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DAMAGES OF MACHINES AND STRUCTURES IN GREAT EAST JAPAN EARTHQUAKE AND LESSONS FROM THE DISASTER

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ABSTRACT:

The Japan Society of Mechanical Engineers (JSME) has constituted an investigation committee on damages of machines and structures caused by the Great East Japan Earthquake and the following tsunami. The committee consists of the following seven working groups:

WG1: Damages of machines and devices, and effectiveness of the earthquake-proof technologies
WG2: Mechanism of damages of machines and structures due to tsunami
WG3: Applications of robots at the disaster area
WG4: Traffics and logistics
WG5: Damages of energy infrastructure
WG6: Review of codes and standards in NPP.
WG7: Risk management against the earthquake and accidents in NPP.

The committee started its activity from the end of March, 2011, and expects to publish the final report at the end of March, 2013. Each WG works aggressively and there are many data about damages and lessons learned from the good practices. This paper provides an interim report on the overview of the JSME activities.

Key Words: Great East Japan Earthquake, Tsunami, Machines and Structures, Earthquake-proof Technology, Applications of Robots, Traffics and Logistics, Energy Infrastructure, Codes and Standards in NPP, Risk Management, NPP Accident

INTRODUCTION

The “Tohoku Region Pacific Coast Earthquake followed by the vast tsunami ”, which attacked Japan on March 11th ,2011, caused unprecedented disasters in Japan, especially in Tohoku and North Kanto prefectures. Further, the accident at the Fukushima Daiichi Nuclear Power Plant(NPP), caused by the earthquake and tsunami, resulted in the meltdown of the fuels in the reactor core, collapse of the nuclear reactor buildings due to the hydrogen explosion and the large scale spread of the radioactive materials to the environment, and continues to menace the people living in that area. We are facing to a severe situation that we have never experienced.

Here again, we would like to present our condolence to those who have passed through the disaster, and send our massage that “We are always with you.” to those who are suffering from the disaster. Further, we would like to send the same message to the engineers and workers who risk their own lives to tackle with the accident to put an end of it.

The Japan Society of Mechanical Engineers has settled the following two committees just after the earthquake:

- Committee on emergent damage analyses, surveys and proposals
- Committee on long range proposals

The members of both committees have been working aggressively from the viewpoint of :

- What the engineers and researchers, who are engaged in the mechanical engineering, have to reconsider and learn from the disaster?
- What they can do towards the future?

The characteristics of the present earthquake are :

- The scale of the earthquake was very large, that is, M9.0.
- The scale of the tsunami following upon the earthquake was enormously huge.
- The disaster area is extensively wide, and there are so many people who suffered from the disaster.
- We meet new difficulties to deal with the NPP accident and the spread of the radioactive materials.

There are many items to be surveyed and many subjects to be investigated. In order to do this job effectively, JSME settled 7 WG’s in the first committee while 4 in the second. In this paper the author focuses the attention to the activities done by the first committee, that is,’ the Investigation Committee on the Great East Japan Earthquake’.
The committee started its activity from the end of March, 2011, and expects to publish the final report at the end of March, 2013. The investigation policy is such that

- Investigation should be fair, right and open.
- Investigate damages due to earthquakes and/or tsunami.
- Questionnaire and hearing investigations are recommended as well as information published by government, companies, etc..
- Find out good practices.
- Send messages to the public as well as JSME members as quick as possible.

Each WG works aggressively and there are many data about damages and lessons learned from the good practices. This paper provides an interim report on the overview of the JSME activities.

WG1: DAMAGES OF INDUSTRIAL FASCILITES

Seismic Damage Distribution in Industrial Facilities

Figure 1 shows the seismic damage distribution of industrial facilities, as of July 5th, 2011, caused by the Great East Japan Earthquake. Red mark indicates the industrial facilities with damage, while green mark without damage. It is confirmed that the seismic damage is located over a wide area in Japan.

Statistics Results of Seismic Damage Investigation by JSME

WG1 carried out questionnaire investigation about seismic damages among companies, including member companies, research institutes and universities during the period of May, June and July, 2011. Total number of answers is 233, of which 118 were with seismic damage, while 115 were without one. Details of the statistic results are shown in the appendix, and they are summarized as follows:
Damage of Machines and Devices: As for the damage by the strong motion, buckling of tanks, failure of hook bolts or run off of overhead cranes, and failure of the utility pipes or air ducts were

commonly observed. As for the damage by the tsunami, equipments, tanks, and unloaders were destroyed by floating objects, or washed out by buoyancy force. Tsunami also caused the short circuit damage of the electrical equipments. On the other hand, there are some cases which seemed to be reduced seismic damages by the earthquake resisting methods taken in advance.

Fig.1 Seismic damage distribution of industrial facilities (As of July 5, 2011)

WG2: MECANISM OF DAMAGES OF MACHINES AND STRUCTURES DUE TO TSUNAMI

WG2 investigates combined damage mechanisms of machines, equipments and structures caused due to tsunami. Generation and propagation mechanisms of tsunami should be studied primarily by Japan Society of Civil Engineers and Japan Association for Earthquake Engineering and so on. The Japan Society of Mechanical Engineers would like to understand the combined damage mechanisms of tsunami from a viewpoint of loss of functions of machines, equipments and structures, together with the generation and propagation mechanisms of tsunami. Based on such understanding, we, as members of WG2, wish to establish failure simulations of machines, equipments and structures caused due to tsunami, and simulation-based methodology for tsunami-proof machines, equipments and structures.

Tsunami has various kinds of potential powers causing damages of machines, equipments and structures, including getting water, invasion of sea water containing sand, massive water crashing, debris collision. In the Great East Japan Earthquake and Tsunami, we often observed deformation and failure of machines and structures crashed by ships and/or containers carried by the tsunami as shown in Figure 2a. In WG2, we focus on not only failure of single component, but also combined failures of multiple mechanisms. As one of examples of our investigation, Figure 2b shows a snapshot of simulation of building attacked by debris carried by tsunami. In addition, we need to consider more complex scenarios such that structures are first damaged by earthquake loading and liquefaction and are then attacked by tsunami.
In general, tsunami height is a primal concern. However, to quantitatively evaluate effects of tsunami ascending and drawing, lifting force causing falling moment, getting water and collision-based failure, large-scale and precise simulations will be needed. We discuss what phenomena current simulation technology can solve, and what are missing in it. We would like to propose what R&D we should perform from now on.

Figure 2a　A factory attacked by a large ship carried by tsunami
（Yahoo! JAPAN East Japan Earthquake Picture Record Project,
http://archive.shinsai.yahoo.co.jp/entry/61926/　）

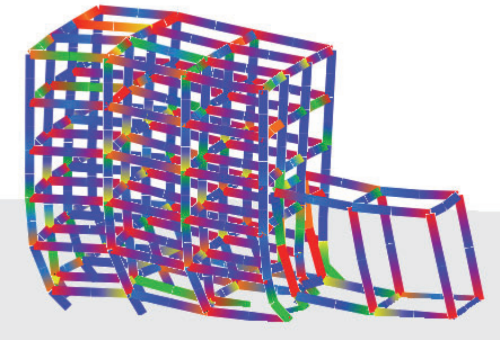


Figure 2b　A snapshot of ASI-Gauss-based simulation of building attacked by debris carried by tsunami (Lynn, K. M. and Isobe, D. (2007). “Finite Element Code for Impact Collapse Problems of Framed Structures”, *International Journal for Numerical Methods in Engineering*, Vol. 69, No. 12, 2538-2563.)

WG3: APPLICATION OF ROBOT TECHNOLOGIES TO THE DISASTER SITE

In the Great East Japan Earthquake many robot technologies have been used and tested in Sanriku Coast and Fukushima Daiichi NPP. In Sanriku Coast, they were used for the investigation of missing persons driven by tsunami under the sea, debris removal in the disaster sites and the inspection of a gymnastic hall in danger of collapsing in Hachinohe. In Fukushima Daiichi NPP, they are now being used for the removal of debris indoor and outdoor of the nuclear reactor buildings, radiation measurement and inspection in the buildings. In the evacuation centers, therapeutic robots “Paro” were introduced into more than 20 centers for providing psychological support to sufferers. The applied robots and robot technologies to the disaster achieved a certain result. The results of practical applications and trials of them, however, present new issues about the operations of these robot technologies.

Sanriku Coast

The devastated area of the tsunami disaster is extensively wide. A tele-operated mobile robot “Kohga 3” developed by Prof. Matsuno with Kyoto University was used for inspecting the damage of a gymnastic hall in danger of collapsing in Hachinohe just after the tsunami, but it couldn’t be used for finding survivors because most of victims died by drowning. Therefore, the robots were mainly used for the investigation of underwater and the removal of debris in the disaster area on land.
Investigation of underwater: After one month from the earthquake, some underwater robots were applied for underwater investigation in order to avoid the danger of divers. “AC-ROB”, “SARbot”,

“LBV-300” and “Seamor ROV” were used for searching victims and inspecting obstacles, underwater portions of piers and bridges for assessment of damage at Minami Sanriku-cho and Rikuzen Takata-shi on 19th -20th and 21st -23rd April respectively. “Anchor diver 3” was used at Warati-cho on 19th -20th. These missions were done in collaboration with IRS(International Rescue System Institute) and CRASAR(Center for Robot-Assisted Search and Rescue).

“SARbot” and “LBV-300” are developed by SeaBotix Inc. and the “SARbot” was mainly used due to the portability and rapid setup/deployment. It is equipped with an enhanced color video camera, the Tritech Gemini 720i multibeam imaging sonar, an accurate GPS system and a limb grasping mechanism. “Seamor ROV” is a product of Seamor Marine Ltd., and it is equipped with high resolution sonar and a grasper. “AC-ROB” is a small robot driven by a battery and just takes movies. It is like a video camera with a thruster. It was mainly used for investigating tight places like under the floating houses. “Anchor Diver 3” is developed by Prof. Hirose with Tokyo Institute of Technology. It is equipped with a high resolution video camera and a 2D-sonar, and driven by two thrusters. It is connected to the operation site by a cable and can keep its own position in tidal streams by the cable tension and the thruster control. The time SARbot was under water is 38minutes on 19th and 189minutes on 20th, and Seamor 178minutes on 20th. Anchor diver 3 investigated about 100m^2 in two days. No victim was found in the mission, but the situations of the bottom of the ports were made clear. Prof. Ura with the University of Tokyo also investigated the bottom of Otsuchi bay and Shizukawa bay by two underwater robots RTV on 29th April-1st May and 15th-16th May, and found 2 victims. The investigation of victims and the inspection of the debris on the bottom of the sea by underwater robots have continued until now.

Removal of debris: A new construction machine ASTACO NEO with two robotic manipulators developed by Hitachi Construction Machinery Co. Ltd. was applied for the removal of debris at Ishinomaki in May and June which revealed the high efficiency of the robot.

Fukushima Daiichi NPP

There was no robot in Japan applicable to the disaster site of Fukushima Daiichi NPP just after the accident caused by the tsunami, but now, many robots are used mainly for the removal of debris indoor and outdoor, the monitoring of radioactivity or other physical parameters and the inspection of the damage of the nuclear reactors and buildings. Much more robot technologies related to the construction machines or rescue systems will be developed and used for the tasks necessary for the decommissioning of nuclear power units 1-4.

Removal of debris: As to the removal of debris around the nuclear reactor buildings, some tele-operated construction machines modified for the disaster site came into use. At first, a backhoe attached with an iron fork at the tip, a crawler dump truck, a monitoring car with a camera and an operation car were introduced. The backhoe, dump truck and monitoring car are tele-operated by operators in the operation car. The technologies installed into the tele-operation system were originally developed for unmanned construction almost 20 years ago and they have been improved as construction robots until now. The system worked very well and the removal of debris outdoors is almost completed. From June, cleaning up of indoor was also started by the military robot “Warrior” developed by iRobot Corp.. A cleaner is attached to the manipulator tip of the “Warrior” as shown in Fig.3a.

Inspection and monitoring: As to the monitoring and inspection, two military robots “Packbot” (Fig.3b) which is a commercial product by iRobot Corp. were introduced for investigating the damage situation of the indoor of the nuclear reactor buildings after the middle of April. One robot is controlled as a monitor robot and takes the images of the other robot by its camera, and the other one is wireless controlled by the operator and measures radioactivity, temperature, moisture and so on. The robot also has a manipulator with (up to) 8 degrees of freedom(d.o.f.) which can open or close a door. These robots got much valuable data about indoor environment, but they couldn’t go upstairs because of the steep stairs. The rescue robot “Quince”(Fig.3c) developed by IRS(International Rescue System Institute) was also introduced from July, whose mobility capacity is very high, and it can go upstairs. The “Quince” has a unique crawler mechanism which has two flippers with crawlers at the front and the rear sides respectively like arms and legs besides the main two crawlers embedded in the body. “Quince” is also equipped with a 6 d.o.f. manipulator and is wired controlled by operators. By using the “Quince”, the damage of the building and the nuclear power plant became much clearer. For the inspection of the building from the air, a micro air vehicle “T-Hawk” was used from April. T-Hawk is a commercial product developed by Honeywell Inc. for surveillance of combat fields and can easily be operated by single person.

As mentioned above, in Fukushima Daiichi NPP, there was no robot applicable to the disaster site at first because of the difficulties of the task environments. The site was radiation-contaminated and also like a heap of debris. Therefore, both the tele-operation function and the mobility on debris are required for the robots. Professional operators and the robustness of the robots are also essential. However, such robots didn’t exist in Japan because of the political and economical reasons. On the other hand, there are many robots and operators in USA for military industry. That is the reason why many robots are introduced into Fukushima NPP from USA. In Japan, it is strongly desired for the government to technically and economically support the anti-disaster robotics technologies.

Fig.3a Warrior with cleaner[1)]

Fig.3b Packbot[2)]

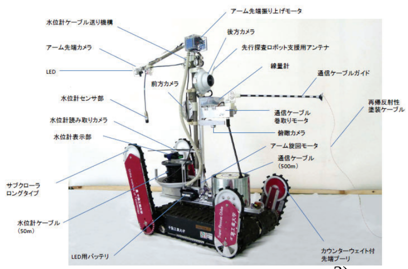


Fig.3c Quince[3)]

1) http://www.tepco.co.jp/en/news/110311/images/110630_4.jpg
2) http://www.tepco.co.jp/en/news/110311/images/110429_1f_11.jpg
3) http://www.tepco.co.jp/en/news/110311/images/110630_4.jpg

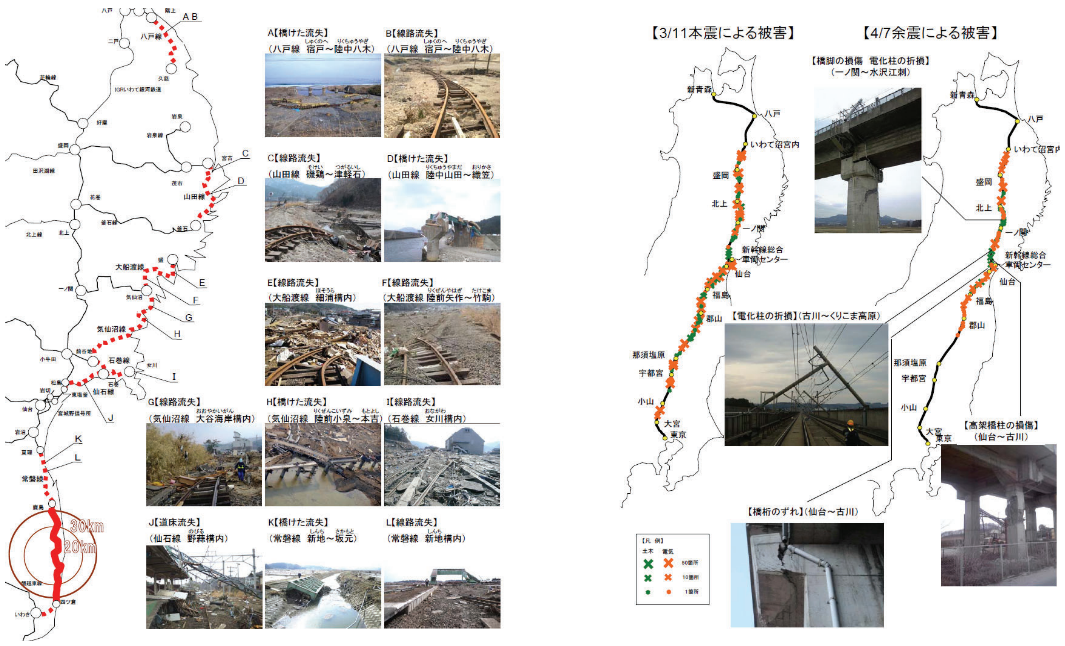
WG4: TRANSPORTATIONS AND LOGISTICS

Transportations of railways and roads were damaged widely and seriously in Tohoku area by the earthquake and/or tsunami.

Railway Transportation

In the case of railway transportation, infrastructures such as station buildings, railway tracks, catenary and pillar etc, were widely and seriously damaged by the earthquake and tsunami, as shown in Fig.4a and Fig.4b. The local lines were directly attacked by both of the earthquake and tsunami, but Shinkansen lines were not attacked by the tsunami. There were not so big damages in the mechanical devices compared with civil infrastructures. There were some trains attacked by the tsunami but all the passengers had evacuated before the tsunami attack.
Although 27 Shinkansen rapid trains were operated in service in Tohoku line during the earthquake, all trains could quickly slow down and stopped without derailment and any passenger fatalities. The quick operation could be done by the UrEDAS and FREQL systems which can detect small P-wave before large S-wave reaches the railways and send the information to the central operation center. These alarm systems have been developed due to the various experiences of huge earthquake attacks so far, such as, 1995 Kobe Earthquake and 2004 Chuetsu Earthquake.
The derailment prevention guard systems have been developed and deployed to Shinkansen vehicles

which can directly avoid the derailment by mechanical guard systems. This new safety system has been developed after 2004 Chuetsu Earthquake.



(a) Local railway along Pacific coast (b) Tohoku Shinkansen line

Fig. 4 Damages of railways by the earthquake and tsunami

Road Transportation

In the case of road transportation, roads and traffic signals were attacked and damaged by the earthquake and tsunami, moreover many cars and trucks were floated and carried away. Gas stations were also damaged, so that many cars cannot be driven due to the lack of gasoline.

A few days after the earthquake, Inter-NAVI information systems were open to the drivers through car navigation systems to know which roads can be used or not. This system was linked by the similar navigation systems of big companies, such as, Honda, Toyota, Nissan and Pioneer. Fig.5a shows the navigation map of available roads drawn by blue lines. Similar navigation system worked as well for commercial vehicles such as trucks.

The “Kushinoha Sakusen” (teeth of comb operation) greatly contributed to the quick recovery of the road transportation and logistics operation. Fig.5b shows the road map to rescue and recover the damaged areas after the earthquake and the tsunami attack.

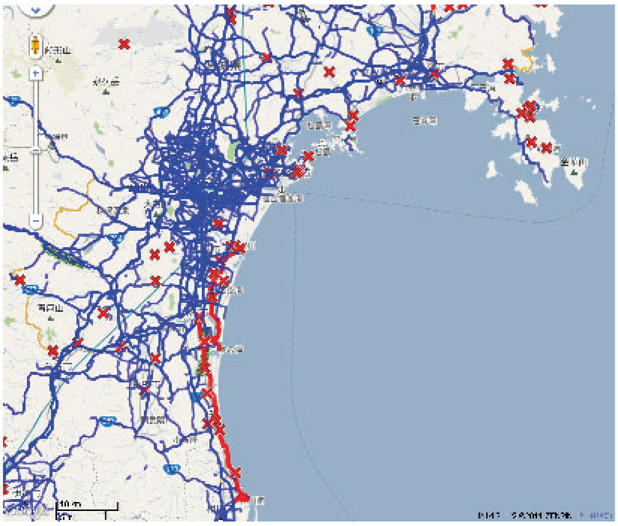


Fig.5a Navigation map around Sendai area

Fig.5b Teeth of comb operation map

WG5: DAMAGE OF ENERGY INFRASTRUCTURE

The following four areas were selected to be investigated:

+ Nuclear Power Station
+ Thermal Power Station
+ Other Energy Infrastructures
+ Energy Policy.

The view points of the investigation are

+ what happened?
+ what was the cause?
+ what is effective to protect machines and structures from severe damage?

through researchers' and engineers' eyes, which may contribute possible improvement for establishing more robust society. Faced to such severe disasters of nuclear power stations, JSME, as the third party not involved in the interested parties -- government, electric power companies and thousands of evacuated people after the emergency --, has a position to give valuable and dignified opinions.

Nuclear Power Station

A field research and a questionnaire survey were performed. Group members visited the Tokai No. 2 nuclear power station of the Japan Atomic Power Company, the Onagawa nuclear power station of the Tohoku Electric Power Company and the Hamaoka nuclear power station of the Chubu Electric Power Company. The questionnaires were sent to four research reactors of the Japan Atomic Energy Agency; the Japan Research Reactor No. 3 (JRR3), the Japan Materials Testing Reactor (JMTR), the Joyo, the High Temperature Engineering Test Reactor (HTTR), and the Tokai No. 2 nuclear power station. These facilities locate on the coast of the north-eastern part of Japan along the Pacific Ocean except for Hamaoka. The area was suffered from the Great East Japan Earthquake, and then the Onagawa and the Tokai No. 2 nuclear power station were attacked by the subsequently occurred huge tsunami. Fukushima Daiichi, although most severely damaged, and Fukushima Daini Nuclear Power Stations were excluded from the investigation since these are substantially under the control of the Japanese Government and the accident investigation by the Japanese Government is in progress.
Investigation results at present are summarized as follows;
Against the earthquake:

+ S class facilities were not visibly damaged by the earthquake, while B and C class facilities suffered some damages.

+ All devices and plants functioned properly provided only for the shaking due to earthquake.
+ Employees evacuated smoothly by following an emergency manual.
+ Rubbed marks were found on turbine blades.
+ Two additional items are suggested:
  ・The fall of the steel tower of a power transmission cable resulted in the off-site power loss, and the fire of switchboards led to the blackout.
  ・The power supply is indispensable to control facilities.

Against the tsunami:

+ Once electric devices such as motors and valves were flooded, these devices lost their functions. Power sauces submerged in water could not supply electricity for most of the equipments (Fig. 6a). Even air-operated valves could not be operated since pilot valves were designed to be driven by electricity.
+ The properly waterproofed area was free from submergence.
+ A diversity of communication tools is essential between the onsite and the offsite.

The most important lesson learned was electricity supply ready for use for power and light electric equipments in any conditions. Various back-up systems as well as waterproof are indispensable to assure security. There could happen various events beyond human knowledge. Even so, it is requested to provide the way how to cope with the incident. Continuous check/review and updating on the system and system performance is of substantial importance. It is also important to estimate the survival-time allowance of nuclear power station when isolated from off-site power. A diversity of access methods to the power station is needed, e.g. from air and sea. These are useful in an emergency. The organizational governance is of prime importance at an emergency. One bright evidence to be pointed out is that the waterproofed area was free from flooding (Fig. 6b), which suggests the potential of modern technology for the robustness against the incidents beyond the human knowledge.

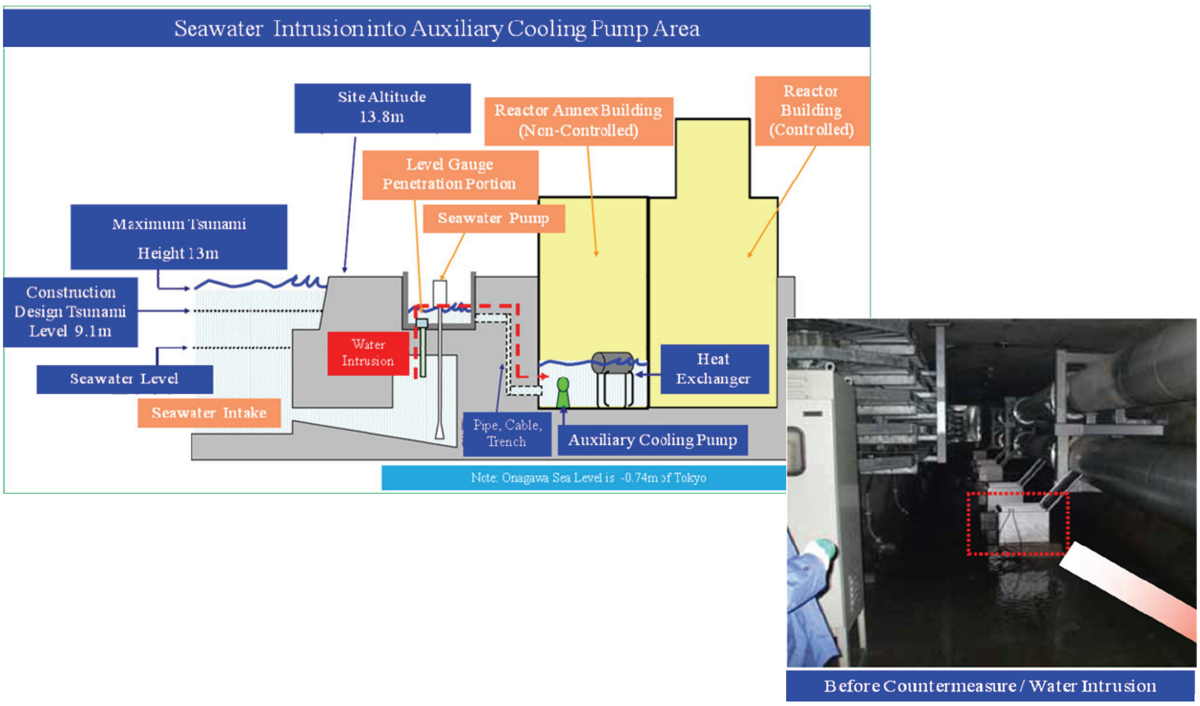


Fig. 6a Sea water penetration pass at Onagawa No. 2 reactor. Water does not fail to notice any tiny cranny to come into inside.

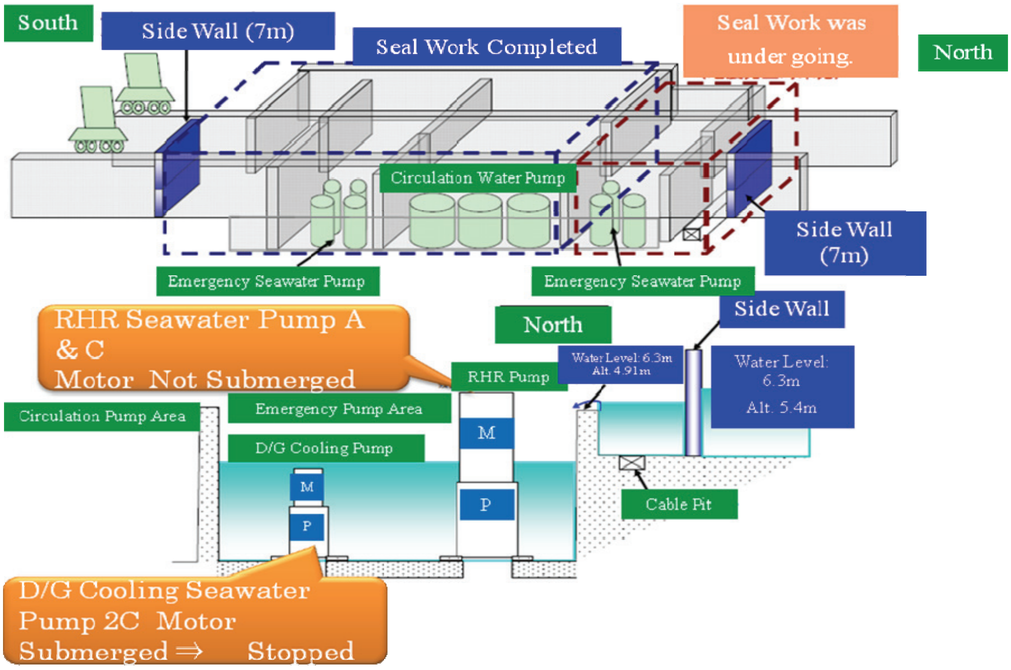


Fig. 6b Sea water penetration was blocked at Tokai No. 2 reactor. Waterproof treatment is important.

Thermal Power Station

Field researches were conducted for the Hitachi-Naka thermal power station of the Tokyo Electric Power Company, the Shin Sendai and the Haranomachi thermal power station of the Tohoku Electric Power Company. Questionnaire surveys were also conducted for the Hirono, Hitachi-Naka and Kashima thermal power station of the Tokyo Electric Power Company, the Shinchi thermal power station of the Soma Kyodo Power Company, the Nakoso thermal power station of the Joban Joint Power Company, the Sendai, the Shinsendai and the Haranomachi thermal power stations of the Tohoku Electric Power Company and the Integrated Coal Gasification Combined Cycle (IGCC) power generation site of the Clean Coal Power R&D Company. All those power stations were located along the coast of the Pacific Ocean and were involved in the present earthquake and the tsunami. Although some of those were restored, some are still under the restoration process and will be commissioned again in 2013.

No major damage of main facilities, e.g. boiler and turbine, was caused by the earthquake. Employees evacuated following an emergency manual and human damage was suppressed only in small number. Land subsidence occurred at some power stations, which harmed the transportation for restoration work after the disaster.

Since the thermal power station located close to the sea, all power stations were damaged by the tsunami which followed the earthquake. The degree of the damage depended on the height of the tsunami and was in wide dispersion. A coal hoist collapsed through the severe pitching/rolling of a coal ship. (Fig. 7a) Fuel tanks were crashed and washed-away by the tsunami. (Fig. 7b) The tsunami invaded into buildings including control buildings (Fig. 7c) and switchboard buildings (Fig. 7d). Power loss was caused, which harmed the communication between on-site and off-site. An emergency power source was installed on a turbine floor at some power station and effectively functioned. It is essential to equip various communication tools.

Fig. 7a Damaged coal unloader

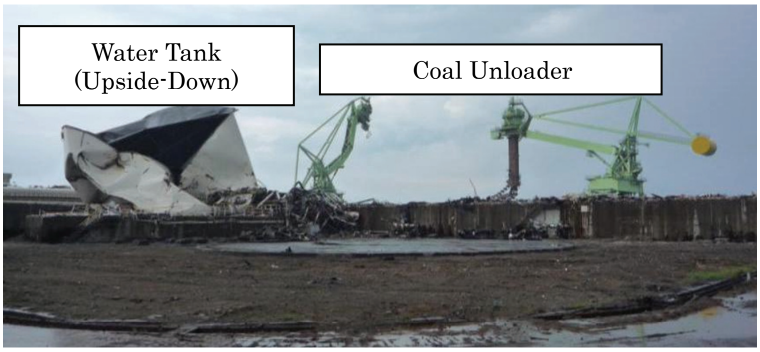


Fig. 7b Crashed and washed-away fuel tank

Fig. 7c Second floor of control building

Fig. 7d Switchboard building

Other Energy Infrastructures

Questionnaire surveys were conducted for the Tokyo and Tohoku Electric Power Company and two oil factories.

The damage to insulators of power transmission lines by the earthquake was reported. The fall of the steel tower of the power transmission cable was not caused by the earthquake except for only one case, as mentioned in the above section of " nuclear power station". The earthquake caused severe damages to aerial and underground power transmission cables at many places. Liquefaction might be one cause of the break. Circuit breakers were also damaged by the earthquake.

A few buildings were damaged by falling rocks caused by the earthquake at some hydro power stations. The walls of aqueducts at the hydro power station suffered from cracking by the earthquake.

When the earthquake hit the oil factories, electric power supply was maintained by an emergency power source or off-site power. Evacuation was executed smoothly. Communication and governance well functioned. Fire of a liquefied petroleum gas (LPG) tank happened at one oil factory. Fall of tanks and reactors and also buckling of a high stack were caused by the earthquake.

Many steel towers of the power transmission cable were collapsed by the tsunami. Transformer substations along the coast were flooded by the tsunami. One oil factory was attacked by tsunami and tanks were washed away. Power supply facilities were also flooded and blackout was caused.

Energy Policy

Questionnaire surveys have been performed for JSME members who registere to the Power and Energy Systems Division. The registered members are approximately 4,400 of which 320 answers are collected, whose age ranged from 20s to 80s. Occupations were company employees, researchers, academic professors, students and so on. They are specialist in the energy-related technologies. Their opinion on the present disasters and resulting events are interesting and valuable to draw and consider lessons learned from calamities. Analyses on questionnaire survey are in progress. The overall trend of the answers is that nuclear reactors are indispensable to produce electricity in Japan. In order to be accepted by the public, it is necessary for engineers and researchers to develop safer and more reliable nuclear technology, otherwise Japan cannot be survived. Most of all members believe that the role of engineers is to sustain modern society. Energy supply, especially electricity supply, is an essential task for retain the society. It is not easy to overcome the present difficulty and to solve the stuck problems, but we, mechanical engineers, are responsible to provide answers.

WG6: NUCLEAR CODES AND STANDARDS

The severe accident and the consequent radioactive material release at the Fukushima Daiichi nuclear power station was an unprecedented serious disaster the human being have ever experienced. On the other hand, it should also be noted that the other power stations survived the earthquake and tsunami safely.

Investigation Policy

The WG 6, titled “Issues and future direction of nuclear codes and standards”, recognizing these situations and learning from the accident, defined its objectives that include;

- To survey damages and their consequences (accident) that the nuclear power stations in Tohoku region suffered, to the extent JSME can be committed
- To gain insights about the (root) causes of the damages and the accident, mainly focusing on the nuclear codes and standards issues
- To analyze effective measures (good practice) against earthquake and tsunami at some nuclear power stations
- To create proposition about a path forward on nuclear codes and standards development related to the severe accident leading to enhanced nuclear safety

It should be noted that the activity of the WG 6 is underway in a close cooperation with the Main Committee on Power Generation Facility Codes (MCPGFC) of JSME that develops and maintains codes and standards for nuclear power plant design and operation.

Overview of Damages and Accidents in NPP’s along the East Japan Pacific Coast

The effects of the earthquake and tsunami that attacked the nuclear power stations located on the Pacific Coast of Tohoku region can be summarized as shown in Table 1 below.

Table 1 Earthquake / Tsunami Affected Nuclear Power Stations

Station/Unit	Earthquake (gal)*1	Tsunami (m)	Plant Safety Functions		
			Shutdown*3	Cooling*4	Containment
Higashidori 1	17 / 450 *2	> 4	Success	Success	Success
Onagawa 1-3	573 / 512	~ 13	Success	Success	Success
Fukushima Daiichi 1-6	550 / 438	14 ~15	Success	Failure*5	Failure*5
Fukushima Daini 1-4	277 / 428	~ 7	Success	Success	Success
Tokai Daini	225 / 400	5.4	Success	Success	Success

*1 Representative value of maximum acceleration, taken as maximum observed/design ratio
*2 Observed value / Design value
*3 Automated reactor scram due to earthquake
*4 Structural integrity of reactor cooling systems and security of emergency power supply
*5 Units 1 through 3 failed. Units 5 and 6 succeeded in attaining safe cold stand-by. Unit 4 was in outage.

One can observe from the Table 1 that;

- While the maximum observed accelerations slightly exceed the design values at Onagawa and Fukushima Daiichi, they are well below the design values at other stations.
- All the operating nuclear power plants were successfully shut down automatically sensing earthquake acceleration.
- Fukushima Daiichi station was attacked by a huge tsunami that was far higher than that of plant safety design assumption (~5.7 m), while the height of tsunami did not significantly exceed the design assumptions at other stations (for Onagawa, about 15 m was assumed in design).

The accident sequence at Fukushima Daiichi station can be outlined as;

- The operating units were automatically shut down by the seismograph signal.
- All the offsite power was lost due to the earthquake (a pylon was collapsed).
- The emergency power supply system lost its function by the attack of the tsunami that lead lasting period station blackout.
- The reactor core cooling capability was lost, which resulted in melting of the nuclear fuel and hydrogen explosion.
- As a result, a large amount of radioactive material was released to the environment.

For other nuclear power stations, the response of the plants can be roughly summarized as below;

- The operating units were automatically shut down by the seismograph signal.
- The offsite power was lost due to the earthquake (one line survived at Onagawa station).
- The emergency power supply systems survived the tsunami attack and maintained their function.
- No damage or malfunction is reported for the systems, structure and components important to safety.
- All the reactors were successfully cooled down to a stable status

Review of Nuclear Codes and Standards

Based on these observations and publicly available information such as the government reports and utilities' reports, the WG 6 has defined three viewpoints and started its investigation. Studies and discussions of the WG 6 from these viewpoints are currently underway, and here are some important aspects and outcomes of these discussions.

Viewpoint #1: Why Fukushima accident could not be prevented?

While the direct cause of the Fukushima accident is the loss of offsite and onsite power due to the earthquake and tsunami, it was obviously a failure of risk management and there should be underlying root causes of this failure. These may include issues related to the safety regulatory system and its operation by the government, regulation and codes and standards issues, issues of (lack of) implementing the up to date technology in a timely manner and so on. The discussion is now underway and the insights gained are to be put together for the proposition on "what the regulatory system should be", "what the codes and standards should be" and so on.

View point #2: What is needed for the nuclear codes and standards after Fukushima accident?

One of the most important lessons we have learned from the Fukushima accident is that "nuclear plants should be designed and prepared such that a severe accident can be prevented or avoided even when the plant is suffered from severe natural hazards exceeding the design level". It is a mission of JSME, as one of the major Standard Development Organization for nuclear power plant design and operation, to develop relevant standards to implement this lesson learned using the state-of-the-art technology. Since the nuclear safety consists of a wide spectrum of technology, there are number of standards to be developed and they should be developed systematically.

Among these needed standards, a representative one is "a guideline for countermeasure design to prevent severe accident under severe natural hazard conditions". The purpose of this guideline is the prevention of accidents and provides technical requirements, for example, for the back-up equipment to be prepared for core depressurization and cooling under a station blackout condition. Another representative one is "a guideline for structural integrity evaluation under severe accident conditions", The structural integrity of a containment vessel under the severe accident condition is quite important to mitigate the accident influence by suppressing radioactive material release to the environment, and this guideline literally provides structural integrity evaluation methods and criteria. Under the MCPGFC development of these guidelines has already started.

<u>Viewpoint #3: Did current seismic design technology function?</u>
As mentioned earlier, all the operating units were automatically and successfully shut down during the earthquake. No significant damage, failure, or malfunction is reported on the systems, structures, and components important to safety. In this sense, one may be able to argue that the current seismic design technology functioned and the design rules (except for the definition of design earthquake) are appropriate.

On the other hand, since the possibility of an earthquake larger than the design level can never be precluded, it is quite important to clarify the ultimate strength of structural components and functionality of active components under seismic loading, and quantify the design margin that is included in the current seismic design.

WG7: RISC MANAGEMENT AGAINST THE EARTHQUAKE AND ACCIDENTS IN NPP

Essential Viewpoint

In WG7 we investigate how people, who are responsible to the management, respond against the crisis caused by the earthquake and tsunami. The validity of the decision at the crisis is discussed. When we found a wrong decision we discuss the reason why and how the wrong decision was made. The factors of the wrong decision could be

- -lack of information
- -imperfection of organization and/or laws
- -sense of values and ethics of people working in the organization

The items of the inspection is focused to

- -accidents in NPP's
- -railway transportation ~Tohoku Shinkansen and JR at the metropolitan area~
- -Pet-bottle drink (especially focused to the robustness of the cap)

Results Currently Obtained

Fukushima Daiichi NPP:

1. Even if the total power supply was shut down, the melt down of the fuels in the reactor core could be prevented if they could have prepared the power supply due to the power source vehicles or if they could have done the cooling water supply by the fire engines in a few

hours after opening the vent valves.
The lack of the preparation and the training for the above two items is pointed out.

2. One major reason why they did not do the preparation and training leis in the regulation enacted by the government where the total power loss is neglected. Engineers had been in the situation of stop thinking.

Tohoku Shinkansen and JR at the Metropolitan Area:

-The points of reflection and the intrinsic problems against the criticism done after the accident

- ・Is it wrong to give the first priority to the safety issues?
- ・Which should be criticized, decision or preparation?

-Subjects for the future

- ・Development of simulation technologies for the emergent situations.
- ・Improvement of information management where how quick the correct information can be collected.

CONCLUDING REMARKS AND AKNOWLEDGEMENT

As already mentioned in the introduction, the investigation committee is now on the way to the final goal. Therefore, this paper gives an interim report about the subjects to be tackled with. At the moment the author described the summary of activities in each working groups respectively. In the rest of the period the author, as the chairman of the committee, will draw the subjects to be discussed and proposed for the society. These discussions and proposals will be included in the final report.

Finally the author would like to express his sincere acknowledgement for the support of the members in the committee and WG's. Without their support this report could not be completed.

APPENDIX

Statistics Results of Seismic Damage Investigation in the JSME

The following tables show the statistics results of seismic damage investigation carried out by the Japan Society of Mechanical Engineers (JSME) in the period from May to July, 2011. Total number of answers is 233 facilities. Of the total, 118 were with seismic damage, and 115 were without one.

[Maximum seismic intensity・Availability of acceptance for damage investigation・existence or non-existence of photos and reco damage]

Maximum seismic intensity	Under intensity 3	Intensity 4, 5	Intensity 6, 7
	7	43	46
Availability of acceptance for damag investigation	Acceptance	Reject	
	19	78	
existence or non-existence of photo and records of damage	Existence	Non-existence	
	61	38	

(Total number of answers 233 with damage 118 without damage 115

Damage situation of mechanical and euipment	Damage caused by Earthquake		Damage caused by Tsunami	Damage caused by Earthquake and Tunami synergy	Mitigation of Damage due to the lessons learned from past seismic event
	Vibration	Ground Deformation			
(1)Foundation・Wall surface・Supporting section	66	23	1	4	10
(2)Large machinery・General machinery・Precision Machinery	52	8	2	2	11
(3)Tank	5	9	1	1	4
(4)Boiler・Cooling machine・Air conditioning machine	24	8	3	2	4
(5)Pump	13	4	3	2	2
(6)Pipe	54	14		2	8
(7)Electric generation・Electric transmission, distribution and transfomation equipment・Access to electricity	20	7	1	1	6
(8)Emergency power system	1	2		2	2
(9)Crane	23	3	2		3
(10)Elevation machine	17	3	2	1	2
(11)Transportation・Train-related equipment	4	3	3	1	1
(12)FRP tank	14	4	1	1	
(13)Medical equipment	2	1			
(14)Base isolation・Vibration control system	3				2
(15)Other machinery equipment	23	4	1	3	6
Damage of production network	23	5	6	13	4
＊Power plant facitilies	3				

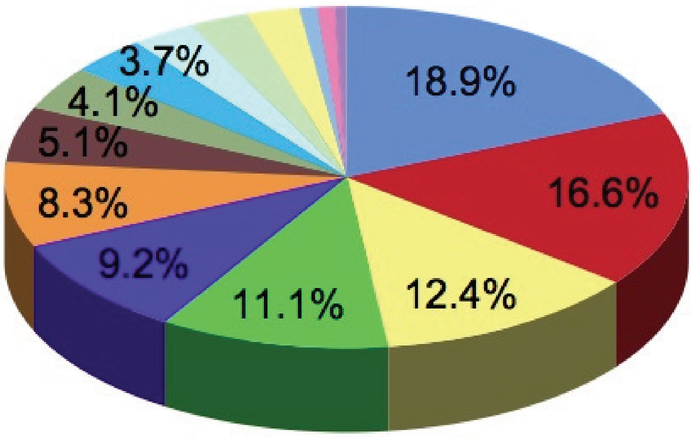
Characteristics of the damgae of machinery and equipment	Discribed comment
	89

[Questions in terms of crisis management]

1. Presence or absence of manual for emergency assuming seismic event	Presence	Absence	Partially presence		
	88	25	1		
2. Useful Effect of emergency manual	Useful	→	Useless		
	31	47	10		
3. Inconvinience while at work in th next day and the day after	With problem	→	Without problem		
	38	74	49		
4. Most helpful method to contact the head office from industrial facilities	Phone	Email	Direct visit	Other	
	61	50	16	23	
5. Number of days required to grasp the reality of the damage	Within a day	5 days	10 days	10 days – 30 days	30 days – 50 days
	30	50	11	13	3
Agenda and characteristics of risk management	Discribed comment				
	78				

Category of industry of Seismic Damage Investigation in the JSME

Figure A1 shows the percentage in the category of industry of seismic damage investigation in the JSME.



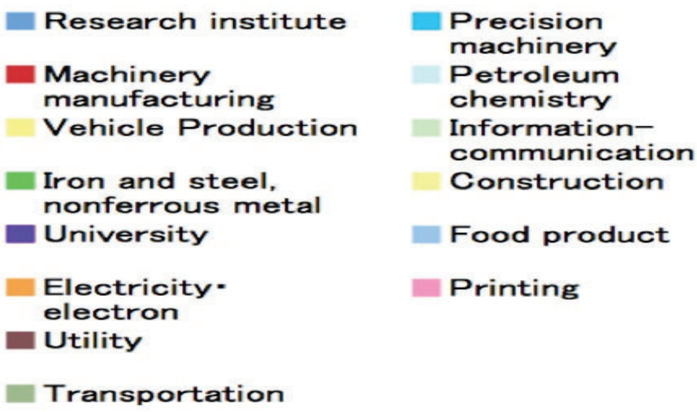


Figure A1 Percentage in the category of industry of seismic damage investigation in the JSME

Major Seismic Damage from Damage Investigation Results

• Damage of pipe in the ground
• Overflow stream in Liquid storage pool
• Breakage of embedded pipe caused by ground sinking
• Damage of shutter
• Damage of structure into hoistway
• Damage of steel-frame large structure
• Inclination of equipment caused by change of center of gravity
• Damage by aftershocks
• Malfunction in re-operation after emergency shutdown
• Equipment failures due to power outage
• Damage reduction and improvement of the lessons learned from past seismic damage

Major Seismic Damage from Site Investigation Results

• Manifestation of unprecedented damage due to long duration of seismic motion
• Seismic interaction between different structures
• Damage by seismic input
    • Plastic deformation of the bolts that hold the overhead crane rails
    • Fall of piping equipment and suspended structures
    • Buckling of tank
• Tsunami damage
    • Outflow of tank
    • Flooding of equipment
    • Damage by collision of floating object
•Damage by ground deformation
    • Deformation of foundation
    • Inclination of equipment
    • Deformation of piping supports