Study on Quantification Methodology of accident sequences for Tsunami Induced by Seismic Events

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ABSTRACT

On 11 March 2011, Great East Japan Earthquake brought loss of all AC power and final heat sink of Fukushima Daiichi nuclear power plant unit 1, 2 and 3.Since AC power could not restored, unit 1, 2 and 3 led to core damage, core melt and release of radioactive material. According to this severe accident of NPPs, it is considered that risk assessment of earthquake and tsunami is the urgent issue. The purpose of this study is to develop PRA methodology for simultaneous occurrence of earthquake and tsunami, and to contribute to safety enhancement of nuclear-related facilities from the insights derived from such PRA.

Keyword: *PRA, Tsunami Induced by Seismic Events, Core Damage Frequency, Monte Carlo Simulation, DQFM Methodology.*

I. BACKGROUND

On 11 March 2011, Great West Japan Earthquake brought loss of all AC power and final heat sink of Fukushima Daiichi nuclear power plant unit 1, 2, and 3. Since AC power could not restored, unit 1, 2 and 3 led to core damage, core melt and release of radioactive material. According to this severe accident of NPPs, it is considered that risk assessment of earthquake and tsunami is the urgent issue. Some of tsunami PRA have been disclosed or reported by several organizations so far, however, any tsunami PRA considering simultaneous damage caused by earthquake and tsunami are not disclosed or reported.

This study aims to develop the quantification methodology of accident sequences for tsunami Induced by seismic events using DQFM (Direct Quantification of Fault Tree using Monte Carlo simulation) methodology developed by Japan Atomic Energy Agency. Then assuming a simple nuclear power plant model and fragilities of components which consists of simple plant model, trial analyses will be conducted to verify the developed methodology. Because there are not sufficient disclosed data regarding to tsunami induced by earthquake, composite hazard are not considered in this study, however, quantification methodology for conditional core damage probability will be presented and this means core damage frequency could be calculated by obtaining the composite tsunami and seismic hazard.

II. METHODOLOGY

This Study methodology is consisted of following steps;

1. To consider the combination of discrete tsunami heights and seismic ground motion levels.
2. To calculate composite seismic and tsunami hazard by calculating excess occurrence frequencies of all combinations of earthquake and tsunami. (However, as described above, composite hazard are not considered in calculating CDF in this study.)
3. For each combination of seismic levels and tsunami heights, to calculate conditional core damage probability based on fragilities in viewpoints of seismic and tsunami impacts by DQFM methodology. (The calculation flow chart is shown in Fig. 1)
4. To calculate core damage frequency by multiplying for each combination, then to integrate by all rage of seismic levels and tsunami heights to calculate total CDF.

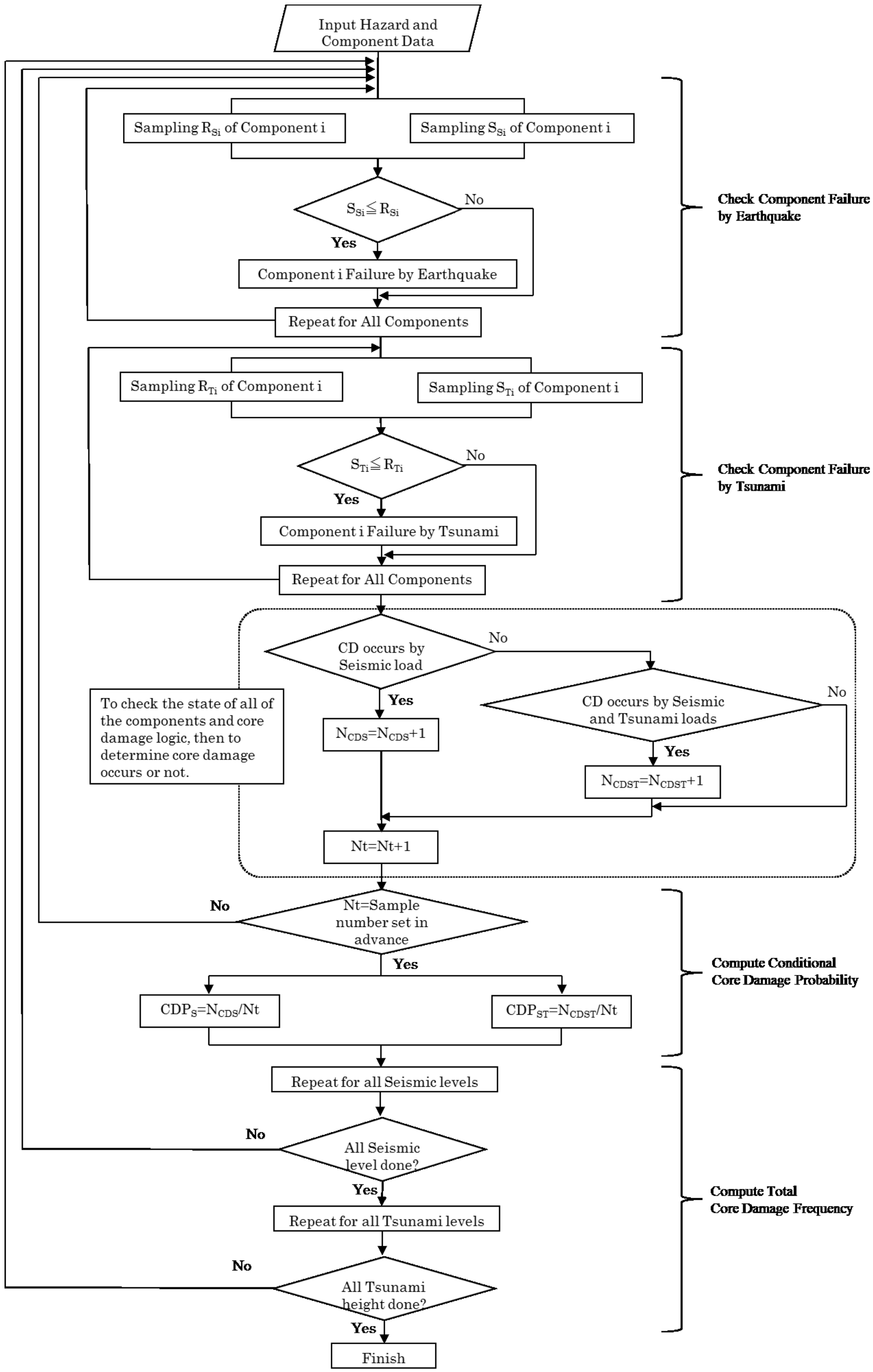

Fig.1 Calculation flowchart to Obtain Conditional Core Damage Probability

II.A. Composite Hazard Assessment in Consideration of Ground Motion and Tsunami Height

Usually, integrated tsunami and seismic hazard evaluation is considered in a way that tsunami hazard occurrence frequency are distributed in each ground motion level of seismic hazard occurrence frequency. This image is shown in Fig. 2. However, there is little disclosed tsunami and seismic hazard data in particular site. So in this study, hypothetical combinations of ground motion level and the tsunami height were considered but excess occurrence frequency of each composite hazard won't be assumed. Then, the combination h(a4, t4) was set as an example and conditional core damage frequency was calculated for this.

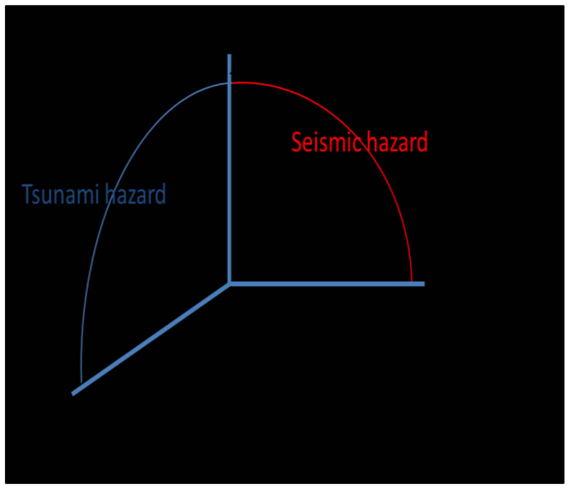

Fig.2 Image of integration hazard assessment

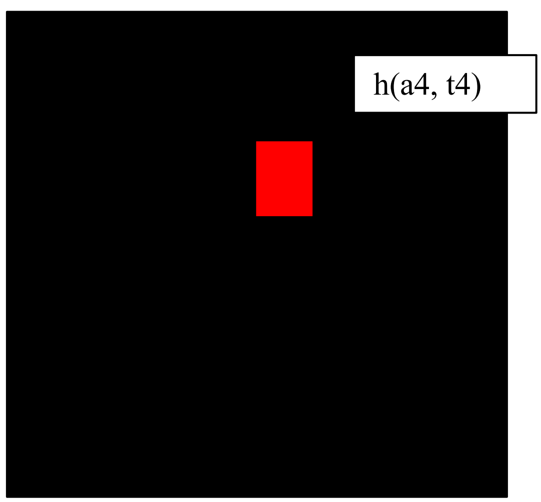

Fig.3 Image of Composite Occurrence Frequency of Seismic and Tsunami

II.B. Calculation of Conditional Core Damage Probability

Calculation steps of conditional core damage probability are followings;

1) Determine State of All Components (Failure or Normal) by using DQFM methodology
   First, strength Ss and realistic response value Rs of each component will be sampled based on median value and uncertainty that was given by the strength and realistic response of each component.
   Then components are broken if Rs> Cs.

This process will be repeated for all components of the model plant.
For tsunami, same as seismic, strength St and realistic response value Rt of each component will be based on sampled median value and uncertainty that was given to the strength and realistic response of each component.
Then components are broken if Rt> Ct.
This process will be repeated for all components of the model plant.

2) Discriminate whether combination of damaged components led to core damage or not
Based on the results calculated in step 1), a combination of broken equipment is judged whether has led to core damage. These are determined by MCS of model plant.

3) Count the number of sequences led to core damage
Step 1) and 2) are repeated by number of attempts of the Monte Carlo calculation.
Then, the number of sequences led to core damage will be counted.

4) Calculation of conditional core damage probability
Conditional core damage probability (CDP) is calculated as shown in Eq. (1).

Core damage probability (CDP) = core damage of number of samples / total number of samples **(1)**

Steps 1) to 4) are repeated for each combination of ground motion level and the tsunami height.

II.C. Calculate Core Damage Frequency (CDF)

Multiplying occurrence frequency and CDP in each cell, CDF can be obtained. At last, total core damage frequency can be determined by sum of all of CDF.

Core Damage Frequency (CDF) = CDP × Occurrence frequency of earthquake and tsunami **(2)**

III. ANALYSIS CONDITIONS

III.A. MODEL PLANT DESCRIPTION

The model plant in this study is shown Fig.4. Still, total amount of inundation to nuclear plant is considered that tsunami height is equal to Installation height. And if tsunami height exceeds installation height of components, failure probability is 1.0. The image is shown in Fig.5. Based on the above, embodying the analysis method according to the following process, carry out the trial analysis.

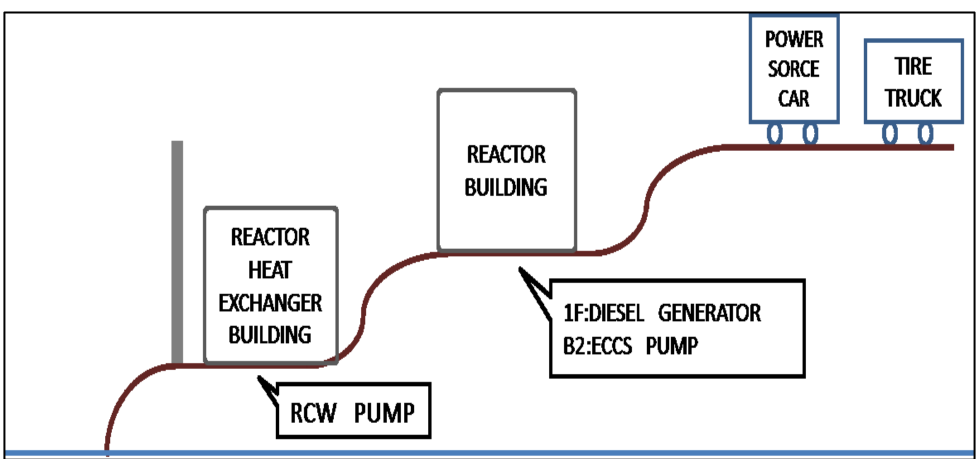

Fig.4. Overview of Model Plant

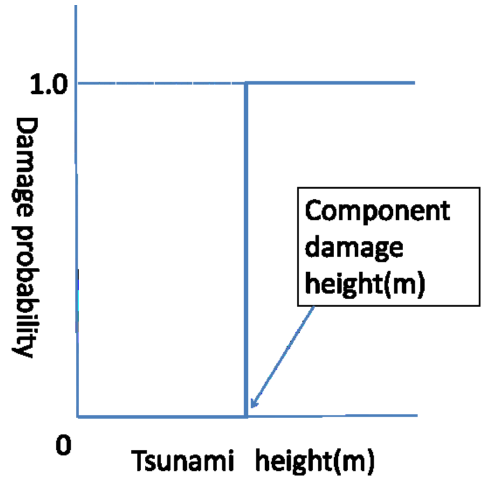

Fig.5. Fragility curve of components by tsunami

III.B. ANALYSIS CODE: SECOM2-DQFM

In this study, SECOM2-DQFM is used for analysis that has been developed for system reliability assessment for the seismic event. SECOM2-DQFM code system consists of 14 elements of code that has been developed in Fortran90 basis. In SECOM2-DQFM, the realistic response of equipment that can be obtained in response analysis, and capacity of equipment obtained by the capacity analysis and conditional damage probability of equipment of ground motion each levels are calculated. Core damage probability (Core Damage Probability: CDP) will be calculated for each seismic level because core damage becomes a top event of fault tree (Fault Tree: FT). Moreover calculating CDF (Core Damage Frequency: CDF) combined the results and seismic risk obtained in seismic hazard assessment. Other, importance ratings and uncertainty analysis as applied as applied functions, it is possible to evaluate in consideration of correlation.

III.C. CORE DAMAGE SCENARIO

FT of a modelplant is shown Fig.6 in this study. It derive Minimal Cut Set (Minimal Cut Set: MCS) from the FT, One by one the number of trials by the Monte Carlo method is discriminated whether has led to core damage or not. In addition, by discriminated the accident sequence leading to core damage in scenario of 3 patterns, calculate the contribution ratio of each accident scenario.

a) Core damage caused by broken components by earthquake.
b) Core damage caused by broken components by tsunami.
c) Core damage caused by influence of both earthquake and tsunami.

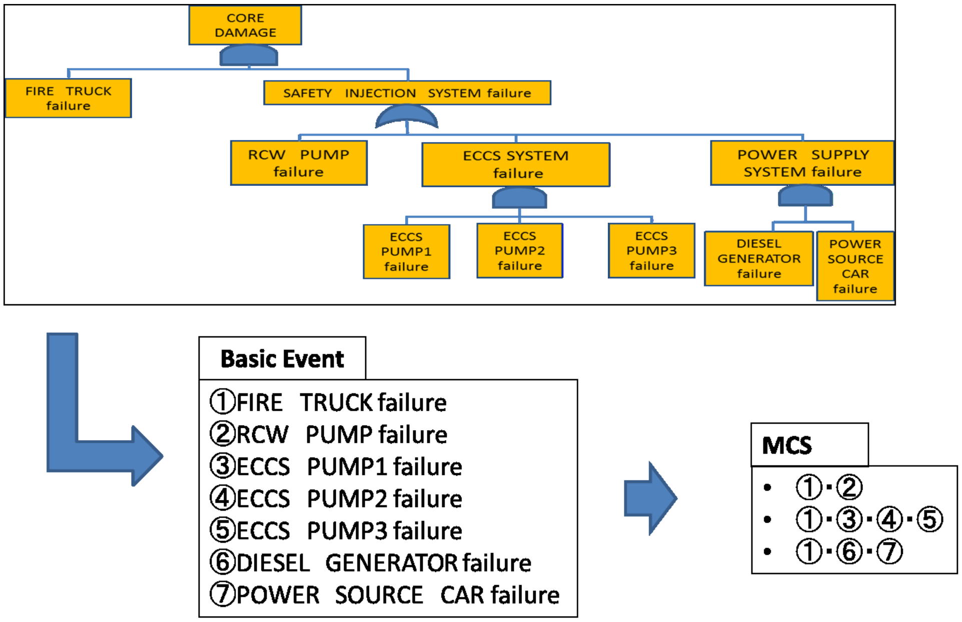

Fig.6. FT and MCS of a modelplant in this study.

As an example from the MCS (1), (6) and (7) of model plant is shown in Fig. 7.

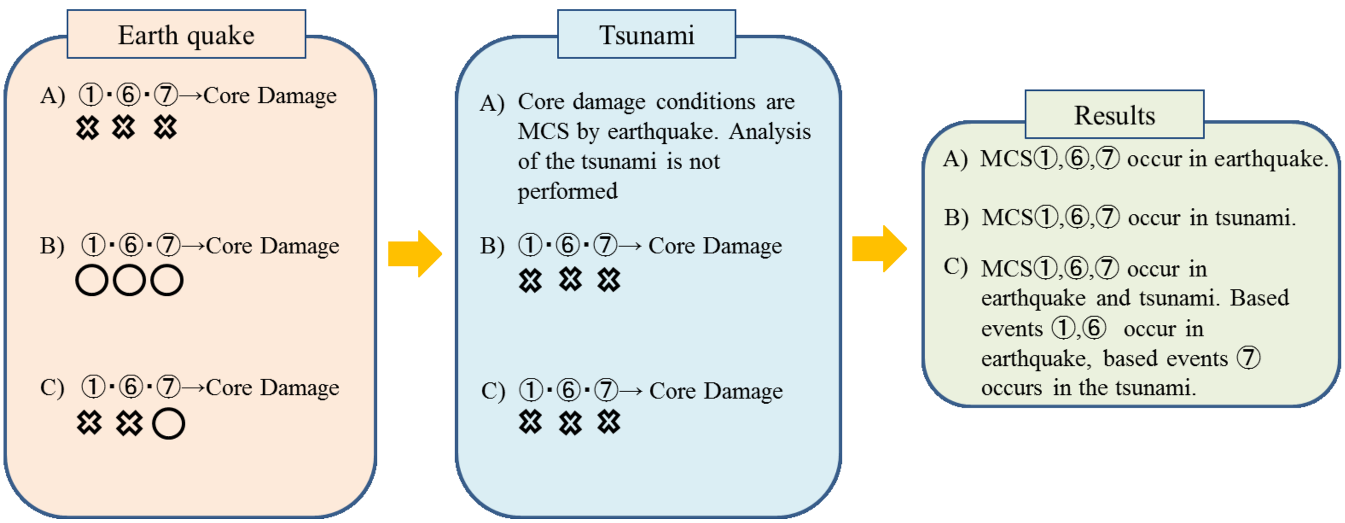

Fig.7. example from the MCS (1), (6) and (7) of model plant

III.D. FRAGILITY ASSUMPTION

Strength data of components are referring to the published data of Kashiwazaki-Kariwa Nuclear Power Station No. 6 and No. 7 reactor, Probabilistic risk assessment .Both of the earthquake and tsunami. Also Accident scenario is set for each tsunami height about the tsunami.

Table 1 Classification of Tsunami Scenarios

Tsunami height	Scenario pattern	Breaked components	Overview of scenario
4.2≦X＜4.8m	Loss of ultimate heat sink	RCW PUMP and ECCS PUMP	Through the manhole of site from the water intake, it flooded on the underground first floor of the turbine building.
4.8≦X＜15m	Station black out	Emergency METAL-CLAD	Emergency metal-clad is submerged by the tsunami height 4.8m. It leading to the total loss of AC power supply.
15m≦X	Loss of function of fire truck and power supply car	Fire Truck and Power Supply Car	Site is submerged by tsunami that is higher than levee. It lead to loss of function of the fire truck and power supply car.

IV.RESULTS OF TRIAL ANALYSES

IV.A. The analysis results of core damage probability.

As described above, conditional core damage probability will be analyzed for particular composite hazard. Therefore, ground motion level was assumed as 1000gal, and tsunami height caused by the earthquake was assumed as 4.5m. Based on these conditions, conditional core damage probability became 3.3E-01(/RY). Contribution ratio of each initiating event leading to core damage is shown in FIG.8.

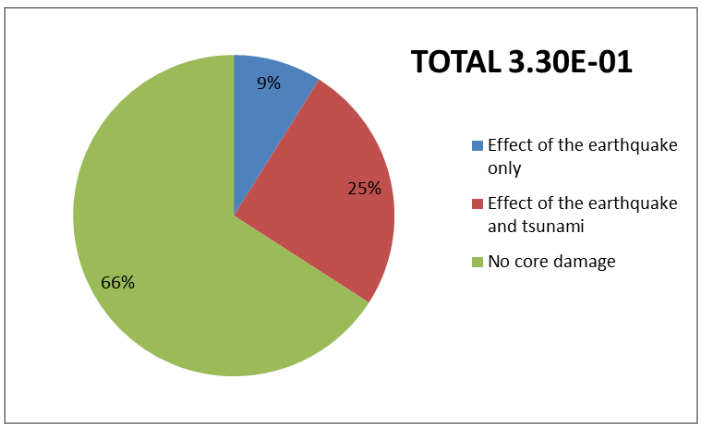

Fig.8. Conditional Core Damage Probability and Contribution Percentage of each Initiating Event

Fig.8 shows that reactor core damage due to only the influence of the earthquake is 9%. Core damage due to the effects of the earthquake and tsunami is 25%. The probability that does not lead to core damage became 66%. The low contribution rate of core damage caused by the earthquake is considered to be for resistance against the high earthquake of equipment related to core damage. This time, core damage sequence is not present due to the effect of the tsunami. Because In tsunami of 4.5m do not lead to damage of the fire truck. That does not meet the MCS of the conditions of Fig.8.
Then graph of the contribution percentage of each accident sequence is shown in Fig 9. Further, description of the accident sequence in FIG.9 are shown in Table 2.

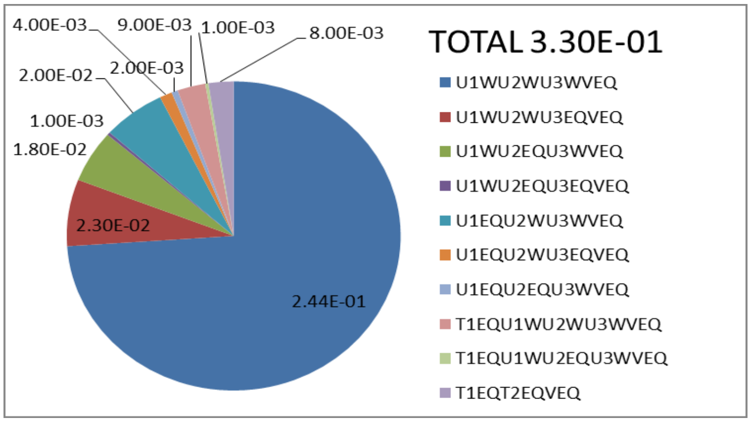

Fig.9 Contribution Percentage of each accident sequence

Table 3. Chart of based on events symbol and basic event name

Based on events symbol	Based on event name
T1EQ	DIESEL GENERATOR operating failure by earthquake.
T1W	DIESEL GENERATOR operating failure by tsunami.
T2EQ	POWER SORCE CAR operating failure by earthquake.
T2W	POWER SORCE CAR operating failure by tsunami.
U1EQ	ECCS PUMP1 operating failure by earthquake.
U1W	ECCS PUMP1 operating failure by tsunami.
U2EQ	ECCS PUMP2 operating failure by earthquake.
U2W	ECCS PUMP2 operating failure by tsunami.
U3EQ	ECCS PUMP3 operating failure by earthquake.
U3W	ECCS PUMP3 operating failure by tsunami.
WEQ	RCW PUMP operating failure by earthquake.
WW	RCW PUMP operating failure by tsunami.
VEQ	FIRE TRUCK operating failure by earthquake.
VW	FIRE TRUCK operating failure by tsunami.

From Fig.9, U1WU2WU3WVEQ sequence accounted for about 75 percent. It is considered to be strength of earthquake of ECCS is high and all of ECCS is loss of function by loss of final heat sink.

V.CONCLUTION

As follows, this study could explain the accident sequences evaluation method of seismic accompanying tsunami event using DQFM method logically. As findings from the study of this stage, seismic accompanying tsunami event found to increase possibility that lead to core damage compared with only seismic event. Further, it was found that the risk that threatens the safety of nuclear power plants in tsunami of 4m class is sufficient. Especially, island country like Japan is considered to require urgent measures of the tsunami. In this study, it is assumed that accidents only when the equipment has been flooded by the tsunami. Therefore, when consider such as core damage because of collision of flotsam or human operating mistake, it is believed to lead to further improvement of the risk. Future topics are to verify of validity of this analysis technique and perform an analysis that assumes various hazards. Ultimately, it is required to calculate the CDF using detailed hazard data.

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