## Special New Year Program:

# Roundtable discussion by researchers studying the evaluation of tsunami wave forces on bridge structures

## Introduction

Following the Great East Japan Earthquake Disaster, the JSCE Concrete Committee established a survey research committee on the evaluation of tsunami wave forces on bridge structures, and this committee has engaged in intensive research activities from 2011 to 2013. In this roundtable discussion, committee members and researchers in the field of disaster prevention discussed the committee's activities and future directions.

### Roundtable participants:

Kyuichi Maruyama, Committee Chairman
(Professor, Nagaoka University of Technology; *Structural Engineering*)

Norimi Mizutani, Committee Member
(Professor, Nagoya University; *Coastal Engineering*)

Kimiro Meguro
(Professor, University of Tokyo; *Disaster Management*)

Moderators:

Kohei Nagai (University of Tokyo); Hiroshi Murata (Taisei Corp.)

## Summary of committee activities

The Great East Japan Earthquake of March 11, 2011 was the largest earthquake in recorded history in Japan and its coastal waters, with a magnitude (Mw) of 9.0. The enormous tsunami caused by the earthquake struck the coast of the Tohoku region with many casualties, and many residents were forced to evacuate when large amounts of radioactive contamination were emitted by the malfunctioning Fukushima Daiichi nuclear power plant. As of June 10, 2013, 15,883 fatalities of the earthquake have been confirmed, with 2,671 persons reported missing. In addition, more than 2,600 persons have died in evacuation shelters and the like. As we prepare this report, we would like to express our condolences to those who have lost their loved ones.

In this earthquake disaster, many bridge beams were washed away over a wide area ranging from southern Aomori Prefecture to northern Chiba Prefecture. Another enormous earthquake and tsunami are expected to occur in the near future in the Tokai and Tonankai regions. This has led to recognition of the urgent need to evaluate the tsunami resistant performance of existing bridges and develop ways to reinforce them, instead of focusing attention on tsunami resistant design for new bridges. Therefore, the JSCE Concrete Committee established a survey research committee on the evaluation of tsunami wave forces on bridge structures, and the committee commenced its activities in July 2011.

The committee's activities have been as follows.

(1) All of the bridges located within the region inundated by the tsunami were surveyed. Not only bridges whose bridge beams were washed away, but also unaffected bridges were surveyed in detail. Satellite imagery from the Internet was fully utilized as a means of investigation, with supplementation by aerial photography. This data was compiled into a database so that it can be referred to as necessary.

(2) There were 1,793 bridges within the region inundated by the tsunami, and 252 of these bridges were damaged or washed away. Bridge characteristics were analyzed as parameters in relation to whether or not each bridge had been washed away.

(3) The analysis was performed using the discrimination formula proposed by Prof. Kosa of the Kyushu Institute of Technology. Tsunami flow velocity is an important parameter, and although the discrimination formula does not provide a high level of accuracy when applied to all bridges, it was still somewhat useful in evaluation, probably because the differences in tsunami flow velocity within a specific watershed are not great.

(4) In certain areas, local residents captured imagery of the tsunami using digital cameras. Analysis of those images revealed changes in tsunami height and changes in tsunami flow velocity as the tsunami was heading inland.

(5) Committee members who specialize the field of coastal engineering performed various hydrological tests to identify the factors related to the washing away of bridge beams, as well as developing simulation techniques.

**Interim reports on the committee's activities were included in the following newsletters.**
**URL: http://www.jsce.or.jp/committee/concrete/e/newsletter/newsletter26/index.html**
**URL: http://www.jsce.or.jp/committee/concrete/e/newsletter/newsletter29/index.html**

## Roundtable discussion

Nagai (Moderator): To begin the program today, I would like to hear from each of you, Prof. Maruyama, Prof. Mizutani, and Prof. Meguro. First, Prof. Maruyama, please give us an overall picture of the committee's activities as well as its future outlook. Next, Prof. Mizutani, please tell us about your views from the standpoint of coastal engineering. Last, Prof. Meguro, please talk about the roles of bridges in disaster prevention and expectations for bridge performance. After that, I would like to move into the discussion.


**Prof. Maruyama**

Maruyama: After the Great East Japan Earthquake, JSCE sent out a survey team, and it became clear that the loss of bridges had been greater than anticipated. JSCE's present Standard Specifications do take the power of water into consideration in terms of hydrostatic pressure and safety factors for coastal structures, but no consideration at all was given to tsunami forces. This committee was formed because of the need to consider changes in the Standard Specifications (Design Code) in light of the fact that so much damage had occurred. We asked researchers in the field of coastal engineering to join the committee, because this task requires their expertise in addition to that of concrete engineers.

First, the committee performed field surveys of bridges. Regardless of whether each bridge had been washed away or not, we surveyed all of the bridges in the inundated region.

We also had help from Prof. Kosa of the Kyushu Institute of Technology, who had surveyed bridge damage due to the Sumatra tsunami. Prof. Kosa did not participate in all of the field surveys, but he found people who had videos of the tsunami and collected a great deal of data.

Prof. Kosa had proposed a determination formula for bridge washout after the Sumatra earthquake, and that formula has now been tested with additional data. Initially, the answers were scattered because there were many assumptions, but the results were consolidated by means of testing and numerical analysis from a coastal engineering perspective. Through these efforts, based on the distance from normal water level, bridge span information, and bridge configuration, it has become possible to determine the approximate force that may be applied, so that this can be used in design.

I anticipate that it will take about two more years of work before we are able to issue guidelines. Therefore, our aim is to have our findings reflected in the Standard Specifications five years from now. Specifically, we intend to provide an indication as to whether bridges will be at risk or expected to survive with some degree of probability when tsunami forces act on them, considering these factors.

The formula needs to be simplified for design purposes, but it should be possible to determine the risk level of existing bridges by using this formula with respect to the types of tsunamis that are predicted to strike the Tokai and Tonankai regions in future. When those risks are understood to some extent, it will be possible to use that information in subsequent evacuation planning and disaster prevention planning. Those are the objectives that we are currently pursuing.

Prof. Mizutani

Mizutani: My area of specialization is coastal engineering. When I joined this committee, I was impressed by its extremely high level of activity. Frankly, I was amazed that such a large number of field surveys could be completed in such a short time.

It has been a very helpful experience for me to participate in research related to bridges in this committee since the earthquake disaster. The committee includes members from different fields than coastal engineering, such as steel structures, urban planning, and management, and this has been an interdisciplinary endeavor with cooperation between coastal engineering and various other fields.

Prof. Meguro

Meguro: Although I am not a member of the committee, I am interested in its activities. I believe Prof. Maruyama raised an important issue at the beginning of this discussion when he mentioned the output, or the question of how the results will be used. Additionally, it may be possible to control the input forces to some extent by making effective use of the knowledge of coastal engineers to find ways to reduce wave height, by means of artificial changes in the seabed topography, for example. There may also be ways to reduce flow velocity. In addition, the issue of floating debris is another factor that has extremely important effects.

I believe that there may be a need for a new approach to the designing of bridges as part of an overall system. At present, the level of importance of a bridge is generally based on its daily traffic volume. However, the importance of a bridge as an evacuation route during emergencies should also be a factor, and this cannot be determined by looking at a bridge in isolation. It is important to realize that there are additional factors that should come into play concerning the importance of a bridge, based on the roles assigned to it in terms of its surrounding environment, and that these factors should be taken into consideration in various ways in the design process. I feel that a clearer picture of the interplay between these types of input and output will emerge in the future.

Nagai: Thank you. Prof. Maruyama, you mentioned that ultimately, it would be desirable for the research findings to be reflected in the design standards. The probability of occurrence of tsunamis is considered to be low in comparison to that of earthquakes, so what sort of approach can be taken for incorporating this into design standards?

Maruyama: That issue has not yet been adequately debated, but I expect that the same approach will be taken as that of earthquake resistance. In earthquake resistant design, two levels of earthquakes are taken into consideration. Loosely speaking, the first stage is based on the type of earthquake that may occur once or twice within a service period of approximately 100 years. The second stage is based on the type of major earthquake that occurs with low frequency, such as once every 1,000 years. The aim is for a bridge to behave elastically during earthquakes of the first stage, and to avoid structural collapse during infrequent earthquakes of the second stage. I expect that tsunami resistant design will also be based on this dual-stage approach, with bridges being designed to suffer practically no damage from tsunamis of a certain level, while accepting that a bridge could be washed away by a tsunami in excess of that level. As Prof. Meguro just mentioned, this should be considered ultimately in the context of urban planning. It will need to be linked to urban disaster prevention planning, such as determining which roads will need to remain intact even if others may be destroyed.

Mizutani: The same kinds of approaches can be applied to tsunamis as well. There is the "hardware" approach of trying to protect not only human lives, but also property, livelihoods, and the economy, while for damage above that level which cannot be prevented by "hardware" alone, there is the "software" approach of disaster mitigation, or trying to find ways to protect human lives as the main priority while also minimizing other losses. The problem is that at the practical level, most of the debate at present is focused on trying to maximize protection by means of "hardware." Basically, the structures of concern have been coastal levees and tide embankments, and the focus of attention at present is on these structures as a means of protecting lives. Meanwhile, there has not been much discussion from the standpoint of disaster mitigation with regard to the bridges that lie inland from those coastal structures.

Nagai: What is the current status of the debate concerning the height of levees?

Mizutani: At present, the national government is conducting studies to determine the target levels of earthquakes and tsunamis to be used, and those numbers should be announced in the near future. Therefore, I believe that more discussion will be needed to determine the level of tsunami that should be actually used as a structural design standard.

Meanwhile, in the Tohoku region, there are some communities that are demanding extremely high levees, while other communities have indicated that such high levees would pose problems. This will require some very difficult decisions. I do not believe that it would be realistic to make uniform, across-the-board decisions, since there could be serious effects on the livelihoods and economic infrastructures of local communities if the opinions of residents are not taken into consideration. To make realistic decisions about infrastructure development, these issues must be considered in combination with evacuation planning.

Another issue is the question of how the region will change in the future. Although the population is shrinking and increasingly elderly, it will be necessary to maintain the structures that are built. There are many areas of uncertainty, including the question of how to address both of these kinds of issues.

Meguro: In perceptions of the numbers announced by academic researchers, there is a wide gap between the way experts and engineers see these statistics and the image taken away by the general public or the mass media. Experts understand that there is a certain range of error in such numbers. It is normal for predictions of tsunami height to be off by ten or twenty percent. However, the general public tends to take these as precise figures when discussing levee height. It is not possible to achieve that level of accuracy when it comes to tsunamis. The differences are even greater in the areas considered by scientists.

It is extremely important to explain this properly and promote understanding. This is an area where science interpreters could play an important role, because when people do not understand this concept, they may decide whether to accept or oppose a proposal based on very small numerical differences. It is difficult to hold a proper discussion when we cannot debate and analyze various factors and announce our findings to the general public without the risk that they will misunderstand them or oppose our findings because of incorrect interpretations of their significance.

Nagai: To return the discussion to technical aspects, I wonder whether the committee has discussed the advisability of anchors to prevent bridges from being washed away, or the relative merits of steel and concrete bridges, in light of factors such as flow velocity.

Mizutani: That has not yet been discussed much. My intuition about making bridges more resistant to tsunamis is that if the beam is not washed away, the piers will be destroyed; and if the piers are strongly reinforced, the foundations will be destroyed. The question is how to achieve the best balance. For example, in the 2011 tsunami, very low, small bridges were not washed away. The reason appears to be that the velocity of the tsunami was not yet very high when its leading edge first arrived, so these bridges remained covered by the waters of the tsunami and were not exposed to the worst of the storm of forces that were going on above them.

I am currently working on distinguishing between bridges having certain characteristics that make them unlikely to be washed away, and bridges in a gray area where the outcome is more uncertain. There are some bridges that could not be expected to survive in the case of a larger tsunami, and if the intention is to protect such bridges, planners could consider whether to raise the height of a bridge or build a bridge further back from the coastline. I want to make it possible to consider such questions as part of the planning process.

Nagai: What are the differences related to failure of a bridge's beam, piers, or foundation?

Mizutani: It is easiest to rebuild if the beam is washed away. Therefore, the proposal has been made that bridges should be built with beams that can easily be washed away. To go into a bit more technical detail, because the flow of water is analogous to the flow of air, in the case of a long bridge, one can take the approach of designing beams that are minimally resistant to the flow. In addition, we have developed some understanding of the mechanism of a tsunami, and it involves a certain amount of lifting force, so it would be possible to take steps such as designing bridges with consideration for such forces as well.

Nagai: Is that now coming to be better understood, based on the results of tests or numerical analyses?

Mizutani: Yes, the role of unidirectional lifting forces appears to be quite large. However, vertical forces can change very subtly between the upward and downward directions, so this is a difficult area. If we can design bridges in such a way that the forces will always act in the direction that we intend, this should lead to promising technical outcomes.

Nagai: Some have put forth the view that bridges should be fixed in place with cables and the like, similar to the means taken to prevent bridges from collapsing during earthquakes.

Maruyama: That is practically useless. The forces are just so extremely large. There were some bridges in our survey where the piers were fractured, and when we investigated later, we learned that those bridges had been firmly held in place with devices intended to prevent bridge collapse. After some bridges had slipped out of place during the earlier earthquake off Miyagi Prefecture, steps were taken to prevent slippage and attach them firmly in place. Because the beams were held so tightly that they could not be washed away, the piers were destroyed. And if the piers are reinforced, the foundations are destroyed. The quickest way to restore a bridge is if the beam is washed away and then replaced. That way, the piers are left undamaged.

Nagai: So far, we have been talking about the resistance of bridges. Prof. Meguro mentioned controlling the input forces by measures such as coastal excavation to regulate the routes for faster flows of water. What are the possibilities there?

Mizutani: I think there are some things that could be done. There are ditches along the coastline in the areas of Sendai, and some believe that these may help to reduce tsunamis. Studies are underway to determine how much they help.

However, because of the great length of a tsunami, I do not think it is realistically possible to actually change the orientation of a tsunami. If at all, I think it would only be possible to control it cross-sectionally by raising or lowering the tsunami in the vertical direction. So I think that the aim will be to reduce the force of a tsunami little by little through changes in its cross section, either by adding another layer of coastal levees or conversely, by excavation under the sea.

Nagai: On a different subject, how are the discussions coming along with engineers on the planning side?

Mizutani: I myself have not been directly involved, but those discussions are necessary because of the need to take a comprehensive approach when considering issues of disaster mitigation. The various types of measures that can be taken for predicted tsunamis include early detection technologies, methods for communicating warnings, means of evacuation, finding the best evacuation routes, and predicting how people will act in a panic situation. Taking an overall view, it should be possible to say which bridges may be destroyed and which ones can be expected to survive. This will make it possible for the people who handle evacuation plans as part of disaster prevention planning to make decisions. I feel that it is important to create a forum for this kind of comprehensive discussion.

Nagai: Prof. Meguro, I believe that you are familiar with evacuation simulations.

Meguro: I have given a great deal of thought to evacuation. For example, some roads will be closed, and it will not be possible to do everything at once because of the limited availability of both time and money, so decisions will have to be made about priorities; and in order to save as many people as possible, judgments will be needed about what to do and in what sequence. That has been the conventional approach for issues related to evacuation. However, although there was time for evacuation in the Great East Japan Earthquake because the epicenter was somewhat distant, the situation will be different in the predicted Nankai Trough earthquake. The first wave is expected to arrive in as little as two minutes after the earthquake in some places, with the largest wave arriving after about 20 minutes in many areas. This would not be enough time for evacuation. The shaking is expected to continue for a long duration of several minutes, and this means that people would need to begin evacuating before the shaking stops. However, that is not feasible. If buildings are damaged, it will take a long time for people to even get out of their houses. Therefore, it is likely that the tsunami will strike while people are still trapped in their houses. These kinds of problems are extremely challenging.

Nagai: One sometimes gets the impression that urban planning can be successful as long as there is adequate information about tsunami predictions and the steps that can be taken, but based on the discussion so far today, there seem to be serious challenges.

Mizutani: I believe that there is an even more important role to be played by the development of legislation than there is for urban planning.

Maruyama: Yes, it is essential to think about these issues with a comprehensive approach, because the government also needs to be involved in decision-making.

Nagai: The scope of our discussion has become very broad indeed. In this context, how far should we as researchers involve ourselves? As we take a broader perspective, considering the involvement of government organizations and community members, what should be the scope of involvement by scientists and academic societies? What are your views on the role to be played by researchers?

Meguro: I believe that our role is to provide the people who make the decisions with information that is as accurate as possible. The most important thing is not so much to achieve numerical accuracy as it is to accurately communicate the meaning of that information. If this is not done well, the people in charge will not be able to make appropriate decisions, no matter how much decision-making authority they may have. I feel that this kind of mismatch is a serious problem in many areas.

Nagai: Thank you all. To conclude, I would like to ask for a comment from each of you.

Maruyama: It would be a good idea to hold this kind of discussion periodically. This would be an opportunity to discuss the current level of capabilities based on technological advances at each stage, or to propose contributions that could be made by engineers and researchers in specific fields. I believe that one of the roles of a society like JSCE could be to provide venues that bring people together from a variety of fields to combine their areas of expertise and exchange views. Although there is value in pursuing a high level of specialization, that alone is not enough.

Mizutani: The approach to designing coastal structures such as levees has not involved the concepts of elasticity or plasticity in relation to failure control, unlike the approach taken in designing above-ground structures; so I think it will be a major challenge to find ways to control the transition from the region of elasticity to structural failure. It will be difficult to adopt the dual-stage approach for design standards, as discussed earlier, unless this is done. This is not an approach that has been commonly used in the field of coastal engineering, but I feel that it will be necessary to take this into consideration in future.

Meguro: I think that our work will be accepted and understood if we take care to clarify just how it can ultimately benefit society. More attention needs to be paid to the importance of interpreting and communicating knowledge in our respective areas to the general public in a way that is both accurate and understandable. There are many different ways to communicate the same facts, and I feel strongly that this could really make a difference.