The Tsunami Disaster Caused by the Great East Japan Earthquake:
How should we draw on the lesson we learned from the national crisis?

Yoshiaki Kawata
Professor and dean of Faculty of Safety Science, Kansai University (professor emeritus at Kyoto University)
Director of the Great Hanshin-Awaji Earthquake Memorial Disaster Reduction and Human Renovation Institution

1. Occurrence mechanism of the greatest tsunami on record

The Japan Meteorological Agency announced two days after the Great East Japan Earthquake that the scale of the earthquake was magnitude 9.0, not 7.9 as previously announced. At this point, it was not anticipated that the earthquake would eventually result in a massive disaster with the number of missing and dead as many as 23 thousand. Due partly to this fact, seismologists made an honest confession saying the disaster was out of bounds. However, I repeatedly pointed out the importance of assuming the worst scenario. In the "Zuiso" column in the March 14 issue of the evening paper of Kobe Shimbun, which I have been regularly contributing to, I wrote under the title "The Threat of Tsunami" that "...There is a looming threat of the occurrence of a tsunami disaster with as many deaths as that in the Sanriku Tsunami of the Meiji Era." In the recent tsunami disaster, the casualties count about 23 thousand people, which is more than the 22 thousand victims in the Meiji Sanriku Tsunami Disaster.

In the forewords of "Tsunami Saigai (Tsunami Disaster)" (issued on December 17, 2010) I authored, I pointed out that if the resident evacuation rate in a Sanriku tsunami was as low as the present, there would be more than 10 thousand victims, which has turned out to be a fact. Why did this tragedy happen? One of the causes is that the recent tsunami was an unprecedentedly massive one. How massive the tsunami was can be easily seen in **Figure 1** which shows comparison between the height of coastal revetment and the height of the tsunami. At many coasts, the latter exceeds 1.5-2 times the former.

What strikes us the most is the size of the epicentral area. It was known that on the west side of the Japan trench, the Pacific plate, which came from east moved to under the North American plate, on which the Tohoku region is located, around 10 centimeters every year. In this sea area, earthquakes with tsunami have occurred at 70-80 year intervals. With this mechanism, the estimated slide amount would have been seven to eight meters. In the recent great earthquake, it is known that the slide amount was 50 meters maximum, and nearly 20 meters on the average.

This movement destroyed the plate interface as large as 200 kilometers east-west, and 500 kilometers north-south. The cause of the occurrence of the extremely massive tsunami was the width of the epicentral area, 200 kilometers. With a normal earthquake, the width of the epicentral area is within 100 kilometers, so the upper North American plate moved twice this distance. It is a fact that the North American plate moved this long distance, but the reason is unknown. **Figure 2** shows the recordings of hydraulic wavemeters installed at the bottom of sea at the depths of 1,500 meters and 1,000 meters respectively. The figure shows, the initial undersea earthquake raised the sea surface by about 1.8 meters over the area of 70 kilometers east-west. Immediately after this traveled west to the shallow sea area at 120 meters per second (430 kilometers per hour), another earthquake occurred in the shallow sea area (the spray fault moved), generating the wave height of about 3.2 meters. This means that extremely massive tsunami of about five meters high was already generated in the sea as deep as 1,000 meters.

Although such a mechanism has not been academically confirmed, when considering the mechanism of Tokai, Tonankai and Nankai earthquakes, which are also inter plate earthquakes, the following points must be considered as possibilities in addition to the conjunction of the three earthquakes:

(1) Conjunction of four earthquakes: Like in the Hoei Earthquake in 1707, conjunction of Tokai, Tonankai and Nankai earthquakes is an issue presently discussed. The four earthquakes further include a tsunami earthquake along the Nankai Trough at depths to the south, which resembles the Keicho Nankai Earthquake in 1605. In this scenario, the magnitude would exceed 8.7, which is the case of conjunction of the three earthquakes.

(2) Expanded conjunction of three earthquakes: The presumed western edge of the epicentral area of a Nankai earthquake is around the Ashizuri Cape in Shikoku. In the Hyuga-nada Sea to the west of the cape, the Philippine Sea plate moves more than 10 centimeters per year. Here, it has been thought that Hyuga-nada Sea earthquakes have occurred independently. If another Hyuga-nada Sea earthquake occurs, this area will be destroyed simultaneously. The expansion of the epicentral area to the west will increase the earthquake magnitude. Unless considered this way, that tsunami deposit discovered in the Ryujin Pond in Saeki, Oita Prefecture was recorded eight times during the past 3,500 years cannot be explained.

(3) Time lag conjunction of four earthquakes: In (1) above, the multiple earthquakes were thought to occur simultaneously or almost simultaneously. However, there is a possibility of the three combined earthquakes and the tsunami earthquake will occur with time lag. In this case, an earthquake in a deep sea area occurs first. If an earthquake in a shallow sea area occurs with certain time lag, tsunami with very complicatedly temporally changing heights will be formed. The heights of tsunami attacking coasts of the Seto Inland Sea are determined depending on the volume of tsunami flow that can pass the Kitan Strait, Naruto Strait and Hoyo Strait. Since this indicates the possibility that the characteristics of tsunami may vary significantly as time passes, tsunami warnings issued temporally change their content. If the residents are not informed of this in advance,

there would be a danger of numerous victims due to the wrong timing for evacuation.

2. Characteristics of damages

As mentioned above, because the tsunami is caused by two earthquakes occurring with time lag, not only the height of the tsunami is great but it is presumed that the mass of water in the raised sea level is also extremely great in volume. It can be presumed that this caused the very long wave length of the tsunami after the recent great earthquake, and maintained deep inundation for a long time after the urban areas were flooded. **Figure 3** shows the proof for this. This figure shows the inundated area of Rikuzentakata, and that the tsunami invaded eight kilometers maximum from the coast and the depth of the midway inundation was around 15 meters. It can be presumed that the tsunami raised the sea level of the entire Hirota Bay to around 15 meters, attacking the coastal area with this height. **Photos 1** and **2** show Takatamatsubara and the six-meter high concrete-made tsunami embankment behind it photographed by the author in October last year. These were completely washed away by the tsunami as shown in **Photo 3**, and the vacant lot sank and was submerged.

In the urban area attacked by the great tsunami, everything was washed away except solid reinforced concrete buildings (some four- or five-story reinforced concrete buildings lost their pile foundation due to liquefaction and fell down like a die by the wave pressure of the tsunami). Like in Ofunato shown in **Photo 4**, which has a long harbor and the tsunami repeated complicated harbor oscillation showing clear difference between flooded areas and non-flooded areas along the coast, is an example of the tsunami-affected areas. **Figure 4** shows the difference between the inundated areas on the hazard map and the actual inundated areas. Although there were cases like Miyako that showed little difference between them, the majority cases showed big difference like Sendai. Because there were victims in Kamaishi for example in its non-evacuation belt zone adjacent with the evacuation area designated on the hazard map, in the future production of hazard maps, unless the prerequisites for what standards are used are easy-to-understand for residents, there is a concern that the same tragedy will be repeated in the future. In the recent great disaster, it is clear that evacuation of residents living in the non-inundation areas was delayed. All concerned parties must recognize the issue of drawing a line between the inundation area and non-inundation area as an extremely important one.

Table 1 is a summary of human damages in Iwate, Miyagi and Fukushima Prefectures where the tsunami attacked with enormous damage. For comparison, it also shows the cases of Sanriku Tsunami in Meiji and Showa Eras. From this table, it is known that the human damage from the recent great tsunami disaster shows a similar death rate as in the case of Showa Sanriku Tsunami. What should be pointed out first is that the death rate is more than ten times that, 0.1%, in the Great Hanshin-Awaji Earthquake in 1995, the Marmara Earthquake in Turkey in 1999, the Chi-chi

Earthquake in Taiwan, the Great Sichuan Earthquake in China in 2008. Because the injured people counted about 53 hundred, which is less than one eighth in the case of the Great Hanshin-Awaji Earthquake, the tsunami disaster from the Great East Japan Earthquake reminds us of the importance of “You will be safe if you evacuate, but you will be a victim if you don’t.” This death rate, expressed for the unit of municipality, is distributed around several times to one severalth of the average value of the prefecture. Clarifying the cause for these differences will further clarify the effectiveness of evacuation.

As for physical damages, except for the accident at the Fukushima No.1 nuclear power plant, it is known that the majority was caused by the tsunami. There is land sinkage in about 560 square kilometers of the coastal area. Although this will return to the original level by upthrust in the future, this is a major impediment for the recovery of the affected areas. Especially almost all the deaths in Iwate and Miyagi Prefectures were caused by the tsunami, and human damage was caused by the tsunami while it is also a compound disaster.

What need tentative recovery immediately are the affected coastal flood prevention facilities. Approximately 190 kilometers of costal revetments and tide embankments were destroyed. These facilities are meant to protect coasts from high waves and storm surge as well as tsunami. Since we are already in the typhoon season, it is understandable that immediate restoration is required.

3. Tsunami disaster prevention in the future

The basic policy is to mitigate a disaster under the worst scenario. The worst scenario is not limited to the setting of abnormal external force such as tsunami. It also means to prevent damage from being extremely enhanced. There are two target cases as shown below:

(1) In areas with weak protection against disasters, when the external force becomes large, damages occurring there become large as they are controlled by the scale of the external force. Damages in regional towns and cities, semi-mountainous areas and coastal colonies belong to this.

(2) In large cities such as Tokyo, Nagoya and Osaka where abnormal external force is applied to the complicated wide-area urban structure, damages expand discontinuously in proportion to the scale of external force. Underground submergence by tsunami flooding is an example.

In the case of (1), a combination of hardware-based disaster prevention and software-based disaster prevention has been considered traditionally. However, this only works in the case where the design tsunami can be set in advance, and the combination does not assume cases where the design tsunami is exceeded. This is perhaps the most important reason why there was such extensive damage in the recent great earthquake disaster. Based on a combination of the worst scenario and disaster mitigation, the new policy for measures against disasters can be outlined as follows:

Setting the target tsunami: The height of tsunami shall be those of past tsunami that frequently occurred and the highest tsunami that possibly occurs. It is not good to set a tsunami that occurs once in 50-150 years from the beginning. This is the level 1 policy that was adopted by the Japan Society of Civil Engineers after the Great East Japan Earthquake. This is a concept based on “tsunami prevention structures first,” and it is a diversion of the earthquake-resistant design method of structures after the Great Hanshin-Awaji Earthquake, therefore it is necessary to realize the existence of ambiguous issue such as a moderate damage.

What is the most important is how to protect human lives. Based on this concept, excavation is to be given the first priority, and for this purpose, town planning and the construction of evacuation routes are the top priority. And, the existing structures such as tsunami revetments need a robust performance design that is not easily destroyed even if tsunami overflows. Because large scale tsunami normally attacks five or six times, if the facilities are destroyed at an early stage, there will be no disaster prevention effect.

For example, the coastal revetment (**Photo 2**) in Rikuzentakata which was overflowed by the recent great tsunami was completely washed away, resulting in the loss of its original function. It is known that as a revetment is overflowed by tsunami, the whirl formed at the base of the revetment scours the seabed ground opening a large hole, and scouring prevention work is necessary on the sea and land sides of the base of the revetment. It is also known that a tide prevention forest is not effective if the tsunami height is larger than the height of the trees. Therefore, it is necessary to plant trees on an embankment protected with robust stone pitching. The existing disaster prevention facilities need to be improved in their tenacity.

It is also true that it is extremely difficult to protect with such front line protection. For this reason, it is necessary to construct a secondary or tertiary levee in the urban area using the embankment of roads and railways, or to raise the ground on which important facilities are constructed, or transfer residential houses built on coastal lowland which are likely to receive enormous damage to higher land, to avoid damage. And, as mentioned above, based on the evacuation policy, residents must continue efforts to avoid becoming victims through evacuation drills. This is what needs to be considered in the recovery city planning, and it is important to realize at an early stage the system in which as many people as possible can evacuate (city planning taking evacuation routes into consideration, construction of evacuation buildings, protection of school facilities, etc.). For this reason, school education regarding disaster prevention is also necessary to exercise the right to live.

4. Improving issuance procedure of tsunami warnings

The Japan Meteorological Agency has organized a report on the present situation and problems, and it will improve the problems as follows:

(1) Issuance of tsunami warnings based on speedy estimation of accurate magnitude

(2) Speedy updating of tsunami warnings using offshore tsunami observation data

As for (1), in the calculation of magnitude based on seismic data, (a) with the traditional calculation of magnitude at an early stage conducted by the Meteorological Agency, there was a possibility of evaluating the magnitude lower than the actual if the scale of an earthquake was larger than magnitude 8 due to the seismograph going off the scale. (b) For accurate calculation of moment magnitude, since the agency had to use overseas observation data due to the seismograph going off the scale, it took two full days before it evaluated the earthquake as magnitude 9. For this reason, broadband seismographs, which never go off the scale, must be installed.

As for (2), it is necessary to install tsunami gauges in or around the wave source area, thereby reflecting the recorded data on forecasting and warning. Although the system for issuing forecasting and warning could have been improved, the problem occurred because too much importance was placed on the data recorded on seismographs. Although technology development for installing hydraulic wavemeters, buoy-type wavemeters and GPS wavemeters in a deep-sea area was finished, the Meteorological Agency cannot escape being criticized for its negligence of actively introducing the technology to forecasting and warning.

The Meteorological Agency needs to reflect on this problem seriously, and their immediate task is to introduce an issuance system of forecasting and warnings that can contribute to evacuation of residents. Installation and management of these tsunami gauges require cooperation of the Ministry of Land, Infrastructure, Transport and Tourism. Concerned parties need to give priority to issuance of actual tsunami forecasting and warning, not academic research and observation.

Establishment of such an observation system requires a great amount of financial resources. But, since the information obtained from the system is basic for reducing the number of victims, if we do not change the system immediately, there would be unprecedented damages when tsunami attacks caused by Tokai, Tonankai and Nankai earthquakes.