DEVELOPMENT OF PROBABILISTIC METHODOLOGY FOR EVALUATING TSUNAMI RISK ON NUCLEAR POWER PLANTS

H. Sugino[1], Y. Iwabuchi[1], M. Nishio[2], H. Tsutsumi[1], M. Sakagami[1] and K. Ebisawa[1]

[1] *Seismic Safety Division, Japan Nuclear Safety organization (JNES), Tokyo, Japan*
[2] *Safety Analysis and Evaluation Division, Japan Nuclear Safety organization (JNES), Tokyo, Japan*
Email: sugino-hideharu@jnes.go.jp

ABSTRACT :

Since nuclear power plants in Japan are located on the seashore, it is also required to ensure sufficient safety against tsunamis and high tidal waves. The Examination Guide for Seismic Design of Nuclear Power Reactor Facilities revised by the Nuclear Safety Commission in 2006 refers to safety consideration of tsunamis and landslide of slopes around site as accompanying phenomena of earthquake as well as residual risks of earthquakes. JNES has been developing the methods for probabilistic safety assessment for tsunami events (tsunami PSA), in order to quantitatively evaluate the safety level of nuclear power plants against tsunamis. The tsunami PSA consists of 4 components, schematic analyses of accident scenario, tsunami hazard evaluation, tsunami fragility evaluation and accident sequential analysis. In this paper, outline of tsunami PSA and tsunami hazard and fragility evaluation applying numerical tsunami simulation are described.

KEYWORDS: tsunami, nuclear power plant, probabilistic safety assessment, hazard assessment, fragility assessment, accident scenario evaluation

1. INTRODUCTION

The locations of our nuclear power plants and tsunamis occurred in the history are shown in figure 1[1]. All the nuclear power plants in Japan are located on the seashore, and most of them have possibilities attacked by tsunamis. It is also required to ensure sufficient safety against tsunamis and high tidal waves. The Examination Guide for Seismic Design of Nuclear Power Reactor Facilities[2] revised by the Nuclear Safety Commission in 2006 refers to safety consideration of tsunamis and landslide of slopes around site as accompanying phenomena of earthquake as well as residual risks of earthquakes.
By the way, there are existing uncertainties of tsunamis occurrence as natural events. Considering these uncertainties, we cannot describe that there is no possibility that the coming tsunami will not exceed the standard tsunami used in designing. Therefore, it is necessary to evaluate the effect of tsunamis on safety of facilities and provide feedback information to designing.
JNES has been developing the methods for probabilistic safety assessment for tsunami events (tsunami PSA) [3]-[6], in order to quantitatively evaluate the safety level of nuclear power plants against tsunamis.

2. OUTLINE OF TSUNAMI PSA METHOD

Figure 2 shows the possibilities of accident that can be occur at the nuclear power plant by tsunami attacks. Seawater intake facility, water storage facility, power transformer and oil tanks will take the severe damage from the tsunami attack. The seawater intake system will be malfunction when the seawater pump is submerged or seawater level is drawn back by tsunami. And those outdoor facilities, for example, power transformer and oil tank can be submerged in seawater and cause the loss of safety functions.
These effects from tsunami on nuclear facilities are evaluated by the conventional deterministic approach as follows. Figure 3 shows the evaluation of effects from tsunami.
Firstly, Tsunami analysis is performed using tsunami sources model and topographical data, and the tsunami height and duration on site shore line are calculated. Next, the run-up simulation is performed, and the inundation area, water level, wave force and sand deposition area are calculated. Based on these results, the damage level of the facilities located at indoor or outdoor can be judged. When these facilities will be damaged,

an evaluation for accident scenario including safety function loss based on the cause of damage will be made. It is possible that the facilities damaged by earthquake will consequently be damaged by tsunami attack. However, now the damages are focused by only tsunami attack.
The tsunami PSA (Probabilistic Safety Assessment) is a method to quantitatively evaluate the probability on safety function loss and core damage by considering the uncertainties on tsunami occurrence (location and frequency), wave propagation and effects on NPP facilities. These various uncertainties are expressed in probability models.
Figure 4 shows the flowchart of tsunami PSA method. The tsunami PSA consists of 4 components, schematic analysis of accident scenario, tsunami hazard evaluation, tsunami fragility evaluation and accident sequential analysis. Schematic analysis of accident scenario is responsible to evaluate the strength of nuclear power plant facilities against the tsunami. Tsunami hazard evaluation is responsible to evaluate the relationship between wave height and occurrence probability at the plant site. Tsunami fragility evaluation is responsible to evaluate the relationship between wave height and probability of functions loss due to tsunami run-up analysis. Accident sequential analysis is responsible to evaluate the damage probability of the reactor core from modeling of accident sequences using events tree and fault tree based on the results from previous components.

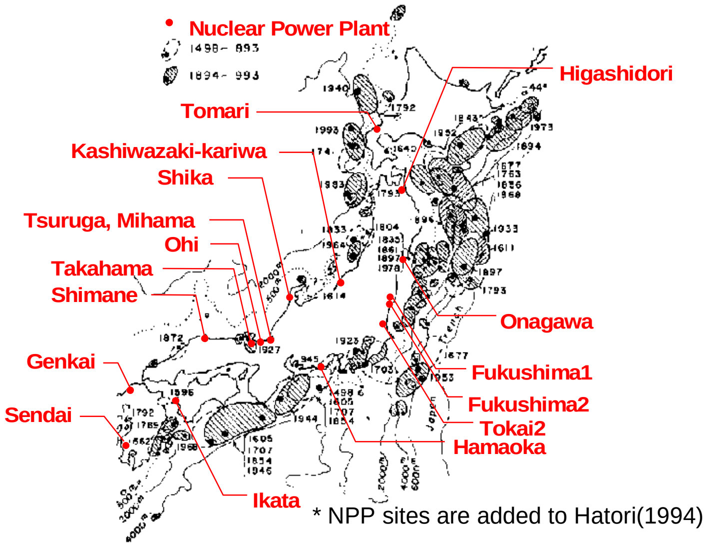


Figure 1 Location of nuclear power plants and tsunami sources in Japan

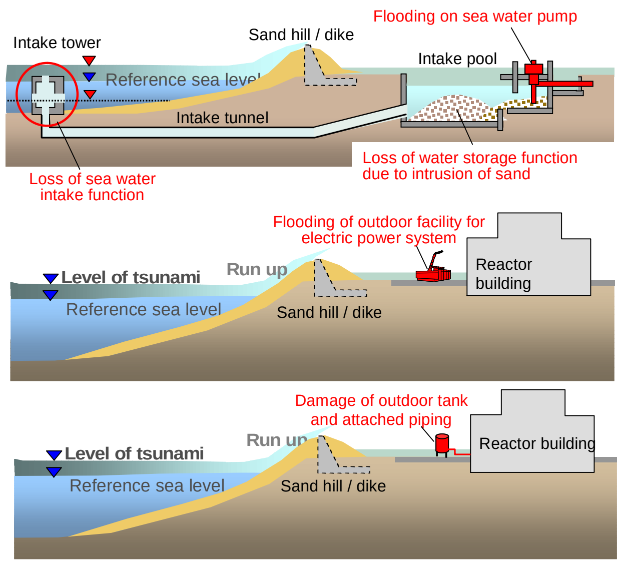


Figure 2 Possibilities of accident at the nuclear power plant by tsunami attacks

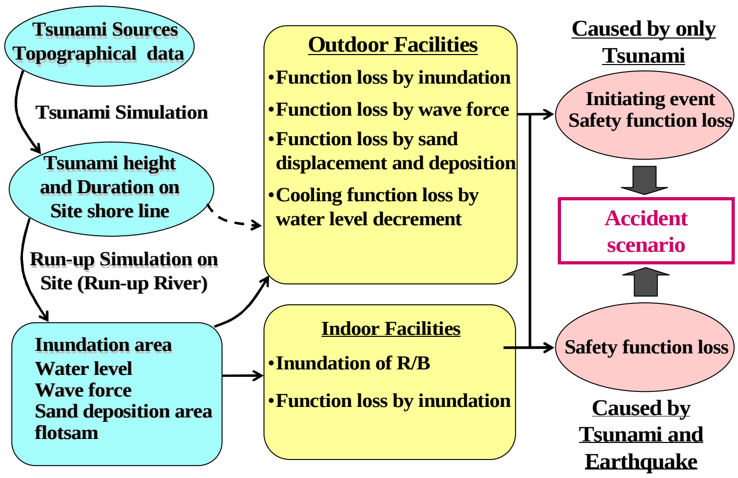


Figure 3 Effects of tsunami on nuclear facilities

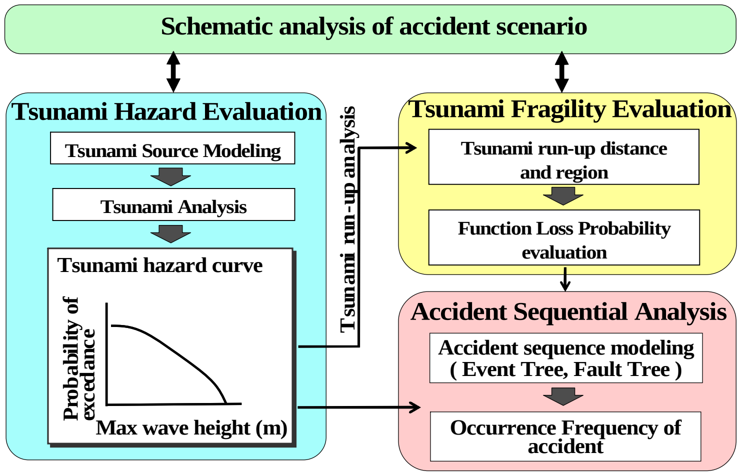


Figure 4 Flowchart of Tsunami PSA method

3. SCHEMATIC ANALYSIS OF ACCIDENT SCENARIO

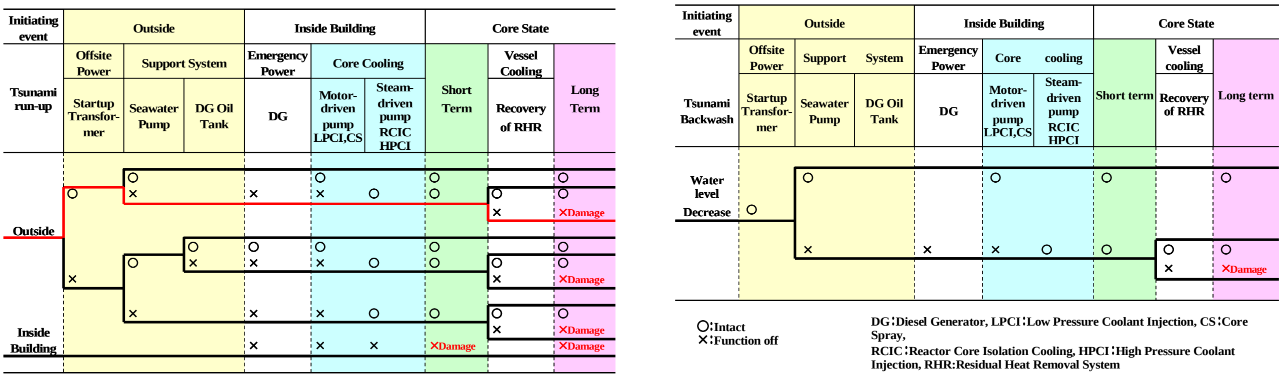
The damage modes of nuclear facilities due to Tsunami are described in section 2.1. The tsunami effects are divided into 2 scenarios, 1) tsunami run-up and 2) backwash.

When the tsunami run-up, inundation of primary outdoor facilities in seawater are considered. For example, the loss of cooling function due to inundation of seawater pump, loss of offsite power due to inundation of power supply system, loss of function of emergency diesel generator due to inundation of oil tank.

On the other hand, when the backwash occurred by tsunami, seawater level decrease below the minimum pump-able level in the storage pit, and the cooling system loss its function.

Figure 5 shows the guideline for accident scenario in NPP system. Plant type is BWR. Left figure is in case of tsunami run-up and right one is in case of backwash. For example, when the outdoor facility is submerged in water causing seawater pumping function loss, RCIC and HPCI are able to provide cooling function to the reactor core temporarily so that the reactor core will not suddenly break down. However, if the pumping system is not recovered for long period, the reactor core will get damage. Such kind of logical sequence is shown in figure 5-1). In case if water drawn back causing water level decrease, similar logic sequence can be expressed as in figure 5-2).

If the mitigation system cannot be recovered within a short time, the reactor core will get damaged. Approximate time from system malfunction until core damage is calculated in this case. As a result, this time is about 100 minutes.



1) In case of tsunami run-up 2) In case of tsunami backwash

Figure 5 Accident scenario in NPP system

4. TSUNAMI HAZARD EVALUATION METHOD

The flowchart of tsunami hazard evaluation method is shown in figure 6. Earthquakes which may cause a tsunami are selected from the earthquakes relevant to the past tsunami records around the sites and ocean-trench earthquakes to determine their occurrence frequencies. The earthquake source faults and their fracture scenarios are examined for the selected earthquakes to establish a fault displacement model as the tsunami wave source. Tsunami analysis is performed with the fault displacement model to calculate time variation tsunami wave height (run-up and backwash) around the objective site. The relation between the maximum wave height and occurrence frequency is obtained for each of the tsunami scenarios (represented by logic trees) and a tsunami-hazard curve is generated by combining the relations.

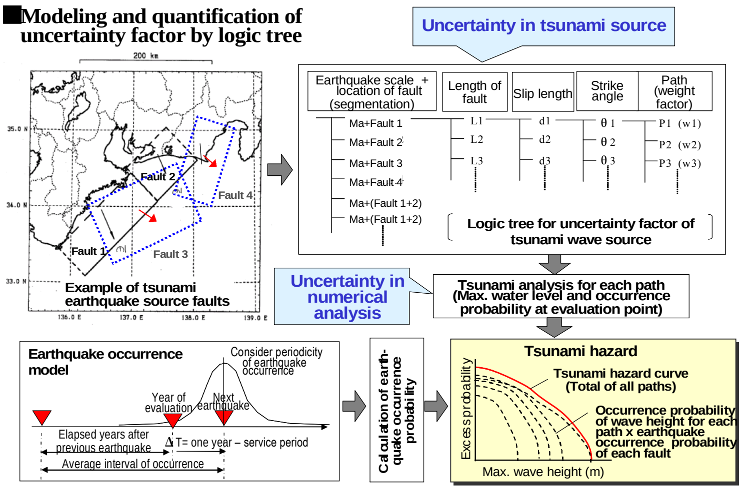


Figure 6 Flowchart of tsunami hazard evaluation method

5. TSUNAMI FRAGILITY EVALUATION METHOD

Run-up analysis is performed for each tsunami wave height to calculate the probability distribution of flooding area and flooding water level at each facility location, taking account of the uncertainty of analytic models and the water level variation due to tide level, wind and waves. From this analysis, the probability that flooding water level exceeds the facility height (loss-of-function probability) is computed. Analysis of wave force and migration of earth and sand during run-up is also performed to examine the impacts on facilities (possibility of functional loss).

Table 1 shows the corresponding facilities, damage mode, threshold value and evaluation index according to

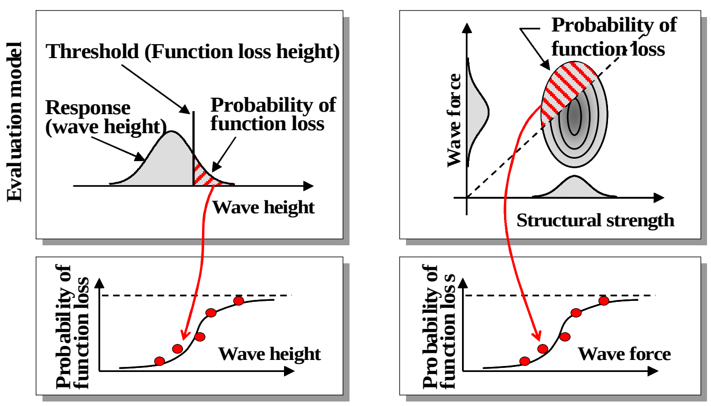
the tsunami PSA method. For the outdoor facilities, seawater intake system and power transmission system are considered. For the indoor facilities, cooling system is considered. Damage modes for each facility are described previously. Threshold and evaluation index are arranged based on each damage mode. There existing other damage modes by wave force (attack) and sand displacement, but most of the facilities are damaged by inundation.
Next, figure 7 shows the evaluation method for the tsunami fragility curve. These are 2 examples of damage of damage mode by inundation and by wave force. In the case of inundation damage mode, variation in tsunami intensities is very small compared to that of the tsunami wave height. From this reason, the probability of function loss is calculated as shown in the figure 7-1). On the other hands, in the case of wave force damage mode, the probability of function loss is calculated while considering variations of structural strength as shown in the figure 7-2). In the seismic PSA method, all facilities are corresponding to this mode. When the tsunami PSA is compared with the seismic PSA, difference points are as follows.

- Number of facilities to be considered is very few.
- Most of the facilities are damaged by inundation. Therefore, a simple model to evaluate the tsunami fragility is used.

Next, the relationship with tsunami hazard evaluation is shown in figure 8. It is efficient to evaluate the whole site by only one hazard curve. Therefore, the wall is assumed at the coastal line as the boundary condition for tsunami analysis. On the other hands, it is necessary to evaluate the fragility curve for each facility location, and it needs to calculate the run-up height at the objective facility location from the tsunami run-up analysis by assuming the virtual tsunami. Also it is necessary to perform the tsunami analysis to obtain the maximum wave height at the prescribed boundary conditions against the virtual tsunami. These are the proposal methodology for obtaining the tsunami fragility curves.

Table 1 Facilities and damage modes

Facilities		Damage mode	Threshold	Evaluation index
Out-door	Seawater intake system	Function loss by seawater pump inundation	Located height	Wave height
		Damage of intake structure by wave force or flotsam	Structural strength	Wave force
		Loss of cooling water by backwash	Core cooling time	Duration of water level decrease
		Closed intake by sand moving	Intake height	Sand deposition height
	Transmission system	Loss of transmission function by inundation	Located height	Wave height
In-door	Core cooling system	Loss of core cooling function and heat removal function by building inundation	Opening height of building	Wave height



1) Inundation damage mode 2) Wave force damage mode
Figure 7 Evaluation method for tsunami fragility curve

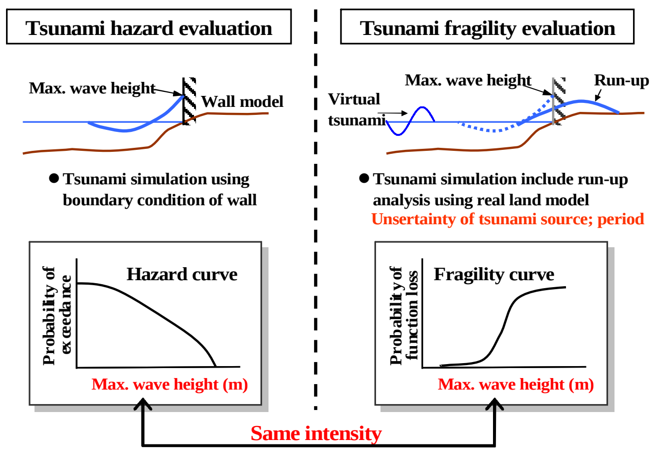


Figure 8 Relationship with tsunami hazard curve

The flowchart to evaluate the tsunami fragility curve is shown in figure 9. First of all, the objective facility and virtual tsunami that have wave amplitude and period as variables are set. Next, tsunami analysis is performed using these data and the maximum wave height along the shoreline of the site is calculated. Next, run-up analysis using the same virtual tsunami is performed to obtain run-up height at the objective location. The calculation for all virtual tsunami is repeated and the result is represented as in this graph (Fig. 9). The analytical result is represented as the relationship between the maximum wave height along the shoreline and the run-up height at the objective location. Since the result is given as various data, it is necessary to find average by curve fitting. The fragility curve can be plotted from the probability portions that exceed the function loss height.
The example of calculation of the tsunami fragility curve is described. The virtual NPP site and analysis conditions are shown in figure 10. The site location is assumed at the Japan costal line along the pacific ocean. This figure shows the area to perform tsunami analysis. Virtual tsunami is inputted from the bottom line. The shape of the virtual tsunami is assumed to be a one-period sine curve as shown in this figure. Amplitude of 0.8m to 1.5m with 0.1m interval is assumed and periods are from 5minutes to 60minutes.
The analytical result from the run-up tsunami analysis is shown in figure 11. It shows the relationship between the maximum wave height and run-up distance from shoreline. As the maximum wave height become larger the run-up distance increases. These circles show the inundation area. Next figure 12 shows the run-up height at the location of 600m distance from shore line and a calculation example of fragility curve. The reactor building location is assumed at 600m away from shore line. And the function loss limit height is set TP+4.5m. From the data variation between the average curve and analytical results, the fragility curve is plotted by assuming the probability distribution.

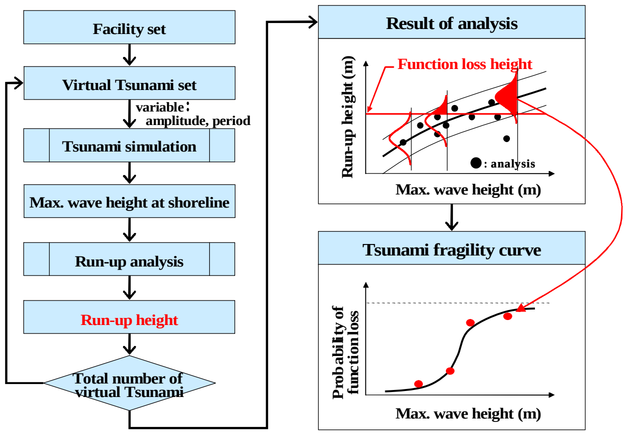


Figure 9 Flowchart to evaluate the tsunami fragility curve

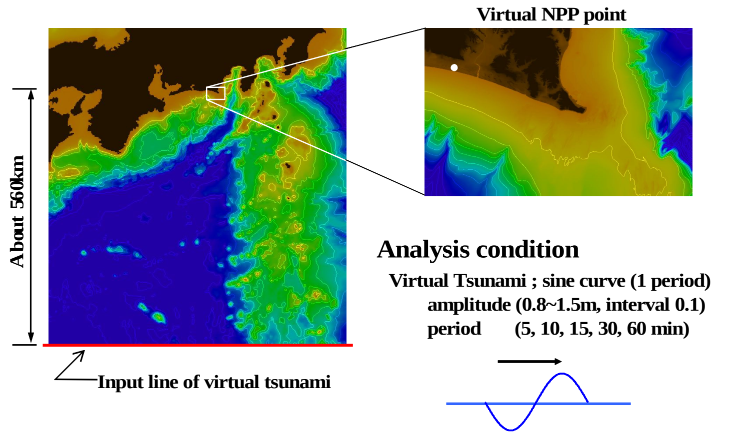


Figure 10 Virtual NPP site and analysis conditions

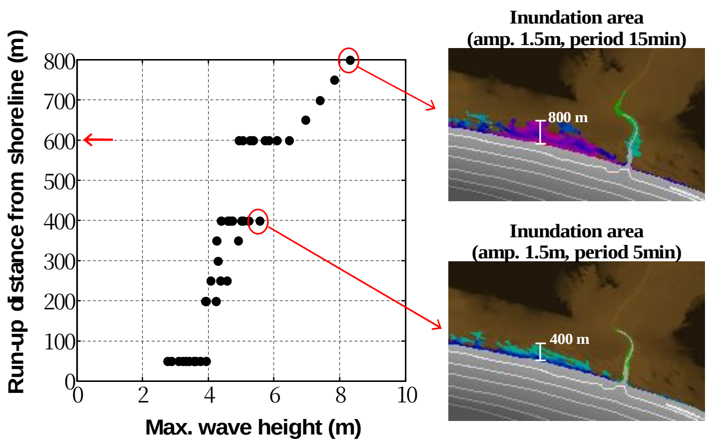


Figure 11 Analytical results from the run-up tsunami analysis

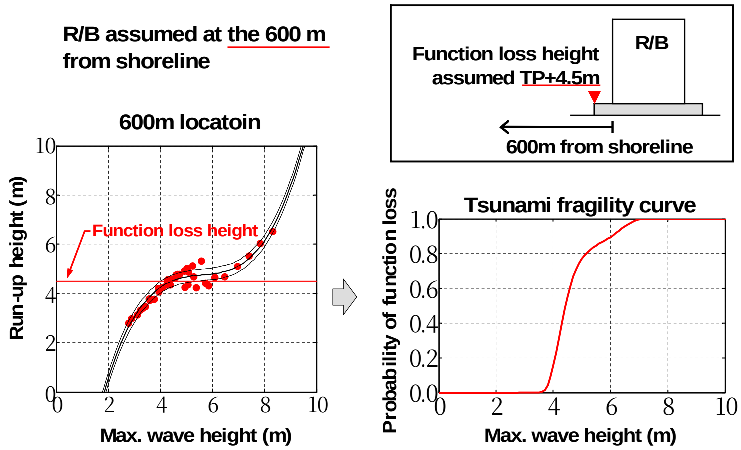


Figure 12 the run-up height at the location of 600m distance from shore line
and calculation example of fragility curve

6. CONCLUSION

Outline of the tsunami PSA method were described. And the tsunami fragility evaluation method using tsunami analysis is proposed as one of the components of the tsunami PSA method. According to this proposal method, it is estimated a fragility curve as hazard curve with a common index, maximum wave height along the shore line. Also, the topography effect of site original can be considered in the fragility evaluation method and hazard evaluation method. And, the tsunami PSA method is very simple in comparison with seismic PSA considering few facility and most of facilities damaged by inundation.
In future, accident sequential analysis method will be developed, and tsunami PSA method will be applied to a real plant.

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