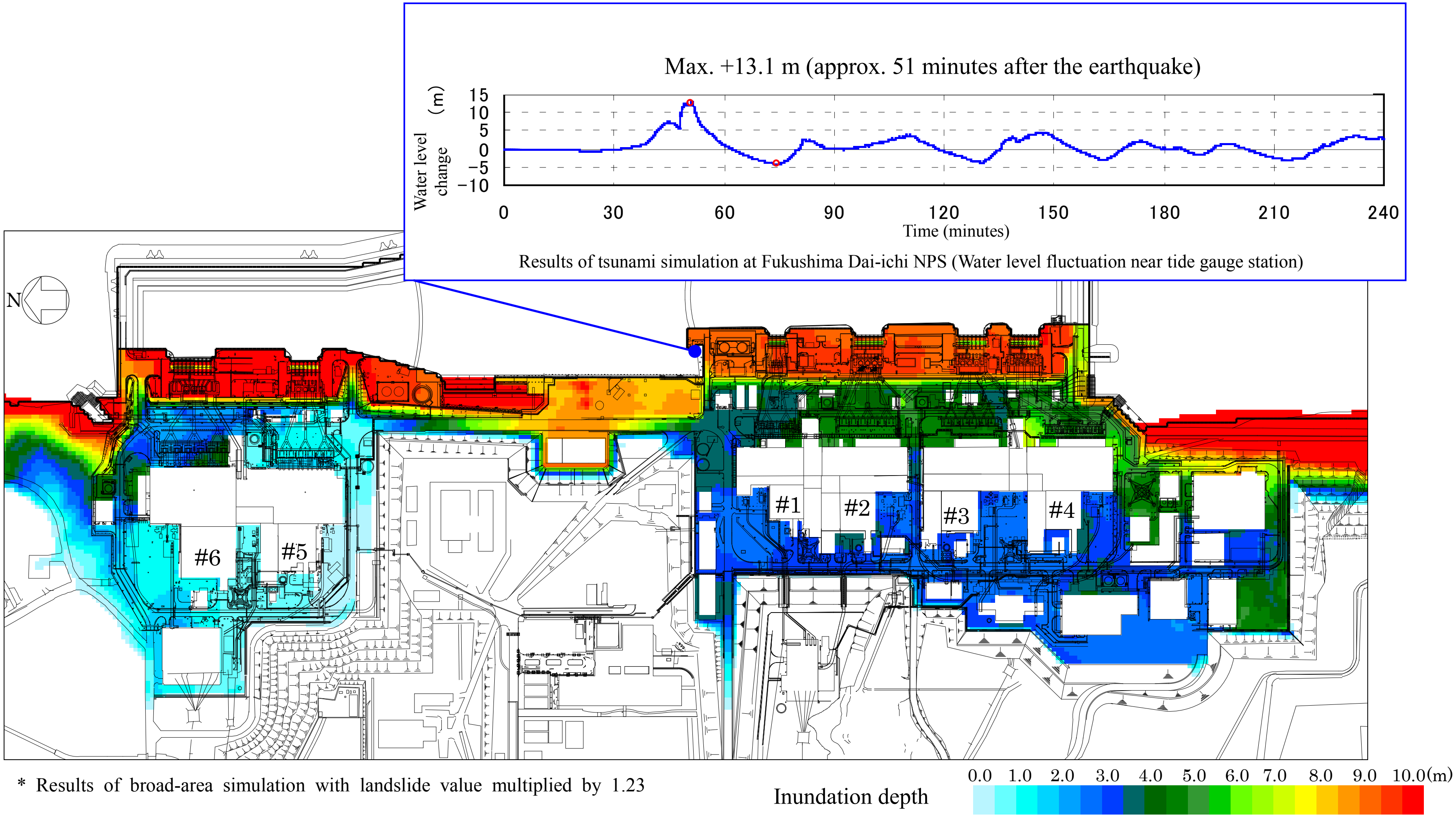


Figure II-2-23 Investigation Result of Tsunami at Fukushima Dai-ichi NPS (Inundation height, inundation depths and inundated area)



* Results of broad-area simulation with landslide value multiplied by 1.23

Figure II-2-24 Result of Tsunami Simulation at Fukushima Dai-ichi NPS (Inundation depth and inundated area)

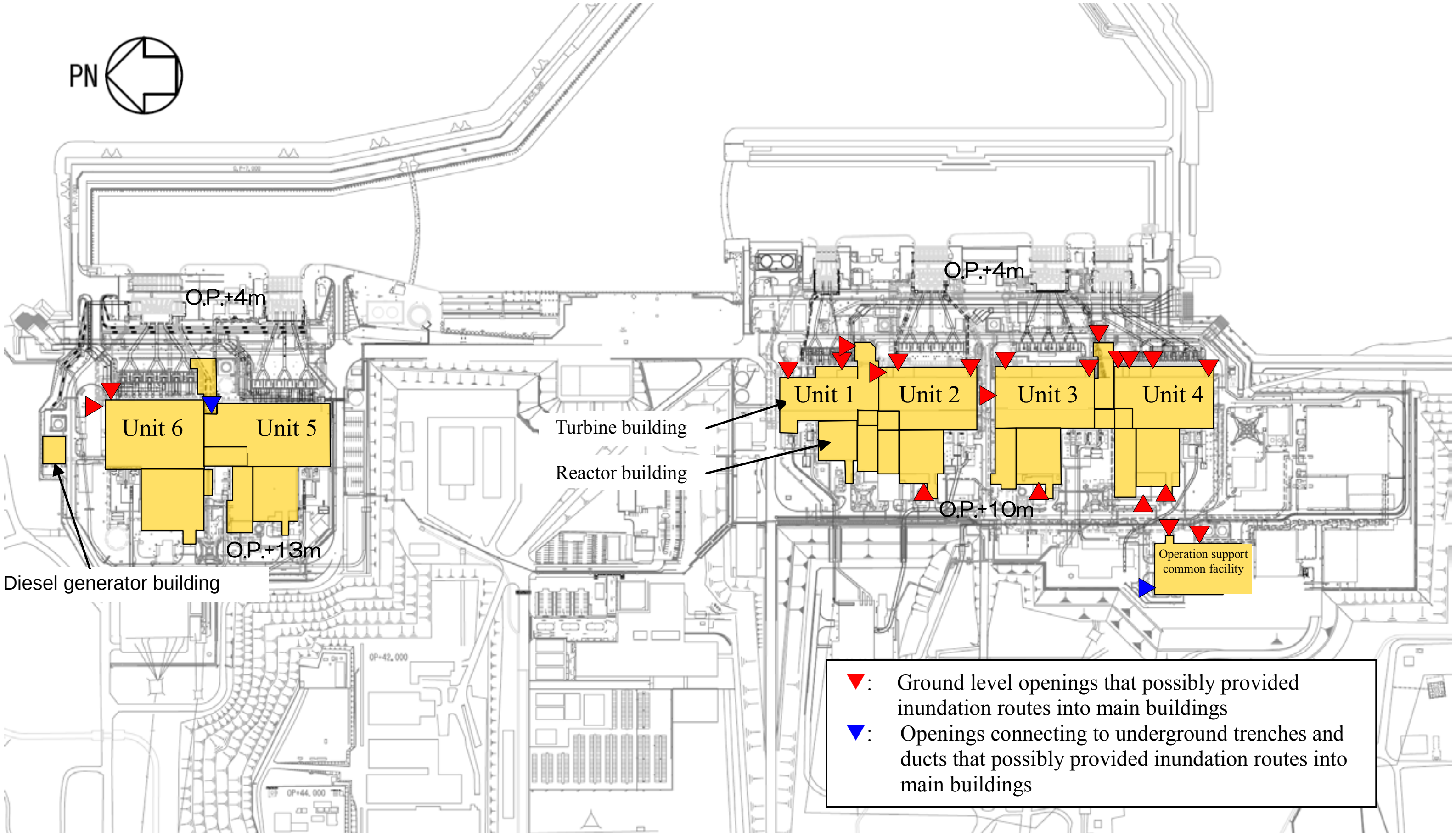


Figure II-2-25 Locations of Openings that Possibly Provided Inundation Routes into Main Buildings at Fukushima Dai-ichi NPS

3) Responses at the time of accident

In the June Report, based on the records of each kind of plant parameter and the analysis results of reactor core, development of events of the accident as well as the emergency measures were reported.

Subsequently, from the information and the accident report released and submitted to Ministry of Economy, Trade and Industry by TEPCO as well as from the investigation conducted by the Nuclear and Industrial Safety Agency, the responses at the time of the accident in the Fukushima Dai-ichi NPS (especially of Units 1 to 3 which led to the accident) have come to light.

In this report, it is introduced about the responses to the whole power stations and each Unit, and is overviewed the efforts on restoration of power supply and instrumentation and hydrogen measures, as well.

a. The NPS in overall terms

○ Systems

Because the occurrence of earthquake was in a weekday afternoon, emergency operation staff (about 400 staff) for emergency response, was being secured for Fukushima Dai-ichi NPS. Not only playing their designated role, the mobilized staff had to carry out various responses, to the situation of series of disasters at multiple Units as this time.

Especially, in the accident this time, all AC power supplies were lost and parameter of reactor could not be checked so that restoration of power supply and instrumentation was considered as urgently need. Since most of workers of cooperative companies had sheltered from the NPSs due to major tsunami alert being announced immediately after the earthquake, most restoration work was forced to be carried out only by staff of TEPCO under very difficult surroundings.

○ Communication delivering

Due to the loss of all AC power supplies, the status of communication tools in the power stations was extremely limited. PHS, normally used for communication among the staff in the NPSs, became dysfunctional, and communication tools between the main control room of each plant and the emergency response headquarters of the power stations where the plant manager, etc. gathered were limited to hotline and landline.

In addition, in the emergency response headquarters of the NPS, the Safety

Parameter Display System (SPDS) had been deployed but due to the loss of power supply, instrumentation device monitoring parameter etc. did not function, thus transmission to SPDS was impossible. Accordingly, SPDS was usable with emergency power supply, however, as there was no displayed data, eventually it was unusable. Because of this, it became difficult for the emergency response headquarters of the NPS to figure out the status of plants and to plan measures on the basis of it.

○ Working environments

Due to the deteriorate working surroundings such as inundation by tsunami, aftershocks occurring intermittently, darkness due to electric outage, and high-level radioactivity and strewn rubbles after the explosion, restoration work was restricted.

Indeed, other than the aftershock of seismic intensity above 5 observed five times on March 11 in Fukushima Prefecture, a major tsunami alert was announced at 14:49 on the 11th and continued until it was shifted to a tsunami alert at 20:20 on the following day on the 12th.

○ Guidelines of response in the NPSs

In the NPSs, immediately after the occurrence of earthquake, the reactor was scrammed and achieved subcritical, and to “stop” the reactor was successful. Although the external power supply was lost by the earthquake, since emergency DG was operating normally and power supply was secured, cooling operation in accordance with designated process was being conducted.

Tsunami struck in such a moment, all AC power supplies were lost and, except a part of cooling system using steam (IC), a reactor core isolation system (RCIC), and a high pressure core injection system (HPCI), emergency cooling function was lost. Therefore, water injection by fire protection systems (fire protection pump of diesel-generated or fire extinguishing vehicle is used so that power supply is not needed) was conducted as is stipulated as an accident management (AM) measure. In conjunction with this, efforts were made on restoring power supply by utilizing power supply vehicles to operate equipment, such as the Standby Liquid Control Systems (SLC) and the Control Rod Drive (CRD), which are capable of injecting water with high pressure to the reactor.

b. Unit 1

After the Tohoku District-Off the Pacific Ocean Earthquake, the Unit 1 did a reactor scram due to the high seismic acceleration. Thereafter, automatic shutdown of the reactor was achieved by the control rod insertion, but due to the impact of the subsequent tsunami, all AC power was lost. After this point, the cooling operation was continued by the IC and emergency measures, such as arrangements for power supply trucks, progressed towards recovering the power supply. Nevertheless, the work was heavy going.

After the accident, in order to secure the water injection function, along with the depressurization of reactor, fire engines injected water into the reactor. In the meantime, operations in the primary containment vessels (PCV), such as venting, were executed concurrently but there was an explosion around 15:36 on March 12 at the reactor building of Unit 1 caused by what is believed to be hydrogen gas.

As indicated in the following, in addition to the explanations in the Summary section of the report submitted to the IAEA in June, the response at the time of the accident which has since become clear is described below.

○ Summary of the June IAEA Report

Unit 1 was operating at its regular rated power output before the earthquake. After the occurrence of the earthquake at 14:46 on March 11, a reactor scram occurred due to the high seismic acceleration, and at 14:47, the control rods were all inserted into the reactor making the situation sub-critical, such that Unit 1 automatically shut down, as normal. Furthermore, due to the earthquake, damage was incurred on the circuit breakers for receiving power on the NPS's side for Lines 1 and 2 of the Okuma Line. As a result, external power supply was lost. Consequently, both the emergency DGs were automatically started up.

The main steam isolation valve (MSIV) closed, causing an increase in pressure in the reactor pressure vessel (RPV); and at 14:52 on March 11, the IC automatically started up. Thereafter, in accordance with the operating manual for the IC, to ensure that the RPV temperature does not fall at a rate greater than 55 degrees/h, the IC was manually shut down at 15:03 on March 11. In addition, during the period from 15:10 to 15:30 on March 11, only A train of the IC was manually operated three times, and reactor pressure fluctuated up and down.

At 15:37 on March 11, Unit 1 seawater pumps for cooling and the water of the power distribution panel were submerged due to the tsunami, as a result, the operations of both the emergency DGs were stopped. Also, the distribution board of the generating line for emergency use was submerged, resulting in the situation of all AC power being lost. Similarly, since Unit 2 had also the loss of all AC power, power supply from Unit 2 could not be diverted to Unit 1.

Lastly, the information about the parameters for the loss of all the D/C power function could not be confirmed. In addition, since the function for the pump of the component cooling water system was also lost due to the tsunami, the function of the component cooling system was naturally also lost. As a result, the shut-down cooling system (SHC) could not be used and the decay heat could not be moved to the ocean, the place finally allows the heat to escape (hereinafter, referred to as “heat sink”).

TEPCO performed the operation of opening the valve for the IC A system after the tsunami hit, and this operation was continued to maintain the function of the IC. However, according to the results of the investigation on the valve circuits TEPCO conducted in April, it is not definite to what angle the valve was opened, and so, at this stage, it cannot be determined to what degree the IC fulfilled its function.

TEPCO confirmed there is a possibility that the pressure of the PCV at 00:49 on March 12 exceeded its maximum operating pressure, and the Minister of Economy, Trade, and Industry issued an order at 6:50 on March 12 to suppress the PCV pressure of Units 1 and 2 pursuant to the provisions of Article 64(3) of the Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (hereinafter the “Reactor Regulation Act”). In order to lower the pressure of the PCV, TEPCO performed the operations of the PCV vents. However, because the environment inside the reactor buildings already had a high radioactivity, the work was hard going. In the end, the pressure of the PCT was lowered as of 14:30 on March 12, and so, TEPCO decided that the operation of the PCV vents was successful.

At 05:46 on March 12, TEPCO commenced alternative water injection (with fresh water) using fire engine pumps. Accordingly, assuming that the interruption of cooling by the IC and the total loss of AC power at 15:37 on March 11 happened simultaneously, the cooling by water injection was interrupted for a total of 14 hours and 9 minutes.

○ Operation of IC

There was a possibility that the function of the IC in Unit 1 was lost by the impact of the tsunami which had hit at around 15:30 on March 11. The NISA also learned from officials of TEPCO during its survey that the IC was stopped at the time when the tsunami hit.

A little after 18:00 on March 11, possibly because DC power supply was recovered, the display lamps of return line and feeder line isolation valves of System A were lighted again to show the valves were closed. Because of this, valve-opening operation was performed at 18:18 on March 11; it was confirmed by station employees that vapor was generated from the exhaust port. However, closing operation of return line isolation valves of System A was performed at 18:25 on March 11 because it became impossible to confirm the vapor immediately after that.

After that, opening operation of return line isolation valves of System A was performed at 21:30 on March 11 to maintain the open state after steam generation was confirmed.

Regarding the operating status of the IC, it seems that the NPS Emergency Response Headquarters could not recognize it enough. It was recognized at the NPS Emergency Response Headquarters that the operation of the IC was continuing by the information that vapor from the exhaust port was confirmed and that a water gauge display was above the top of available fuel (“TAF”) at the time when the water level at the reactor became able to be confirmed.

However, TEPCO has stated that it is not possible at this time to judge to what extent the IC was functioning because the switching condition of the isolation valve existing in the PCV is unclear, based on the results of the survey on the valve circuits performed in April.

Further survey is necessary to reveal the reality.

○ Alternative Water Injection

Since all AC power was lost and emergency cooling system became unavailable due to tsunami, TEPCO worked for cooling the reactor with alternative water injection. The staff were forced to work under the severe environment where the major tsunami warning continued, evacuation and work were interrupted, there were no tools for lightening and communicating, and the debris and dirt were stranded by tsunami. The response status is described as follows in a chronological order.

17:12, March 11, TEPCO started to take into consideration using alternative water injection measure set as AM actions (fire protection system, FP) , make-up water condensate system（MUWC）and fire engines using fire cistern set up as a lesson from the Chuetsu-oki Earthquake.

In the main control room, in order to confirm the alternative water injection measures, the AM operational procedure was submitted to the shift supervisor, alternative water injection lines to reactors were confirmed, the preparation for activating diesel-driven fire pump have been started.

Regarding water injection to reactors, in order to develop alternative water injection line via the core spray system（CS）from FP line, staff entered the reactor buildings in the dark, manually opened valves of CS, etc, then after the depressurization of reactor pressure (less than 0.69MPa gage), made the condition available for water injection.

At 17:30, March 11, the diesel-driven fire pump was confirmed to be in a workable condition. Since the indicated value of the supervisory instrumentation in the main control room was invisible, the staff entered into the reactor building and confirmed that the pressure gauge indicated 6.9MPa gage (20:07, March 11). After that, the water-level gauge was restored at 21:19 on the same day, confirming the indication of TAF+200mm.

At 01:48, March 12, staff confirmed that the diesel-driven fire pump which had been in operation for injecting water to the reactor stopped at some point, thus they carried and supplemented light oil manually, carried batteries kept in cooperative firms on the site for replacement, etc, but could not restart the operation.

In order to start injecting water as soon as possible, preparation for injection of water via fine engines was implemented along with restoration of diesel-driven fire pump. One of three fire engines deployed in the NPS was used. Second one was broken down due to tsunami, and the third one was not usable as it could not be transferred from the side of Units 5 and 6.There were also many obstacles in deployment of the usable one. The road in front of the former main office building was not trafficable as it was blocked with a tank drifted by tsunami. As the gate of the security office could not be opened with any electricity, after thorough search for trafficable routes, they made the fire engine pass through by breaking a key of the locked gate located between Units 2 and 3.

The fire hydrant which should have been used for the water source was not usable as water spewed out from it, thus search for other water sources was implemented. As a result of it, fire cistern was confirmed to be usable.

At 02:45, March 12, it was found that the reactor pressure was 0.8MPa gage, meaning depressurization proceeded to the level enabling the injection of water via fire engine. At 05:45, March 12, injection of fresh water via fine engine from FP line was started.

As for the initial injection of water, the discharge pressure was considered to be insufficient from the position of the fire cistern, thus the series of work such as transferring water from the fire cistern to the tank of fire engine, the relocation of fire engine closer to the rector building, and injection of water from the water discharge canal of FP to the reactor, was repeatedly implemented.

The relocation of the fire engine, however, took long time as it needed to cautiously pass under the crumbling building. Therefore, as a result of try-and-error, with the development of continuous water injection line using the hoses attached to fire engine, continuous injection of water started.

With the arrival of a fire engine which was additionally arranged, transfer of fresh water from the fire cistern of Unit 3 to thatof Unit 1 was repeatedly implemented. Since the fire cistern could accommodate only one hose, in case of fresh water feed, the hose for injecting water to the rector needed to be taken out, accordingly the water injection work were forced to be suspended each and every time. At 14:53, March 12, 80,000ℓ (accumulated total) of fresh water injection was completed.

While fresh water injection was continued, since securing fresh water in the fire cistern had limitation, preparation for seawater injection was implemented.

At 14:54, March 12, the plant manager instructed to prepare for injecting seawater to the reactor. Since the fresh water in the fire cistern was depleted, quick transfer of fresh water from other fire cisterns as well as preparation for switching to seawater injection were implemented. For the injection of seawater, judging from the road condition on the site and the distance to Unit 1, backwash valve pit, which accumulated seawater due to tsunami, was set as water source rather than taking water directly from the sea, and in order to ensure lifting height, water injection line with three fire engines arranged in tandem was completed.

As for SLC, another alternative water injection measure, since the early dawn on March 12, work including laying of temporary cables to transfer power from power supply vehicle via power distribution panel of Unit 2 etc, was implemented, and around 15:30, March 12, cable connections inside the building to the primary side of power center (P/C) and connection with a high-pressure power supply vehicle were completed, then power was transmitted to just beside the SLC pump.

In the meantime, at 15:36, March 12, an explosion occurred in the reactor building of Unit 1.Evacuation from the site, aid and transfer of the injured due to the explosion were executed. The number of the injured of TEPCO was three, and that of the cooperative firms was two. Following this, in order to ensure safety, on-site inspection to study the effect of the explosion (condition of fire engines, damage situation of the building, situation of smoking) was implemented. Windows of fire engines were broken, but the function was not damaged. Cable laid for operating SLC was damaged due to splattered debris, the high pressure power supply vehicle was automatically suspended. In addition, hoses which had been prepared for seawater injection were also damaged.

Until the evacuation from the site and safety check of the staff were executed and the situation of the site was confirmed, nothing could be done for restoration for some time.

Since highly radioactive debris were scattered around Unit 1, under the supervision of radiation control staff, work such as removing the scattered debris (steel panel of the reactor building of Unit 1, etc) and collecting hoses from yard fire hydrants for rebuilding, was implemented.

Finally, at 19:04, May 12, injection of seawater into the reactor using FP lines and fire engines was started.

○ PCV venting

TEPCO started to review PCV venting from the beginning of the accident, because the means to transfer heat to the ultimate heat sink was lost due to the total loss of the AC power supply and the function failure of the seawater system pump by tsunami, and because it was expected that the pressure in the PCV would increase.

In the Main Control Room, the procedure of AM operations manual was confirmed; a necessary valve for venting and its position were confirmed using a valve checklist; a review of the vent operation procedure without power supply was started.

Also, while aftershocks were continuing, station employees went to the main office building to which admission was prohibited due to the earthquake to fetch the drawing showing the model and structure of the valve as well as they inquired collaborative firms in order to confirm if it was possible to manually open suppression chamber (S/C) vent valve (air operation valve (AO valve). As a result of confirming the drawing, it was confirmed that there was a handle at the small valve of the S/C vent valve (AO valve) and that was conveyed to the Main Control Room.

Late at night on March 11 an increase of dose was confirmed in the site; moreover, an increase of drywell (D/W) pressure was also confirmed.

At 21:51 on March 11, admission to the reactor building was prohibited because dose in the building increased.

At around 22:00 it was reported to the NPS Emergency Response Headquarters that alarm pocket dosimeter (APD) had indicated 0.8 mSv on the scene in the reactor building in a very short time. At 23:00 on March 11, radiation dose increased in the turbine building by the impact of the increased dose in the reactor building (1.2 mSv/h in front of the north double door of the turbine building 1st floor, 0.5 mSv/h in front of the south double door of the turbine building 1st floor).

At around 23:50 on March 11, in the Main Control Room the restoration squad of the NPS Emergency Response Headquarters connected a small generator placed for temporary restoration of illumination of the Room to a D/W pressure gauge to confirm the indicated value to be 600 kPa abs.

Therefore, in the Main Control Room materials such as piping and instrumentation diagram, an AM procedure book and drawings of valves, and an acryl board were brought to start to confirm concrete venting procedures such as an operation method and procedure of valves.

At 02:24 on March 12, the evaluation results on the work time with respect to the site operation of venting were reported to the NPS Emergency Response Headquarters indicating that there was only 17 minutes of work time (20 minutes for self-air-set. Iodine preparation needs to be taken.) not to exceed the dose limit (100 mSv/h) in emergency response if in the atmosphere of 300 mSv/h.

At 02:30 on March 12, it was confirmed that the D/W pressure had reached 840 kPa abs (maximum working pressure: 427 kPa gage#).
528.3 kPa abs (=427kPa gage + 101.3 kPa）

At around 03:45 on March 12, exposure dose assessment in the vicinity at the time of venting was performed at the Response Headquarters of the TEPCO main office, which was shared with the NPS. Also, although the double door was opened at the NPS to measure dose in the reactor building, the dose measurement could not be performed because the door was shortly closed at the sight of white “haze something like steam”.

In the Main Control Room, with the goal of vent operation, confirmation was repeated about an order of valve operation, valve arrangement in the torus chamber, and how high the valve was positioned, etc. Also, fire-resistant clothes, self-air-sets, APDs, survey meters and flashlights were collected as many as possible as necessary equipment for work.

At around 04:30 on March 12, the direction of prohibition of operation on the spot was given to the Main Control Room by the NPS Emergency Response Headquarters for the fear of tsunami by aftershocks.

At around 04:45 on March 12, APDs set at 100 mSv and full face masks were delivered to the Main Control Room by the NPS Emergency Response Headquarters. At around 04:50 on March 12, contamination was found about the workers who returned to the quake isolation building, so that it was stipulated that one should wear “a full face mask + charcoal filter + clothes B, clothes C or a coverall”(Attachment II-1) from the entrance of the quake isolation building when one goes to the spot. Then at around 05:00 on March 12, the direction was given to request that the similar equipment “a full face mask + charcoal filter + clothes B” should be worn also in the Main Control Room.

In the Main Control Room, because dose was increasing, the shift supervisor made the people on duty move to the side of Unit 2 of which dose was lower.

At 06:33 on March 12, it was confirmed that the move from Okuma Town to the direction of Miyakoji was under review as a situation of the local evacuation.

At 08:03 on March 12, the direction was given by the head of the NPS that the vent operation for Unit 1 should be aimed at 09:00 on March 12.

In the Main Control Room it was decided that a system of three squads, each of which included two people (composed of a shift supervisor and deputy supervisor levels), considering that the site was such complete darkness that it would be difficult for one person alone to work, high dose was expected, and there might be a possibility of returning due to aftershocks.

In confirming the evacuation situation of the residents, the information was reported to the NPS Emergency Response Headquarters from the TEPCO employee dispatched to the town hall of Okuma Town that the evacuation of part of Okuma Town was not complete as of 08:27 on March 12.

At 08:37 on March 12, it was reported to Fukushima Prefecture that preparation had been underway aiming to start venting at 09:00 on March 12. It was coordinated that venting would be performed after the evacuation was complete.

At 09:03 on March 12, the completion of evacuation of Okuma Town (Okuma district) was confirmed. It was conveyed to Fukushima Prefecture that venting would be performed after it was announced at 09:05.

At 09:04 on March 12, two people on duty started for the site to perform a PCV vent operation. They were equipped with fire-resistant clothes, self-air-sets and APDs. Because power supply was lost, the sites of the reactor building and the turbine building were completely dark, they started with flashlights. There was no communication means and it was impossible to communicate from the site, so it was decided that one squad after another would go to the site, and next squad would start after the prior squad returned to the Main Control Room.

The first squad started for the site from the Main Control Room for the opening operation of PCV vent valve (motor operative valve (MO valve). At around 09:15 on March 12, it made the valve 25 % open as stipulated in the procedure to return to the Main Control Room. The exposure dose was about 25mSv.

Subsequently, the second squad left the Main Control Room for the torus chamber at 09:24 on March 12 for the operation of the small valve of the S/C vent valve (AO valve). However, dose increased on the way and there was a possibility of exceeding the dose limit of 100 mSv, so it returned at around 09:30 on March 12.

The work by the third squad was given up due to the high dose and it was conveyed to the NPS Emergency Response Headquarters.

Upon the failure of the opening operation of the small valve of S/C vent valve (AO valve) on the site, the NPS Emergency Response Headquarters started to review the connected part of the temporary compressor to open the large valve of the S/C vent valve (AO valve) (until around 11:00 on March 12). Also, the direction was given to perform the opening operation of the small valve of the S/C vent valve (AO valve) in the Main Control Room, expecting residual air pressure in the S/C vent valve (AO valve).

Following the direction, the opening operation was performed three times at 10:17, 10:23 and 10:24 on March 12; but, it was unclear if the valve was actually open.

At 10:40 on March 12 increased doses were confirmed at the main gate and a monitoring post (MP), so the NPS Emergency Response Headquarters judged that there was a high possibility that radioactive materials had been released by venting; however, it was confirmed that venting may not have been effective enough because of the decreased dose.

While searching for a temporary compressor to open the large valve of the S/C vent valve (AO valve), the information was received that there were some in a cooperative firm and it was decided that NPS employees would go to the cooperative firm to find one. Because it is impossible to connect a temporary compressor without an adaptor, the connection parts were reviewed using a piping and instrumentation diagram to decide the part to be attached. A squad took pictures of the parts on the spot and returned to the NPS Emergency Response Headquarters.

At around 12:30 on March 12, NPS employees went out to search for an adaptor while a temporary compressor was found in the cooperative firm; they traveled in a Unic Vehicle. Due to high dose of the reactor building, it was installed outside of the large cargo dock of the reactor building. And at around 14:00 March 12, the temporary compressor was started.

At 14:30 March 12, the decreased D/W pressure was confirmed, so TEPCO judged it to be the “release of radioactive materials” by venting. The D/W pressure, which was about 0.75 MPa abs at around 12:00 on March 12, decreased to 0.58 MPa abs at 14:50 on March 12.

c. Unit 2

At Unit 2, after the Great East Japan Earthquake, the nuclear reactor scrammed due to large earthquake acceleration and was automatically shut down by the insertion of control rods. However, all AC power supply was lost due to the impact of the tsunami. After that, emergency measures of arranging power source vehicle to recover power supply were taken while continuing water injection by RCIC, but the operation faced difficulty.

After the accident occurred, in order to secure the function of injecting water into the reactor, along with the depressurization of reactor, fire engines injected water into the reactor. During this time, various measures, including the PCV vent operation, were being taken along with water injection, however a big impulsive sound was observed.

The following explains the outline of the content of the June report to IAEA as well as provides new information on how events were dealt with at the time of the accident revealed after the June report.

○ Outline of the June report to IAEA

Steady operation of rated thermal power was being carried out prior to the earthquake at Unit 2. Following the earthquake, the nuclear reactor scrammed due to the large earthquake acceleration, and automatically shut down as all control rods were inserted to bring the reactor into sub-critical at 14:47, March 11. As a result of the earthquake, the external power supply was lost due to the damage incurred to the receiving circuit breakers of the station at the Okuma No.1 and No.2 power transmission lines. This resulted in automatic activation of two emergency DGs.

Since the closure of the MSIV led to a rise in RPV pressure, and in accordance with the Procedures, the RCIC was activated manually at 14:50, March 11. Then the reactor repeated automatic RCIC shut down due to high reactor water level and manual activation. From 22:00 of March 11 to around 12:00 of March 14, the reactor water level reading (fuel range) remained stable at a level (more than +3000 mm) sufficiently above the TAF.

The reactor pressure was controlled by closing and opening of the main steam safety relief valve (SRV). Moreover, as operation of the SRV and RCIC led to a rise in the S/C temperature, the Residual Heat Removal (RHR) pumps were activated in succession from 15:00 to 15:07, March 11 to cool the S/C water. S/C then showed a tendency to raise temperature from past 15:30 but the RHR pumps successively shut down from around 15:36, March 11. This function failure is considered to have been caused by the tsunami. At the same time, as a result of the impact of the tsunami, two emergency DGs stopped operating and all AC power supply was lost due to flooding and submersion of the cooling seawater pump, the power distribution panel, and the emergency bus bar.

Furthermore, information on parameters could not be verified due to the loss of direct electrical current function. In addition, loss of the Residual Heat Removal Seawater System (RHRS) pump function led to the loss in RHR function, and thus the decay heat unable to be transferred to the sea, the ultimate heat sink.

At 22:00, March 11, observation of the reactor water level was enabled and since the water level was observed to be stable, it can be presumed that the water injection by RCIC was successful. However, the reactor pressure was slightly lower at 6MPa gage than the rated pressure.

From 04:20 to 05:00, March 12, as water level of the Condensate Storage Tank (CST) decreased and also in order to control rising of the S/C water level, the water source for the RCIC was switched from the CST to the S/C for the RCIC to continue injecting water. The reactor water level remained stable at the level sufficiently above the TAF until 11:30, March 14. From that point to 13:25, March 14, the reactor water level began to drop, at which point the RCIC was judged to have shut down. The water level dropped to 0mm (TAF) at 16:20, the same day.

SRV opening and alternative water injection operations commenced at 16:34, March 14, and the seawater injection into the reactor using fire engines was started at 19:54, the same day.

With regard to PCV vent operations to reduce pressure in the PCV, at 06:50, March 12, TEPCO was ordered by the Minister of Economy, Trade and Industry in accordance with Article 64, Paragraph 3 of the Reactor Regulation Act to contain the PCV pressure. Based on this order, TEPCO began PCV vent operations, at around 11:00, March 13 and also at around 0:00, March 15, but a decrease in D/W pressure could not be verified.

○Alternative Water Injection

Since the loss of all AC power at 15:30, March 11, operating status of RCIC was unknown until the early morning on March 12, when the operation was confirmed, thus TEPCO advanced the operation to cool the reactor via alternative water injection. At 17:12, March11, discussion about the adoption of alternative water injection measure set as AM measures (FP, MUWC）, and fire engines using fire cistern set as a lesson from Chuetsu-oki Earthquake was started.

In the main control room, in accordance with AM operational procedure, alternative water injection measure was confirmed and alternative water injection line to the reactor was also confirmed. In the light of radiation dose of Unit 1, before the radiation dose increased, in order to develop alternative water injection line via RHR for injecting water to the reactor, workers opened manually in the dark the valves which were necessary to develop the alternative water injection line, and made the condition available for injecting water after the depressurization of the reactor was achieved (less than 0.69MPa gage).

At 21:50, March 11, due to the restoration of instrument power, the reactor water-level gauge was recovered indicating TAF+3400mm, thus it was confirmed that TAF was covered.

Also, at 02:55, March 12, it was confirmed that RCIC was functioning. Therefore, in preparation for alternative water injection, the monitoring of the reactor condition continued.

As for the seawater injection, the preparatory work in case of RCIC suspension proceeded, and in order to promptly switch to sea water injection after the end of fresh water injection, line development, which sets the backwash valve pit of Unit 3 as water source, was progressed, and hose lying with the deployment of fire engines was implemented.

At 11:01, March 14, however, the explosion in the reactor building of Unit 3 occurred, and an on-site inspection at the beginning of the afternoon revealed that the water injection line which had been ready was unusable due to the damage of fire engines and hoses. As the debris splattered there, injecting water from the backwash valve pit of Unit 3 was judged to be difficult, implementation of direct seawater injection from the landing place was decided, then hose laying proceeded with the deployment of usable fire engines amid high radiation dose due to the scattered debris.

At 13:18, March 14, the reactor water level became on the declining trend, and then at 13:25, March 14, RCIC was judged to be in function failure. Reaching TAF was expected around 16:30, March 14, thus the preparatory work for seawater injection was continued, then 14:43, March 14, the work for connecting fire engines to FP was completed. After that, due to the occurrences of aftershock centered in off the coast of Fukushima prefecture from past 15:00 to past 16:00, March 14, suspension of work as well as evacuation of staff were forced, however, around 16:30, March 14, with fire engines which became workable, the arrangement for starting water injection upon the reactor depressurization was completed.

For injecting water from fine engines, parallel lines were formed at Units 2 and 3. Unit2 needed reactor depressurization via opening of SRV, however due to high temperature and pressure of S/C (As of 12:30, March14、S/C temperature 149.3℃,S/C pressure 486kPa abs), even SRV was opened, vapor condensation as well as the depressurization of AC could be difficult. In the light of this, it was decided that after arrangement of PCV vent, SRV would be opened to depressurize the reactor, and then seawater would be injected.

Around 16:00, March 14, however, it was estimated that it would take time to open the vent valve, thus it was changed to prioritize the reactor depressurization via SRV. Also, the power station manager instructed to prepare for PRV vent along with SRV.

In light of no power supply, batteries were requisite to open SRV, thus the efforts such as collecting batteries from vehicles, carrying them to the main control room, and attempting to operate several SRVs were continued. Then around 18:00 March14, depressurization of reactor was started. However, since its condensation was difficult due to high temperature and pressure of SC, it took time to depressurize it (reactor pressure 6.998MPa gage (16:34, March 14) → 6.075MPa gage (18:03, March 14) → 0.63MPa gage (19:03, March14)).

Regarding the fire engines, their operational status was being monitored on rotation due to high radiation dose on site, and at 19:20, March 14, it was confirmed that workable fire engine which had been ready for injecting seawater was suspended due to the shortage of fuel. After refueling it, injection of seawater to the reactor from FP line via fire engines (at 19:54 and 19:57, March 14, each fire engine was started) was started.

○ PCV venting

TEPCO started a review on PCV venting from the beginning of the accident because an increase of PCV pressure was expected to rise due to the loss of the means to transfer heat to the ultimate heat sink resulting from the total loss of AC power supply and the function failure of sea water system pump by tsunami.

As a result of restoration work of power supply for instruments, at 21:50 on March 11 the reactor water level proved to be TAF + 3400 mm, and at 23:25 on March 11 D/W pressure proved to be 0.141 MPa abs. Moreover, at 2:55 on March 12 the operation of the RCIC could be confirmed. Considering such situation, it was decided that the venting operation of Unit 1 would be prioritized and it was also decided to proceed with the response for performing venting of Unit 1 and continue to monitor parameters of Unit 2.

The preparation for the vent line composition along with Unit 3 was started because venting will be needed in time although water was continuously poured into the reactor by the RCIC and the D/W pressure was stable between about 200 to and 300 kPa abs. Because dose on the spot was low, it was decided that the valves necessary for venting would be left open except for the rupture disk.

When the preparation was proceeded with for venting Unit 1, a review for Unit 2 was also performed if the valve necessary for venting was able to be manually opened using a drawing , and if it was able to forcibly stay open using a jig. Based on this review as well as piping and instrumentation diagrams, AM procedure books and the venting operation procedures for Unit 1, the necessary operation method of venting a valve was confirmed (PCV vent valve (MO valve) is manually operable to be opened; S/C vent valve (AO valve) is not manually operable to be opened), and the venting procedures were prepared. Also, the position of the vent valve on the site was confirmed using a valve check sheet.

Workers on duty started for the reactor building wearing necessary equipment such as self-air-set and carrying a flashlight for manual operation to open the PCV vent valve (MO valve).

At 8:10 on March 13, the PCV vent valve (MO valve) was made open 25% of the stipulated procedure. At 11:00 on March 13, the solenoid valve of the large S/C vent valve (AO valve) was energized by a small generator for temporary illumination of the Main Control Room to perform the opening operation. The vent line composition was complete except for the rupture disk. However, D/W pressure was lower than the rupture disk working pressure (427 kPa gage), the state of failure in venting was retained, and the monitoring of the D/W pressure was continued.

However, at 11:01 on March 14, explosion occurred in the Unit 3 reactor building, the circuit to energize the solenoid valve of the large S/C vent valve (AO valve) was off to be closed, so the vent line composition work was needed again. After the explosion, the workers except for the duty people of the Main Control Room evacuated in the quake isolation building after interrupting all the work. It was impossible to resume the restoration work because of confirming the safety of workers and the situation on the spot.

During this time, the D/W pressure was about 450 kPa abs to be kept stable under the pressure for venting.

After the evacuation direction subsequent to the explosion was lifted, at around 16:00 on March 14, the opening operation of the large S/C vent valve (AO valve) was tried; but, at around 16:20 on March 14, the opening operation was not successful because of insufficient air from an air compressor. Because no reduction in the D/W pressure was shown, at around 18:35 on March14, the vent line restoration work was continued for not only the large S/C vent valve (AO valve) but also the small S/C vent valve (AO valve). At around 21:00 on March 14, the small S/C vent valve

(AO valve) was opened slightly; it was considered that the vent line composition was complete except for the rupture disk.

The D/W pressure was lower than the rupture disk working pressure (427 kPa gage) and the state of failure of venting continued for a while; but, at around 22:50 on March 14, the D/W pressure rose to exceed the maximum working pressure 427 kPa gage, so it was judged that the situation should fall under Article 15 of the Act on Special Measures Concerning Nuclear Emergency Preparedness (hereinafter referred to as the “Nuclear Emergency Act”) “unusual rise of the pressure in the PCV.”

While the D/W pressure had a tendency to rise, the S/C pressure was stable between about 300 and 400 kPa abs, so that a situation occurred in which the pressure in the D/W and that in the S/C were not homogenized. Because the pressure on the S/C side was lower than the rupture disk working pressure while the pressure on the D/W side was rising, it was decided that venting would be performed by opening the small D/W vent valve (AO valve). At 0:02 on March 15, the operation was performed to open the small D/W vent valve (AO valve) to once complete the vent line composition except for the rupture disk; it was confirmed that the small valve was closed several minutes later, ant the D/W pressure thereafter did not decline under about 750 kPa abs to be maintained stable at a high level.

In such a situation, at around 6:00 to 6:10 on March 15, a large impulsive sound occurred. During the same time period, the pressure within the S/C indicated 0 MPa abs.

After that, about 650 people temporarily evacuated in the Fukushima Dai-ni NPS except for about 70 people necessary for monitoring the plant and emergency restoration work. During the time also, parameters of the D/W pressure, etc. were retrieved by the workers on duty by going to fetch data to the Main Control Room every few hours.

At around 11:25 on March 15, the decline of the D/W pressure was confirmed. (730 kPa abs (7:20 on March15) → 155 kPa abs (11:25 on March15)). The cause for the decline of the D/W pressure is not clear.

d. Unit 3

At Unit 3, after the Great East Japan Earthquake, the nuclear reactor scrammed due to large earthquake acceleration and the reactor was automatically shut down by insertions of control rods. However, all AC power supply was lost due to the impact of the tsunami. After that, emergency measures by arranging power source vehicle towards recovery of power supply were taken while continuing water injection by RCIC and HPCI, but the operation faced difficulty.

After the accident occurred, in order to secure the function of injecting water into the reactor, along with the depressurization of reactor, fire engines injected water into the reactor.. During this time, various measures, including the PCV vent operation, were being taken along with water injection, but the reactor building of Unit 3 was damaged from what seemed to be a hydrogen explosion at around 11:01 on March 14.

The following explains the outline of the June report to IAEA as well as provides new information on the responses to the accident, which was revealed after the June report.

○ Outline of the June report to IAEA

Steady operation of the rated thermal power was being carried out prior to the earthquake at Unit 3. After the earthquake, the reactor scrammed at 14:47 on March 11 due to the large acceleration of the earthquakes, and automatically shut down as all control rods were inserted to bring the reactor into sub-critical. In addition to Okuma Line 3, to which no power was supplied due to repair work started before the earthquake, the breaker at Shin-Fukushima Substation tripped and the breaker for receiving electricity at the switchyard in the power station was damaged, disrupting the power supply from Okuma Line 4 and leading to loss of off-site power. As a result, two emergency DGs activated automatically.

The closure of the MSIV resulted in the increase of RPV pressure and at 15:05 on March 11, the RCIC was manually activated as a precautionary measure. At 15:25 on March 11, the RCIC was stopped due to the high water level in the reactor.

At 15:38, as a result of the impact of the tsunami, two emergency DGs stopped operating due to the flooding and submersion of the cooling seawater pumps, the power distribution panel and the emergency bus at Unit 3, resulting in the station blackout.

In addition, loss of the RHRS pump function due to tsunami led to the loss of the RHR function, resulting in a failure to transfer the decay heat in the PCV to the sea, the ultimate heat sink.

However, the DS bus of Unit 3 escaped being flooded. Power was not supplied through AC-DC transfer from the AC bus, but rather the backup storage batteries supplied power to the loads (RCIC valves, recorders, etc.) that required direct current for an extended period of time compared to those of other units.

Because of the drawdown resulting from the shutdown of the RCIC at 15:25 on March 11, the RCIC restarted at 16:03, the same day and shut down again at 11:36 on March 12. Then, the HPCI started automatically at 12:35 on March 12 due to the low water level (L-2) of the core and shut down at 02:42 on March 13.

The reactor pressure transitioned fairly stably at 7 – 7.5MPa gage after the scram and fluctuated when HPCI shut down until SRV was rapidly depressurized before 09:00 on March 13.

In order to lower the PCV pressure after the HPCI shut down at 02:42 on March 13, TEPCO carried out wet venting from 08:41, the same day. From approximately 09:25 on the same day, though TEPCO started injecting fresh water containing boric acid through the fire protection system by using fire engines, the RPV water level still dropped. Even taking this injection into account, this meant that no water was injected for six hours and 43 minutes since the HPCI shutdown. At 13:12 on March 13, water injection was switched to seawater injection.

Furthermore, to reduce the PCV pressure, PCV vent operation was carried out at 05:20 on March 14.

○ Alternative Water Injection

As for Unit 3, after the station blackout, RCIC and HPCI started the operation for some time, thus cooling of the reactor maintained. However, since these functions might be lost at some stage due to depletion of batteries, etc, TEPCO implemented the preparation for cooling the reactor by alternative water injection.

Under these circumstances, at 11:36 on March 12, RCIC tripped. HPCI, which started the operation just after that (at 12:35), stopped at 02:42 on March 13.

In the wake of these developments, TEPCO attempted to resume the injection of water with existing cooling facilities (HPCI, RCIC, diesel-powered fire pumps). However, HPCI didn’t operate due to battery depletion, and regarding RCIC, though the injection of water into RPV was attempted upon confirming the on-site situation, it didn’t start the operation. Injecting water via diesel-driven fire pump was attempted, but it didn’t operate as the reactor pressure rose to approximately 4MPa after the HPCI was suspended.

Same as for Unit 1, the preparatory work for injecting water via fire engines was implemented but fire engines in plant were used to inject seawater to Unit 1. In addition, despite external backup of fire engines was requested, it took some time for them to arrive.

After the occurrence of tsunami, the traffic between Units 1-4 and Units 5-6 had been interrupted, but recovery efforts of the roads including leveling the ground by setting up sandbags on the gaps as well as removing debris, etc, were gradually implemented on site. As a result, by the morning of March 13, traffic to Units 5 and 6 became available. Therefore, the fire engines at Units 5 and 6 were transferred to Units 1-4. In addition, a fire engine which had been deployed as backup for emergency at Fukushima Dai-ni NPS, was moved to Fukushima Dai-ichi NPS, and the line composition for injecting water which set fresh water of the fire cistern as water source, was formed.

In order to inject water via fire engines, reactor depressurization through the operation of SRV was needed. However, due to the lack of batteries, SRV could not be started. As all the batteries in plant were already collected to restore the instruments etc, of Units 1 and 2, there were no spare batteries. Accordingly, batteries were taken from the cars for commuting of TEPCO staff at the Nuclear Emergency Response Headquarters, and carried to the main control room, then connected to the instrumentation panel. As a result, at around 09:08 on March 13, SPV was opened and rapid depressurization was successfully achieved. Since the reactor pressure fell below the discharge pressure of fire engines, alternative water injection with fire engines started at 09:25 on March 13.

It was estimated that the fresh water in fire cistern would be depleted in a few hours. At 10:30on March 13, the plant manager gave a directionthat the seawater injection would be taken into consideration. At 12:20on March 13, the fresh water in the fire cistern was depleted, thus the line composition was changed to inject seawater in the backwash valve pit of Unit 3. Despite the arrangement was ready for the quick switch, the work was forced to be suspended for some time due to aftershocks which were followed by the evacuation order. Soon after the resumption of the work, the line composition was completed and at 13:12 on March 13, injection of seawater was started.

In case of depletion of seawater in the backwash valve pit of Unit 3, to use the seawater in the basement of the turbine building of Unit 4, the fire engine entered there to take water after breaking the shutter of the carry–in entrance for large-sized equipment, however it didn’t work well. Though water intake from the water discharge channel of Unit 4 or swimming pool of the Training Center was also discussed, but it did not realize.

At 01:10 on March 14, remaining seawater inside the backwash valve pit was running out, thus adjustment of the water intake position such as suspending fire engines’ operation, and deepening the intake position of hoses by moving the fire engines closer to the backwash valve pit, were implemented. As a result, seawater could be taken, and at 03:20 on March 14, injection of seawater was resumed.

At dawn, as fire engines for backup arrived, in order to take seawater from the sea and send it to the backwash valve pit promptly, two fire engines were deployed near the landing place and the line composition was established. Then at 09:20 on March 14, seawater feeding to the backwash valve pit was started.

On the morning of March 14, seven 5-ton water Self Defense Forces trucks which were requested as the source of fresh water, arrived. It was decided that they would be used to refill the backwash valve pit. At 10:53 on March 14, they were deployed in the backwash valve pit, then refilling work was started; however, at 11:01 on March 14, explosion occurred in the reactor building of Unit 3. Accordingly, the refilling was suspended. In addition, all staff in the main control room except the staff on duty stopped working and evacuated to the seismic isolation building. Therefore, the restoration work was forced to be suspended for some time to confirm the safety of staff and the site.

Also, due to the explosion, radioactive debris were scattered around Unit 3, the fire engines and hoses were damaged, thus the seawater injection to the reactor of Unit 3 was stopped. In addition, the backwash valve pit became unusable due to debris. Therefore, in order to inject seawater which was taken form the sea to the reactor directly, the workable fire engines were moved to the landing area and tandemly-connected, then hoses were rearranged to deliver water to the both Units 2 and 3, and at 16:30 on March 14, the seawater injection via fine engines was resumed.

In addition, due to the explosion, four staff of TEPCO, three staff of a cooperation firm, and four members of Self Defense Force got injured.

○ PCV vent

In Unit 3, the means to transport heat to the ultimate heat sink were lost because of the station blackout and the loss of the function of the sea water system pump caused by tsunami. Because of this, TEPCO started to review PCV venting from the beginning of the accident in preparation for a pressure increase in the PCV.

As an advance preparation for performing venting, the venting procedure was started to be reviewed in the Main Control Room just after 21:00 on March 12, the operation order and places of the valves were written on a whiteboard during the investigation.

After the venting operation procedures for Unit 1 were completed, the power generation squad of the NPS Emergency Response Headquarters reviewed on a venting operation procedures while looking at the venting operation procedures for Unit 1 and the AM operation procedures for Unit 3 in cooperation with the restoration team of Nuclear Emergency Response Headquarters at Fukushima, and informed the Main Control Room of the procedures completed on March 12.

At around 4:50 on March 13, the solenoid valve was forcibly energized using a small generator for temporary illumination of the Main Control Room to open the large valve of the S/C vent valve (AO valve); however, it was confirmed that the valve was “closed” by the people on duty who went to confirm its opening on the spot.

At around 5:15 on March 13, the plant manager gave a direction that the works should be started to complete the venting line composition except for a rupture disk and prepare for press.

At around 5:23 on March 13, cylinders were replaced, judging that compressed air was insufficient because the solenoid valve of the S/C vent valve (AO valve) large valve continued to be “closed” although it was energized, so that the S/C vent valve (AO valve) large valve turned “open.” At around 8:35 on March 13, the vent valve (MO valve) was manually operated to opened 15 % as stipulated in the procedures; at around 8:41 on March 13, the venting line composition was completed to wait for the rupture disk to rupture.

After that, because the D/W pressure was decreased from 0.637 MPa abs to 0.540 MPa abs between 9:10 and 9: 24 on March 13, TEPCO judged that the venting was performed during this period. However, because the air pressure of the cylinder attached to the S/C vent valve (AO valve) large valve was declining at around 9:28 on March 13, personnel were dispatched to the spot in order to confirm the state of the connection part of the cylinders, so that they confirmed a leak and fixed the part.

At 11:17 on March13, it was confirmed that the S/C vent valve (AO valve) large valve was closed again due to the pressure leak, a driving cylinder was replaced, and an opening operation was performed; at 12:30 on March 13, the S/C vent valve (AO valve) large valve was made open again.

When workers went to the spot (torus chamber) to maintain the S/C vent valve (AO valve) large valve in the open status for the purpose of preventing closure of the valve, it was so hot in the torus chamber, and also there was vibration due to the SRV operation that the valve was unable to maintain open.

At around 14:31 on March 13, the measurement results were reported of 300 mSv/h or higher on the north side of the reactor building double door (the inside was white and hazy), and 100 mSv/h on the south side. Also, at 15:28 on March 13, the dose in the Main Control Room of Unit 3 was 12 mSv/h, so that the people on duty evacuated to the side of the Main Control Room.

At around 17:52 on March 13, filling of a temporary compressor was completed. Because of high dose in the reactor building, the restoration squad of the NPS Emergency Response Headquarters moved the temporary compressor in a Unic vehicle to the large cargo dock of the turbine building to connect to the Instrument Air-system (IA) line.

At around 20:10 on March 13, it was judged that the S/C vent valve (AO valve) large valve was open due to a decreased D/W pressure.

After that, the opening operation was performed many times because it was difficult to maintain the valve open due to the problems of the driving air pressure for the S/C vent valve (AO valve) large valve and the maintenance of energization of the solenoid valve of air supply line.

Because the D/W pressure tended to rise from around 2:00 on March 14 (0.265 MPa abs at 2:00 on March 14 -> 0.315 MPa abs at 3:00 on March 14), it was decided that opening operations would be performed for not only the S/C vent valve (AO valve) large valve but also the S/C vent valve (AO valve) small valve; at around 3:40, the MO valve was forcibly energized, at 5:20 an operation was started to open the S/C vent valve (AO valve) small valve, and at 6:10 it was confirmed the valve was in the "open" position.

After that, the opening operation was performed many times because it was difficult to maintain the valve open due to the problems of the driving air pressure for the S/C vent valve (AO valve) small valve and the maintenance of energization of the solenoid valve of air supply line.

e. Unit 4

Unit 4 was in periodic inspection at the time of the Great East Japan Earthquake and all fuel assemblies were removed into the spent fuel pool (SFP.)

As a result of the impact of the tsunami, the shutdown of an emergency DG due to flooding of the cooling seawater pump and the power distribution panel led to the station blackout and the cooling and water supply functions of SFP.

In addition, the reactor building was confirmed to be damaged after impulsive sound at around 06:00 on March 15.

The following explains the outline of the June report to IAEA. For Unit 4, there is no new information on the responses during the accident after the June report.

○ Outline of the June report to IAEA

Unit 4 was in periodic inspection and all fuel assemblies were removed from the reactor into the SFP due to the shroud replacing works.

It was recognized that the SFP was fully filled with water as the cutting work of the shroud had been carried out at the reactor side, with the pool gate (a divider plate between the reactor well and the SFP) was closed.

In addition to Okuma Line 3, to which no power was being supplied due to repair work before the earthquake, the Shin-Fukushima Substation breaker tripped and the breaker for receiving electricity at the switchyard in the power station was damaged by the earthquake, disrupting the power supply from Okuma 4 as well, and caused the loss of off-site power on March 11.

The loss of off-site power stopped the cooling water pump for the SFP, but it was possible to use the RHR system and others that were powered by the emergency DGs since the external power supply was lost. However, such switching required on-site manual operation and it did not take place before the arrival of the tsunami.

At 15:38 on March 11, after the outbreak of the tsunami, the emergency DG was shut down due to flooding of the cooling seawater pump and the power distribution panel and led to the station blackout and loss of the cooling and water supply functions of SFP.

After the impulsive sound occurred at around 06:00 on March 15, the reactor building was confirmed to be damaged. Since the exhaust duct of the PCV vent line of Unit 3 was connected to the exhaust duct of Unit 4 before the exhaust pipe, hydrogen discharged by venting at Unit 3 may have flowed backward into the standby gas treatment system (SGTS) of Unit 4 and flowed into it.

f. Unit 5

Unit 5 was in outage for periodic inspection at the time of the Great East Japan Earthquake and on the day of the earthquake, a RPV pressure leakage test was being conducted with fuel loaded in the reactor.

As a result of the impact of the tsunami, all AC power supply was lost and resulted in the loss of cooling seawater pump function, which led to the loss of the RHR system resulting in a failure to transfer the decay heat to the sea, the ultimate heat sink.

On March 19, a temporary seawater pump was installed, and while having the SFP and the RHR of the reactor used alternately to cool Unit 5, the reactor was in cold shutdown at 14:30 on March 20.

The following explains the outline of the content of the June report to IAEA as well as provides new information on the responses at the time of the accident revealed after the June report.

○ Outline of the June report to IAEA

Unit 5 had been in outage for periodic inspection since January 3, 2011 and on the day of the earthquake, a RPV pressure leakage test had been conducted with fuel loaded in the reactor.

At 15:40 on March 11, as a result of the impact of the tsunami, two emergency DGs stopped operation due to the flooding of the cooling seawater pumps and the power distribution panel and resulted in the loss of all AC power. Moreover, loss of cooling seawater pump function led to the loss of the RHR function, resulting in a failure to transfer the decay heat to the sea, the ultimate heat sink.

As for the reactor, the reactor pressure was increased to 7.2MPa gage for the pressure leakage test. Then the pressure moderately rose because of the decay heat, and about 8MPa gage of reactor pressure was maintained.

On March 13, water was successfully injected into the reactor using the condensate transfer pump of Unit 5, which received power from the emergency DG of Unit 6. Accordingly, after 05:00, March 14, the reactor pressure and the water level were controlled by reducing pressure with the SRV along with repeatedly refilling the reactor with water from the CST through the condensate transfer pump.

On March 19, a temporary seawater pump was installed and started cooling, using the RHR system. The SFP and the reactor were alternately cooled by switching the components of the RHR, as for the reactor, cold shutdown was achieved at 14:30, March 20.

○ Pressure reduction operation for Reactor Pressure Vessel

When the earthquake occurred, Unit 5 was in outage for a periodic inspection in which the leakage from the RPV was inspected at the maximum reactor water level and at the pressure around 7MPa gage..

After the earthquake, due to decay heat, the reactor pressure had been gradually increased; therefore operators operated to reduce pressure using RCIC steam lines, HPCI steam line and HPCI exhaust lines one by one. But any change was not observed in the reactor pressure.

Thereafter the pressure was increasing and then maintained at around 8 MPa gage. Accordingly, it was determined that SRV was automatically opened. Also, an operator who was on the way to the field in order to conduct the air supply line operation regarding valves at the top of the RPV, which will be detailed later, identified the noise of SRV working in the reactor building, although the surrounding circumstances did not allow him to confirm the operating conditions of SRV with indication lights because the power supplies for the indication lights in the main control room was lost.

Aiming at decreasing the reactor pressure, the air supply line to open valves at the top of the RPV was established by manually operating the valves in the field of the reactor building, and at 6:06 on March 12, valves at the top of the RPV were opened from the main control room. As a consequence, the reactor pressure could be decreased to the extent of atmosphere pressure.

After that, the reactor pressure started increasing once again due to decay heat; therefore restoration works were started before dawn on March 14 (SRV was inaccessible for operation from the main control room due to the leakage test). Power fuses were restored and the nitrogen gas supply line was completely established by manually operating the valves in the PCV in order to establish the conditions in which SRV could be operated from the main control room. SRV was opened to start the pressure reduction of SRV at 5:00 on March 14.

As handling of the unit after the pressure reduction operation (alternative water injection into the reactor, the restoration of the RHR heat removal function, and temperature increase suppression in the SFP) was simultaneously conducted with Unit 6, which was also under an periodical inspection, the Unit 5 handling conditions will appear with Unit 6 handling conditions later in the paragraph “g Unit 6”.

g. Unit 6

Unit 6 was in outage for periodic inspection at the time of the Great East Japan Earthquake and on the day of the earthquake, the reactor was in cold shutdown and had fuel loaded.

As a result of the impact of the tsunami, 2 emergency DGs (6A, 6H) stopped operating but 1 DG (6B) continued to operate.

After March 14, the reactor pressure and water level had been controlled by depressurization by SRV along with repeatedly refilling the reactor with water from the CST through the condensate transfer pump. On March 19, the SFP and the RHR of the reactor were alternately used with the temporarily installed seawater pump, to cool the reactor, which was in cold shutdown at 19:27, March 20.

The following explains the outline of the content of the June Report to IAEA as well as provides new information on the responses at the time of the accident revealed after the June report.

○ Outline of the June Report to IAEA

Unit 6 had been in outage for periodic inspection since August 14, 2010, and on the day of the earthquake, the reactor was in cold shutdown and had fuel loaded.

At 15:40, as a result of the impact of the tsunami, two emergency DGs (6A, 6H) stopped operating due to flooding of the cooling seawater pumps and the power distribution panel but another emergency DG (6B), which was installed in the DG building, which was located at a relatively high location than the turbine building, stayed operating. Therefore, Unit 6 did not lose all its AC power. But, the function of cooling seawater pumps was lost.

On March 13, water was successfully injected into the reactor using the condensate transfer pump, which received power from the emergency DG. Thus, after March 14, the reactor pressure and water level were controlled by depressurization by SRV along with repeatedly refilling the reactor with water from the CST through the condensate transfer pump. On March 19, a temporary seawater pump was installed to activate the RHR system. The SFP and the reactor were alternately cooled and the reactor was reached to the cold shutdown at 19:27, March 20.

○ Alternative Water Injection to Units 5 and 6

The soundness of condensate water transfer pump of Unit5 was checked by the restoration team of Local Nuclear Emergency Response Headquarters on March13, and the direct temporary electric cables were directly laid from low pressure power distribution panel (MCC) of Unit6, and then at 18:29, March13, the power supply was restored. Accordingly, after the reactor depressurization, at 05:30, March14, using alternative water injection line which connects FP line and RHR line, which were used as AM measures, the water injection into reactor was started.

Condensate water transfer pump of Unit 6 was workable with power supply from emergency DG of Unit6, thus 13:20, March 13, using the line which used in AM; the water injection to the reactor was started.

○ Restoration of function of Residual Heat Removal System (RHR) of Unit 5 and 6

Due to regular inspection, Unit5 had been in outage for approximately two and a half months and Unit 6 had been in outage for approximately for seven months, thus their decay heat at the time of the earthquake was relatively smaller than that of operating plants.

The restoration team of Local Nuclear Emergency Response Headquarters checked the soundness of RHR seawater pumps of Units 5 and 6, and as a result of it, it was found that those were unusable. Working with the head office of TEPCO, consideration of temporally connecting submersible pumps which were generally used, to seawater pipe, and restoring them as alternative cooling seawater pumps of RHR was started

Since March 17, work such as removing debris and leveling ground for roads for construction in the area with regard to laying of submersible pumps, was started. On March 18, temporary electric cables was laid from a high pressure power supply vehicle, and setting up operation panel for yard pump was completed, thus, temporary PHRS pumps restored and actuated at Unit 5, 01:55 March 19, and at Unit 6, 21:26, March 19.

As for PHR pump of Unit5, high pressure power distribution panel (M/C) in the basement of the turbine building of Unit 5 was not able to supply power due to tsunami flooding, thus on March 18, by laying of temporary electric cables, approximately 200m long, from high pressure power distribution panel (M/C) from Unit6, the direct power supply to RHR pump of Unit5 was implemented.

In addition, as RHR pump of Unit 6 was load of high pressure power distribution panel (M/C) from DG of Unit 6, power supply was secured. With restoration of RHR and RHRS pumps, one system of heat removal function of Units 5 and 6 became usable, thus, by switching line composition of RHR, implementation of alternately-cooling of reactor and SFP was decided.

After the temperature of water of SFP declined, line composition of RHR was switched, and then changed to cooling of the reactor. Temperature of the reactor water dropped below 100 degrees, then the cold shutdown of reactors was completed (Unit 5 at 14:30, March 20, Unit 6 at 19:27, March 20).

In addition, regarding Unit5, pump of Fuel Pool Cooling Line (FPC) was actuated at 16:35, June 24, then this pump was used for the cooling of SFP, and RHR was used for the cooling of the reactor.

○Temperature increase restraining for Spent Fuel Pool at Unit 5 and Unit 6

All the seawater pumps at Unit 5 and Unit 6 were in a disabled condition as a result of the tsunami; SEP at where spent fuel were stored was in a disabled condition for cooling.

Monitoring for SEP water temperature was continued until heat removal function was recovered after the evaluation of temperature rising rate on decay heat inside of SEP.

Water was supplied to SEP up to almost full level by using line being used for AM on March 14, due to the recovery of condensed water transferring pump at Unit 5 and Unit 6.

After that, to restrain rising rate of SEP water till the recovery of heat removal function, part of SEP water with rising temperature was discharged at Unit 5 on March 16, and then water supply by condensed water transferring pump with the line used for AM. was conducted.

At Unit 6, power supply was established by emergency DG of Unit 6 to FPC pump, and FPC pump started circulating operation (without heat removal function), agitating SEP water to restrain rising rate of SEP water on March 16.

h. Restoration of power supply and instrument

After the loss of all AP power at 15:42, March 11, in order to recover plant parameter and cooling function, the restoration of power supply as well as instruments and gauge was placed as utmost priorities. The efforts are describe as below.

○Power supply

Regarding Fukushima Dai-ichi NPS, after the first tsunami struck, there were risks of aftershocks and subsequent tsunamis for some time, thus it was difficult to dispatch workers at the site. However, facing the situation the loss of all AC power, the restoration work led by a restoration team of Local Nuclear Emergency Response Headquarters was started.

Firstly, the damage situation of the switchyard and power distribution panel was inspected. The switchyard which was connected to the external power supply was severely damaged, such as the fall switch, thus it was confirmed that prompt recovery would be impossible. In addition, the flooding situation of the power distribution panels (M/C, P/C) in the turbine building (some of which were not there) and the damage situation with regard to the exterior appearance were visually inspected, and insulation resistance was measured. As a result of this, it was confirmed that, as for Units 1 and 3, both M/C and P/C were all unusable, as for Unit 2, M/C were all unusable but P/C were partially usable.

On the other hand, distribution department of TEPCO head office instructed around 17 o'clock all the distribution offices to secure high/low pressure power supply vehicles and confirm route to Fukushima Dai-ichi NPS.

In the wake of this, high/low pressure power supply vehicles of all offices departed for Fukushima-Dai-ichi NPS, however, they couldn't proceed smoothly due to damaged traffic and traffic jam. In addition, Self-Defense Force considered airlifting of power supply vehicles, but it was given up due to over-weight. Tohoku Electric Power Co., Inc was also asked to send high pressure power supply vehicles to Fukushima Dai-ichi NPS.

In the early morning of March12, using the power supply vehicles of TEPCO for backup, in order to restore SLC, etc which can implement high pressure water injection, the work for connecting power supply was started. To ensure necessary power voltage of 480V, it was decided to connect the power supply vehicles to power transformer（6.9 kV/480V）of Unit 2 P/C(2C). In this connecting work, with the distance to Unit2 P/C (2C) and workability of cable laying in consideration, the power supply vehicles was deployed next to the turbine building of Unit2, and approximately 200m cable was laid from the carry–in entrance for large-sized equipment of the turbine building of Unit2 to the above mentioned P/C, which was located the north side of the first floor.

The cable used for connecting was the one kept by on site subcontractor for the work for periodic inspection. The diameter of this cable was more than 10cm, the length was approximately 200m, and the weight was more than 1t, thus normally it would take many days for laying it using machine, nevertheless, approximately forty staff of TEPCO committed to the prompt laying operation by hand, therefore it was completed in 4~5 hours.

The above-mentioned works got bogged down under the difficult working condition such as dark places, puddles due to tsunami, scattered obstacles, and the loss of manhole covers. In addition, the works, such as searching for the penetration parts for cable laying in the dark, breaking the doors and ensuring routes for laying cables at long last, proved to be a great challenge. Also, while major tsunami warning continued, due to repeated aftershocks, evacuations as well as interruptions of the work were forced. Terminal treatment of cables required to connect to P/C, is a work which took a few hours itself, however, it was implemented by a few engineers.

Regarding the correspondence between the Local Nuclear Emergency Response Headquarters and on the site to implement the work, under a situation where most communication unworkable, took time including moving to a place where communication instrument can work.

Under these circumstances, around 15:30, March12, cable connection to P/C of Unit2 and connection of power supply vehicles were finally completed, then power transmission just besode the SLC pump was implemented, but at15:36, March12, the reactor building of Unit 1 was exploded, followed by the damage of laid cable due to scattered objects and automatic suspension of the high pressure power supply vehicles. Accordingly, interruption of the work and full-scale evacuation to seismic isolation building were unavoidable.

As for Unit6, while the operations of two emergencies DG (6A, 6H) were suspended due to the effect of tsunami, a DG (6B) continued the operation. However, as restoration of external power supply was difficult, power supply of only one emergency DG of Unit6 was being continued, causing concerns toward the fuel shortage (depletion). Therefore, fuel oil (light oil) was arranged and since March 18, the light oil was transferred daily from the Kanto area to the NPS by tank trucks, then after the continuous refilling of the fuel tank of Unit 6, the fuel of emergency DG was ensured.

Regarding power supply sharing from Unit6 to Unit5, in the reactor building of Unit5 which was in the dark due to blackout, reactor operators with a flashlight inspected flooding situation and usage of the power distribution panel in the electric panel room. It was confirmed that all high pressure power distribution panels of Unit5 were usable.

Since Unit 6 could ensure in-plant power supply with continuous operation of emergency DP, using the existing cable laid between Unit5 and Unit6 to share power supply with neighboring plants as AM measures, at 08:13, March12, power sharing to Unit5 was implemented. Accordingly, in Unit5, power supply to some of equipments which operate with direct current power supply (A train) became possible.

Also by laying temporary electric cable directly from the instrumentation power distribution panel of the service building of Unit 6 to the instrumental power distribution panel of the control building of Unit 5, among the instrumenttion of Unit 5 in main control room, power supply to AC power-driven ones became possible.

After that, as the high pressure power distribution panel (M/C) of Unit 5 was flooded, power supply to low pressure power distribution panel of Unit 5 was impossible, accordingly, temporary cable laying directly from low pressure power distribution panel (MCC) of the turbine building of Unit6 to the equipments which were necessary to restore the operation of Unit 5, was started. At 21:01, March13, SGTS of Unit5 started the operation (SGTS of Unit6 have been in a continuous operation after the earthquake). Accordingly, reactor buildings of Units 5 and 6 maintained the condition that the negative pressure, as well as kept discharge of radioactive materials just in case being under control.

In addition, regarding the seawater pump for cooling emergency DG (6A) of Unit6, which was submerged by tsunami, after its soundness was confirmed through the visual inspection of flooding situation of yard seawater pump area and the damage situation of exterior appearance by reactor operators and restoration team as well as the measurement of insulation, etc, at 19:07 March18, it started the operation.

At 04:22, March19, emergency DG (6A) of Unit6 started the operation, which meant that two emergency DGs were secured as emergency power supply for Units5 and 6.

○ Instrumentation

In the main control room for Unit 1 and Unit 2, because of the loss of all AC power supplies, lighting and indication lights had faded, and alarming sounds had gone off. Eventually, only emergency lighting become available in the Unit 1 side, and no light became working to cause total darkness in the Unit 2 side. In accordance with the shift supervisor, facilities which were usable and unusable were identified.

As for facilities which could be operated with the DC power supplies, in Unit 1, it was confirmed about the circumstances of IC and HPIC that open/closed indicators for valves were not identifiable for IC; and direction lights had been poorly lit on the control panel but later turned off which indicated that it became unable to start up. With respect to Unit 2, start up circumstances became unknown.

At 15:50 on March 11, power supplies for instrumentation were lost, and reactor water levels became unknown.

Regarding the communication means between the main control room and the emergency countermeasures headquarters, PHS was not usable, and only the hotline and fixed line phones could be used.

In the main control room for Unit 3 and Unit 4, because of the loss of all AC power supplies, available lighting was limited to emergency lighting. Due to the fact that all the fuel had removed during a Periodical Inspection in Unit 4, parameters such as reactor water levels was confirmed with flashlights mainly in Unit 3.

Based on the manual to deal with the loss of all AC power supplies, in order to save batteries for RCIC and HPCI as long as possible, operation to reduce unnecessary burden was conducted.

At 16:03 on March 11, RCIC was manually started up. In the main control room, discharge pressure and rotation frequency were confirmed, and operation circumstances were observed for the preparation of HPCI start up.

Regarding the main control room for Unit 5 and Unit 6, two emergency DGs in Unit 5 and two of those in Unit 6 were confirmed to have simultaneously shut down.

An emergency DG in Unit 6 was not influenced by the tsunami, the frequency was adjusted, the operational conditions were maintained, and the high pressure power distribution panel (M/C) in the combined reactor building was usable; therefore, Unit 6 was continuously used to supply power to a part of emergency equipment (B system) even after the occurrence of the Tsunami.

Because power supplies for lighting and monitoring instruments were maintained, it was possible to confirm the parameters of the reactor and SFP.

Regarding the side of Unit 5, emergency lighting was fading and the site had gradually been surrounded by total darkness. A part of monitoring equipment, however, was in operation with DC power supplies even after the loss of all the AC power supplies. Therefore, it was possible to confirm the readings which were necessary to conduct the operation to restore Unit 5.

At 14:42 on March 12, an emergency ventilation and air conditioning system was manually started up with the power supplies from Unit 6. As a result, in the main control room, conditions in which any full-face mask was unnecessary were maintained.

The restoration group for power station emergency countermeasures headquarters, aiming at restoring instrument in the main control room, started preparing for necessary drawings as well as gathering batteries and cables. These materials were carried in to the main control rooms on the first come basis, the drawings were confirmed, and the connection to the instrument panels in the main control room for Unit 1 and Unit 2 was started.

As for the side of Unit 6, because the phenomenon called “inability of water injection of the emergency Core Cooling System” occurred and the top priority was placed on grasping the circumstances related to water injection into the reactors, reactor water level meters were connected to the batteries which can be operated with DC power supplies in order, and the restoration works were started. The water level (TAF＋200 mm) of Unit 1 was determined at 21:19 on March 11, and that (TAF＋3400 mm) of Unit 2 was determined at 21:50 on March 11.

Furthermore, for the purpose of temporary restoration of lighting in the main control rooms, the restoration group for power station emergency countermeasures headquarters prepared for and installed small sized generators. Temporary lighting was installed in the main control room for Unit 1 and Unit 2 at 20:49 on March 11, and in that for Unit 3 and Unit 4 at 21:58 on March 11.

i. Hydrogen related measures

After recognizing the occurrence of an explosion which seemed like a hydrogen explosion in Unit 1 at 15:36 on March 12, being worried about possible similar explosions which could occur in other Units, TEPCO started discussing the procedure to discharge the hydrogen into atmosphere for the time when reactor buildings would be filled with hydrogen. Taking the advice from the headquarters of TEPCO into consideration, the power station discussed the strategy for the works to open blowing-out panels and to make holes in the ceiling parts. This kinds of works, however, were difficult to immediately realize in the circumstances in which heavy machinery was necessary, the access to reactor buildings were limited due to high level radioactivity and so on. Meanwhile, at 11:01 on March 14, an explosion which seemed like a hydrogen explosion occurred in Unit 3. Also at around 6:00 on March 15, a big impact sound was identified, the S/C pressure of the Unit 2 indicated 0MPa abs, and damage around the roof of the five story reactor building was identified. The blow-out panel of Unit 2 is considered to have opened at the explosion which seemed to be a hydrogen explosion.

As for Unit 5 and Unit 6, the water levels of the reactors and the SFP were maintained since the earthquake occurred, and in these circumstances hydrogen explosions were unlikely to occur. There were, however, still some risks that the injection function and the heat removal function could be lost because of aftershocks. Therefore, accumulated hydrogen gas prevention measures were considered just in case and it was decided to make three holes (about 3.5 cm to 7 cm in diameter) with a boring machine on each of the concrete roofs of the reactor buildings of Unit 5 and Unit 6 on March 18. Work started early in the morning on March 18, during which time two staff members from TEPCO and four employees from subcontractors wearing full-face masks, charcoal filters and coveralls climbed atop the roofs of the reactor buildings of Unit 5 and Unit 6, and conducted work for about 11 hours in total (work was completed at 13:30 for Unit 5 and at 17:00 for Unit 6).

4) Forecasts progress of the accident

From the day of accident of the Fukushima Dai-ichi NPS until March 13, the Nuclear and Industrial Safety Agency had forecasted progress of the accident at the emergency response center (ERC) established in the annex building of Ministry of Economy, Trade and Industry as the secretariat of the Nuclear Emergency Response Headquarters, and sent materials regarding forecast results to the Crisis Management Center of the Office of the Prime Minister.

When an accident occurs, in order to carry out emergency responses, it is necessary to forecast progress after the occurrence of accident. Therefore, the government, through the Japan Nuclear Energy Safety Organization (JNES), had developed a system for supporting forecasts of the progress of the accident (emergency response support system (ERSS)).

The primary functions of the ERSS are to obtain plant information from the NPSs, to judge the status of accident based on the information, and to carry out forecast progress of the accident. However, since transmission of data was stopped and plant information was not available due to the impact of earthquake, it became impossible to forecast the progress of the accident basing on the accurate plant data.

Because of the above situation, the JNES selected the data close to the status of the accident from the plant accident behavior data system (PBS: the database system with compiled a database beforehand analyzing plant behavior to various events, one of the functions of the ERSS) and sent it to the ERC. At the ERC, the forecast of the accident was carried out by comparing the plant information obtained by telephone/facsimile with the above-mentioned accident data.

Process of carrying out forecasts is as follows.

○ Concerning Unit 2, the JNES sent the result of PBS to the ERC plant team at around 21:30 on 11 (Figure 1 in Attachment II-2). The forecasts progress of the accident based on the said result was sent to the staff of the Nuclear and Industrial Safety Agency dispatched to the Crisis Management Center of the Office of the Prime Minister, and was shared in operation room at around 22:44 on the same day and around 0:17 on the following day 12.

- Forecasts sent to the Crisis Management Center of the Office of the Prime Minister (forecasts as of 22:00 on March 11)

March 11	22:50	Uncovering reactor core with water
	23:50	Damage on fuel clad tubes
	24:50	Fuel melt
	27:20	Reaching to the maximum design pressure (527.6kPa) of Reactor PCV

○ Concerning Unit 1, JNES sent the results of PBS to the ERC plant team at around 1:57 on the 12th (Figure 2 in Attachment II-2). The said result was used as input data of the System for Prediction of Environmental Emergency Dose Information (SPEEDI), and the calculation result was output at around 6:07 on the same day (the said result was not sent to the Crisis Management Center of the Office of the Prime Minister.).

○ Concerning Unit 3, the JNES sent the result of PBS to ERC at around 6:29 on 13 (Figure 3 in Attachment II-2). The forecasts progress of the accident based on the said result was sent to the staff of the Nuclear and Industrial Safety Agency dispatched to the Crisis Management Center of the Office of the Prime Minister at around 6:50 on the same day, and was shared in the operation room.

- Forecasts sent to the Crisis Management Center of the Office of the Prime Minister (forecasts as of 6:30 on March 13)

March 13	6:00 – 6:15	Damage to fuel clad tubes
	8:00 – 8:15	Fuel melt (core damage)

With regard to Units 1 and 2, an attempt to analyze using the Analytical Prediction System (APS: the system to analyze the progress of accident with acquired the real time plant information, one of the functions of the ERSS) was made. But, since accurate plant information was not available, ARS was not utilized to forecast the progress of the accident. Also, regarding Units 4 to 6, analysis by ERSS has not been carried out.