Way for establishing Tsunami resistant technology for Nuclear Facility in Japan

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Contents

1. Background

2. Proposal of "Tsunami Resistant Technology" (Fragility enhancement of SCC)
   - Concept of tsunami risk
   - Load effects of tsunami
   - Tsunami resistant technology

3. Development of technical guideline for tsunami

4. Summary
1. Background

(Effect of the 3.11 2011 Tohoku earthquake M9.0)

-The ground motions were generally within the range of the design basis for ground motions based on the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities (NSC, 2006). Some records exceeded design basis, but not very serious from a general earthquake engineering point of view.

-However, tsunami height exceeded the range of design basis seriously and caused serious damages.
  (Loss of power and cooling function, sea water pumps, electrical panels, finally cause radioactive accident. )

One of the key technical issues from 3.11 2011 Tohoku earthquake is to develop “Tsunami resistant technology” for nuclear facility and concrete design/review guideline for tsunami safety.
2. Proposal of "Tsunami Resistant Technology"

(1) Concept of tsunami risk

In the case of tsunami, if the tsunamis exceeded the design level, many devices possibility lost their functions suddenly. (ex: electric devices, etc.)

In this case, fragility function is nearly step functions (called cliff-edge effects).

And the residual tsunami risk in the beyond-design hazard levels becomes discontinuously too large.
（2）Load effects of tsunami

To improve the fragility, various types of load effects of tsunami should be considered and the appropriate design methods depending on the types of load effects should be adopted.

【types of load effects】

○ Inundation height
○ Seawater intrusion through unanticipated paths
○ Hydrodynamic forces
○ Scouring
○ Uplift
○ Sea sand immixed in seawater
Inundation height

In Fukushima I NPP, inundation was the primary cause of triggering the severe accident sequence.

Seawater intrusion

Water creeps in anywhere if it has pressure head and accessible intrusion paths.

In Onagawa NPP, the basement of the RB was partially inundated by seawater that intruded through seawater intake tunnel - pump pit - trenches (pipe ducts)
Hydrodynamic forces should be a key factor for nuclear facilities that directly face tsunami front.

Bent steel pillars (Onagawa)

Sea wall gate destroyed by impulsive tsunami force (Miyako)

Tsunami flew over the tsunami wall across Fudai River (TP+15.5m), and broke maintenance decks.
Many coastal seawalls were destroyed due to scouring by huge flows once tsunami overflows them.

New sea wall constructions are planned or underway at many Japanese NPP sites. They should be constructed with strong wall structures and strong foundations to withstand impulsive tsunami pressure, etc. to prohibit excessive scouring.
○ Uplift

In the Tohoku-Pacific Tsunami, everything that can float floated and drifted (cars, trucks, railway vehicles, storage tanks without tight foundations, ships moving on to the land). The fuel tank at Onagawa NPP floated and dislocated.

(Tohoku EPCO)

○ Sea sand immixed in seawater

Tsunami is a mixture of seawater and sea sand. Sands mixed in the seawater can harm active components such as motors, shaft bearings, etc.
（3）Tsunami Resistant Technology

The most direct way to the tsunami risk reduction is the enhancement of fragility. To enhance the fragility, tsunami resistant technology considering various load effects of tsunamis is needed.

The key issue is the elimination of cliff-edge effects with smooth fragility and/or safe relocation.

Three key points of tsunami resistant technology

*Water Proof (WP)*: Isolate facilities from direct contact with water
*Structural Resistance (SR)*: Withstand hydrodynamic tsunami forces
*Dry Siting (DS)*: Locate facilities at high elevation

The proper combination of WP, SR, DS is particularly important.
(Examples of SR, DS, WP)

− Structural resistance (SR) −
Technical elements for SR are to withstand their hydrodynamic effects such as impulsive and sustained tsunami pressures, etc.

− Water proofing (WP) −
Technical elements for WP include waterproof casings, waterproof cables/connectors, etc.

− Dry siting (DS) −
Technical elements for DS is to install plant facilities and equipments at a high enough elevation so that none of the future tsunamis will ever reach.

Elimination of cliff-edge effects with smooth fragility and/or safe relocation using WP, SR, DS
In this Table, major SSCs critical for tsunami safety issues have been identified. And engineering actions (Waterproof (WP), Structural resistance (SR), and Dry siting (DS)) for enhancements of their fragility have been identified.

<table>
<thead>
<tr>
<th>Structures, Systems, Components (SSC)</th>
<th>Location</th>
<th>Actions (e.g.)</th>
<th>WP</th>
<th>SR</th>
<th>DS</th>
</tr>
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<tbody>
<tr>
<td>*Seawall</td>
<td>*outdoor *facing the open sea</td>
<td>*strong walls *strong foundation *sea bed consolidation</td>
<td>O</td>
<td></td>
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<td>*Residual heat removal function following reactor shut down (scram)</td>
<td>*building basement</td>
<td>*watertight chamber</td>
<td>O</td>
<td></td>
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<tr>
<td>*Core cooling system</td>
<td>*building basement</td>
<td>*watertight chamber</td>
<td>O</td>
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<td>*Emergency power supply system</td>
<td>*(optional)</td>
<td>*(optional)</td>
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<td></td>
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<td>*Emergency component cooling system</td>
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<td>*(optional)</td>
<td>O</td>
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<td>*Electric devices</td>
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<td>O</td>
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<td>*Equipments for emergency management</td>
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<td>*(optional)</td>
<td>O</td>
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<tr>
<td>*Building components</td>
<td>*(optional)</td>
<td>*(optional)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>*Possible paths of intrusion (seepage, siphon effects, etc.)</td>
<td>*(optional)</td>
<td>*(optional)</td>
<td>O</td>
<td></td>
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</table>

This type of clarification will help enhancement of the fragility.
3. Development of technical guideline for tsunami

Concrete technical review/design guideline for tsunami safety is now required

- Nuclear Safety Commission
  Already set up draft supplemental guideline for “Seismic design review guide 2006” at Mar.2012.

- NISA
  On going for setting up more detail review guideline

- JNES
  Developing the detail technical review guideline for tsunami design and evaluation covering review guideline by NISA

- Japan Electric Association is now also preparing tsunami resistant design guideline.
  → PO13 “Formulation of tsunami resistant design standard for nuclear installations in Japan” explain for detail
Outline of the JNSE’s technical review guideline for tsunami design and evaluation

- Based on the implementation guideline of seismic PRA and tsunami PRA by AESJ
  (AESJ : Atomic Energy Society of Japan)
- Considering the lessons learned from the 3.11 2011 Tohoku earthquake

Technical review guideline for tsunami design and evaluation

Contents

I. Technical review guideline for tsunami design and evaluation
   1. Introduction
   2. Purpose and Scope of Application
   3. Definition of Technical Terms
   4. Basic Policies
   5. Matters for review at the Design Stage
      5.1 Tsunami Importance Classification
      5.2 Design Basis Tsunami Wave
      5.3 Policy of Tsunami Design
      5.4 Combinations of Loads and Allowable Limits
   6. Matters for review at the Risk Evaluation Stage
      6.1 Concept of Risk Evaluation
      6.2 Policy of Risk Evaluation
   7. Matters for Review at the Construction Stage
      7.1 Quality Control
      7.2 Pre-Operation Testing
   8. Matters for Review at the Operation Stage
   9. Recording and Storage of Design Data
  10. Proposal of Tsunami Design and Evaluation Methods
      (Ex: Design Methods of Sea Wall, Watertight Doors etc)

II. Example of the Tsunami Trial Design and Evaluation

III. R&D Theme (Mid and long term)
Investigation Scope and Coverage

- This technical review guideline focuses on each stages of NPP life span ("design", "evaluation", "construction" and "operation")
- This technical review guideline is constituted of specification code and performance code.

Constitution of the guideline

This technical review guideline consists of 3 volumes.
- Vol 1: Basic concept of tsunami resistant design, evaluation, etc.
- Vol 2: Example of the tsunami trial design and evaluation
- Vol 3: R&D roadmap (Mid and long term)

Schedule

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<th>2012</th>
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<tr>
<td>Vol1 (Basic concept)</td>
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<tr>
<td>Vol2 (Example)</td>
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<td>(Improvement)</td>
</tr>
<tr>
<td>Vol3 (R&amp;D theme)</td>
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→IAEA
Outline of JNSE’s technical review guideline for each stage

(Each stage: design stage, evaluation stage, etc.)

■ Design Stage

● Basic Policy

Safety facilities are required to have sufficient tsunami-resistance not to reach an accident against design basis tsunami force with high reliability.

a. Basic policy should be to prevent tsunami from flooding into site by protective facilities (example: tide embankment) etc.. In this case, flooding from openings of intake tunnel etc. (preventing from seawater intrusion is difficult because of their functions) shall be limited so that safety functions shall not be affected.

b. Considering the case of tsunami flooding into site, safety facilities shall maintain the functions with tsunami resistant technologies.
Technical Points of Consideration

- Consideration various type of tsunami force
  " Inundation height ", "intrusion ", " hydrodynamic forces ", etc.

- Consideration of damage modes, such as rupture, deformation, leakage, etc. for each facilities

- Application of appropriate tsunami resistant technology for each facilities considering the damage mode and tsunami force type
  " water proof " (WP) , " structural resistance " (SR) , " dry siting " (DS)

- Ascertain of the intrusion paths of the sea water and tsunami run-up area
  Water creeps in anywhere if it has pressure head and accessible intrusion paths. → Necessity of plant walkdown

- Appropriate consideration of tsunami design margin
■ Safety Evaluation Stage

● Basic Policy
  - Recognizing the existence of tsunami risk due to beyond design basis tsunami, an effort shall be made to minimize this tsunami risk.
  - Tsunami risks can be evaluated by tsunami PRA.

● Technical Points of Consideration
  - Multiple Hazard:
    - Tsunami after Earthquake
  - Multi equipments failure, Multi units sites failure:
    - Common cause failure
  - Clarification of uncertainty
  - Necessity of plant walkdown and peer review
## Construction Stage

- **Quality Control (QC):**
  - Quality control for the production, inspection, installation, testing, etc. shall be conducted.

- **Pre-use Examination:**
  - Specific functions (Leak rate, etc.) shall be checked in advance of operation.

## Operation Stage

- Specific functions shall undergo regular inspections, especially considering the effect of aging.
4. Summary

(1) “Tsunami resistant technology” was proposed for NPP safety. The most direct way to the tsunami risk reduction is the enhancement of fragility.

(2) The key issue is to eliminate cliff edge effects in the fragility of SSC by realizing "smooth fragility" or "safe relocation".

(3) A scheme of engineering components "Water Proof (WP)", "Structural Resistance (SR)", and "Dry Siting (DS)" were proposed.

(4) Major SSCs critical for tsunami safety and engineering actions for enhancements of their fragility have been identified.
(5) Tsunami-resistant technical safety/review/design guideline is going to be developed in Japan.

(6) JNES is now developing technical review guideline for tsunami “design”, “evaluation”, “construction” and “operation” stage. JNES will revise this guideline, considering the situation of each country, so that it will be able to be used throughout the world.