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Improvement of Fault Displacement PRA Methodology and Concept of its application to a Hypothetical NPP

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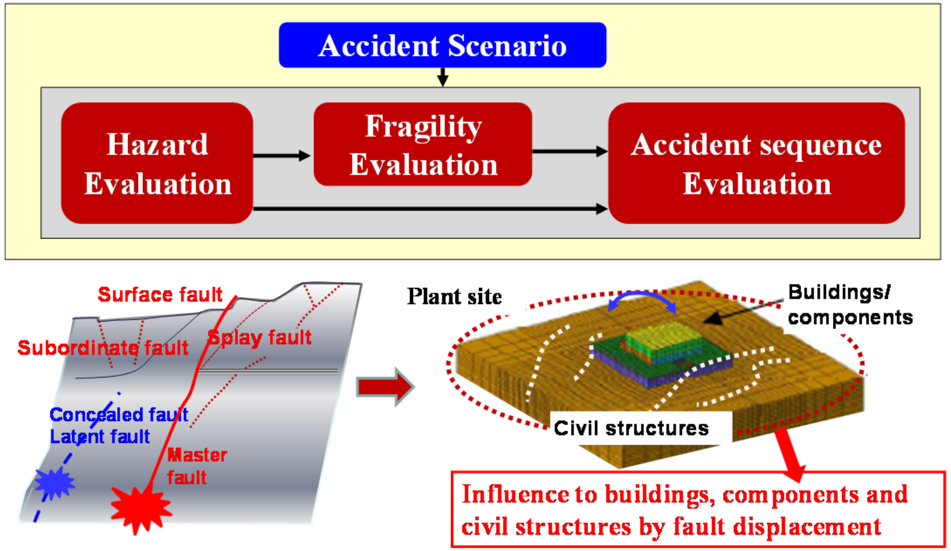
Introduction

- Interest on the impact of main and distributed fault displacement on nuclear facilities has increased recently in Japan.
- Atomic Energy Society of Japan (AESJ) is developing a standard for fault displacement PRA.
- Nuclear Risk Research Center (NRRC) of Japan is conducting examination of fault displacement PRA framework and identification of technical issues.

This presentation describes the fault displacement PRA study performed by Nuclear Risk Research Center (NRRC) of Japan.



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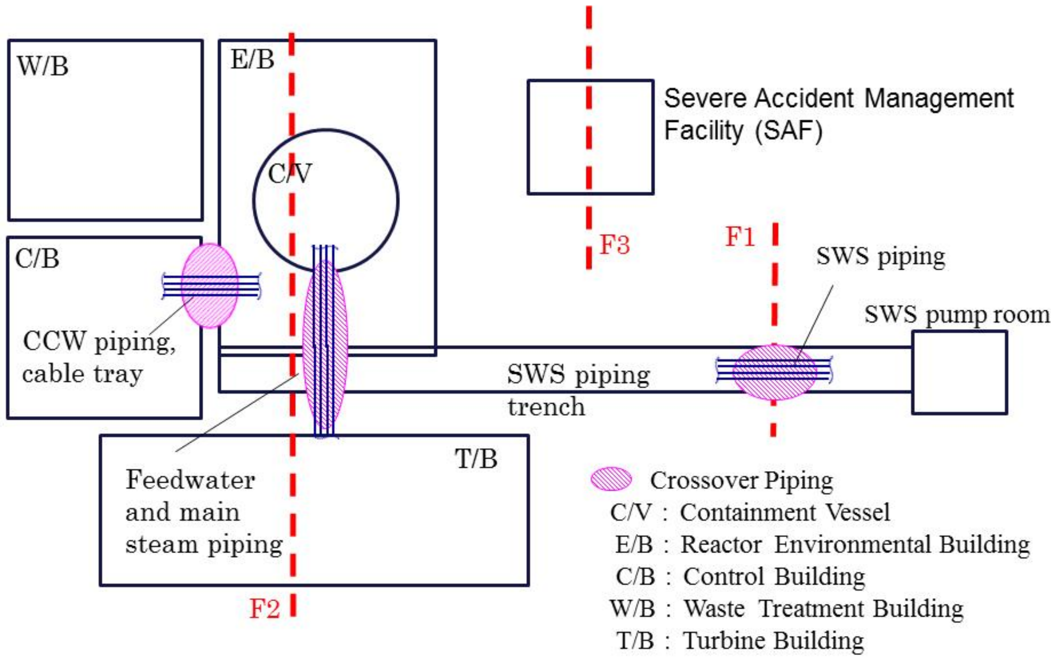
Characteristics of fault displacement event

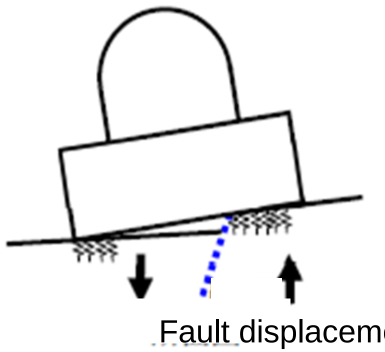
- Fault displacement event
  - Area of effect is locally limited
  - Accompanies seismic motion.
  - Scale and its frequency have large uncertainty.

- Fault displacement induced accident scenario
  - Damage to the buildings and civil structures may affects risk significant components, piping and structures.
  - Nuclear facilities are constructed avoiding areas with faults that have potential of large displacement. Scenarios strongly depend on the site.
  - Variation of scenarios to prevent core damage could exist depending on the location and scale of displacement.

Analysis condition

- Hypothetic PWR plant was assumed to test the PRA methodology
- Three fault displacements (F1, F2, F3) were considered as a test case





Cross sectional view showing point of action

Fig. Hypothetical NPP and location of surface fault displacements assumed in the study

Component failure modes

Three types of failure considered as a result of fault displacement

1. Failure caused deformation of floor
2. Failure caused by inclination
3. Failure caused by relative building displacement

1. Failure due to **loss of support caused by deformation of floor**

- Deformation may occur at the base floor, and affect components located there.
- Upper floors have no direct contact with the fault displacement surface or the deformed slab. They are unlikely to cause local deformation.
- For hazards resulting in significant deformation of the building, the affect will be captured in the building fragility.

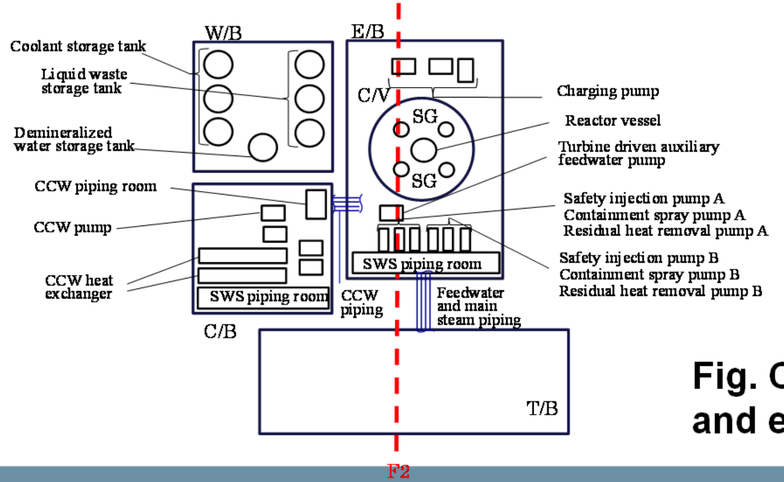
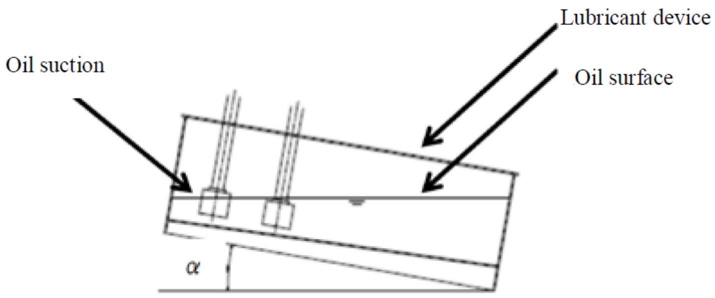


Fig. Conceptual layout drawing of building and equipment at the base floor

Component failure modes

2. Failure caused by **inclination of components**

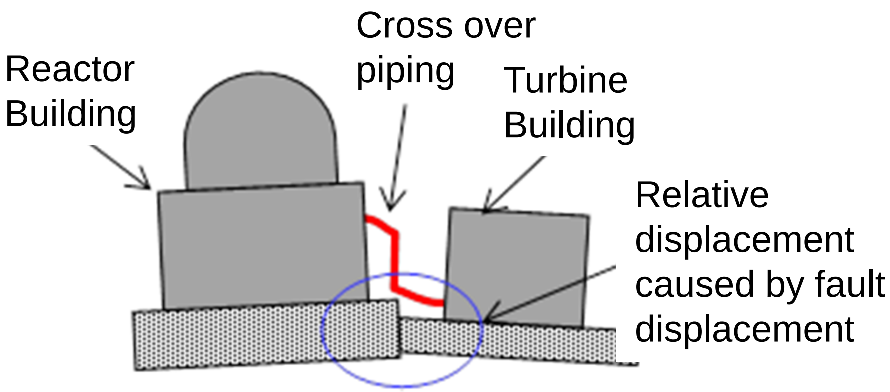
- Inclination can result in functional and structural failures
- Stress on anchor bolts and pump parts were evaluated for each angle
- Failure in lubricant device can be the limiting failure mode



When inclination angle is larger than 5˚, pump may fail because of loss of lubrication.

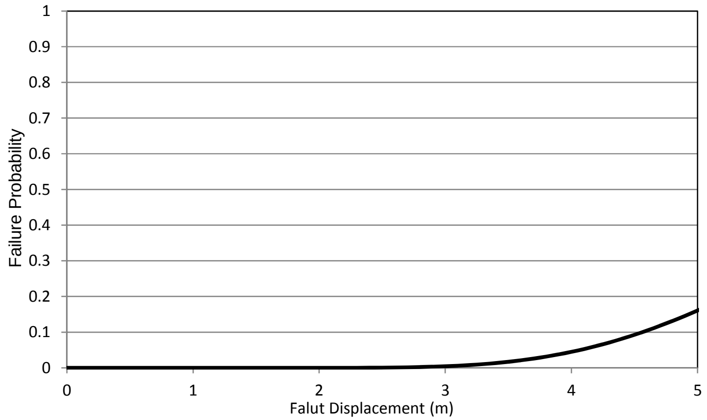
3. Structural failure caused by **building displacement**

- Relative displacement may cause distortion load on the crossover piping
- Cable trays crossing buildings can be also affected



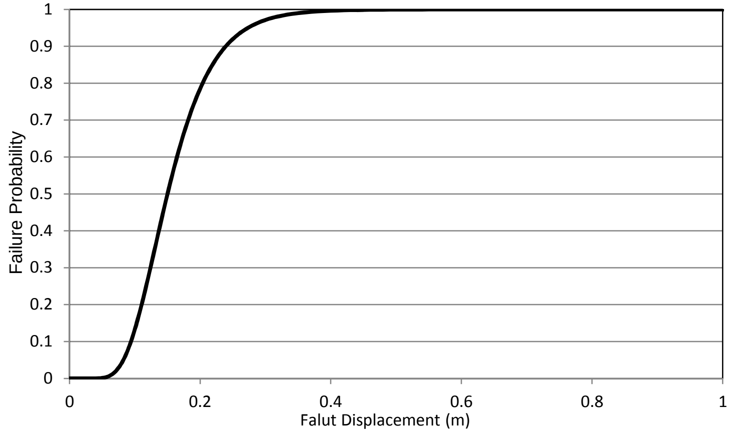
Fragility Analysis

Horizontal pump functional failure



- Fragility curve evaluated focusing on the inclination angle in which the lubricant device can maintain its function
- Inclination buildings caused by fault displacement is small and considered not to significantly effect functionality of active components
- This failure mode can be screened out from quantification

Component Cooling Water System crossover piping structural failure



- Fragility curve from the viewpoint of distortion generated by the relative displacement at the piping member midway between the buildings.

Fault displacement equipment list

- Structures and components subjected to failure have been identified, and the impact on initiating events and mitigation systems has been analyzed.

Example of components effected by deformation of floor

	Initiating Events	Effected Mitigation Function
Charging pump A	—	RCP seal cooling, charging injection
Safety injection pump A	—	Safety injection, Feed and bleed
Containment spray pump A	—	Containment spray
Residual heat removal pump A	—	Residual heat removal, Low head injection
T/D auxiliary feedwater pump	—	SG cooling
SWS piping	Partial or total loss of SWS	Component cooling
Turbine building internal equipment	Loss of main feedwater, Secondary side breaks	SG cooling, Primary side depressurization using SGs

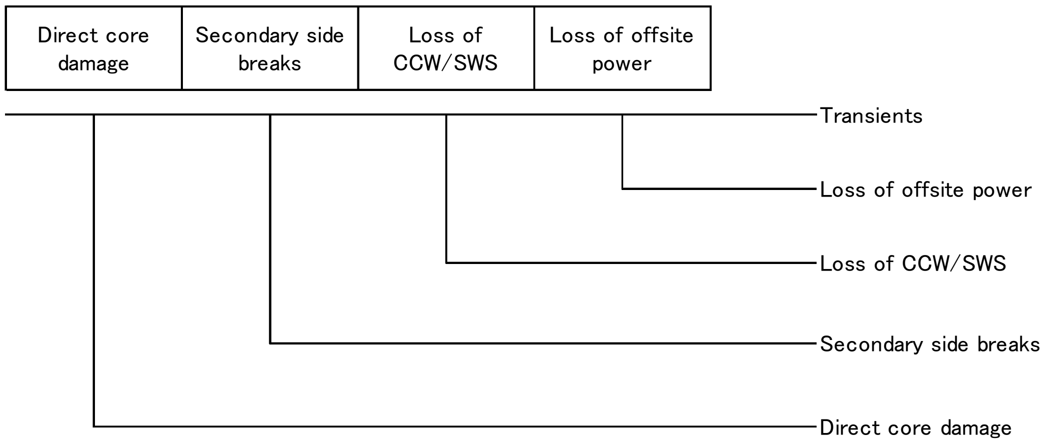
Example of components effected by relative replacement between buildings

	Initiating Events	Effected Mitigation Function
SWS piping	Partial or total loss of SWS	Component cooling
CCW piping	Partial or total loss of CCW	
Main steam piping	Secondary side breaks	SG cooling, Primary side depressurization using SGs
Main feedwater piping	Secondary side breaks	
Cable tray	Transients	Plant monitoring and control

Event tree development

- Hierarchy event tree was developed for the initiating events, based on the initiating events identified.
- Each sequence of the initiating event event tree is linked to the mitigation system event tree
- Basic structure of the event tree is the same with seismic PRA model

Initiating event event tree

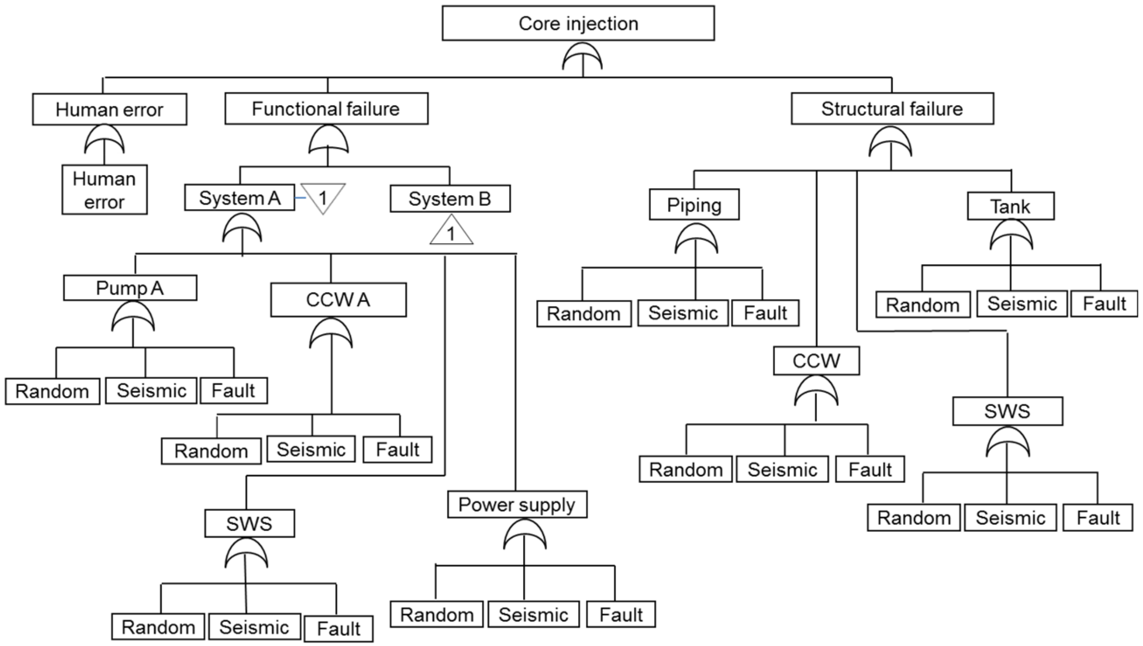


Each sequences linked to the mitigation system event tree

Fault tree development

Failure modes considered in the systems fault tree

- Functional and structural failure caused by the fault displacement
- Random failures
- Human errors
- Seismic failure ⬅ for sensitivity study purpose only



Quantification

Quantification of the core damage sequences have been evaluated to identify the important accident scenarios

Initiating event (I.E.)	Fault location	Most contributing accident sequence	
Secondary side breaks	F2	I.E. + main steam isolation failure + feed and bleed	5.4E-09
Loss of CCW/SWS	F2	I.E + auxiliary feedwater failure	1.4E-08
	F1	I.E + RCP seal LOCA + recirculation mode failure	2.3E-09
	F2	I.E + RCP seal LOCA + alternate CCW failure	1.2E-09
Loss of offsite power	F2	I.E + emergency DG failure + auxiliary feedwater failure	3.6E-09
	F3	I.E + emergency DG failure + alternate ac power failure	8.2E-11
	F1	I.E + emergency DG failure + alternate CCW failure	6.4E-11

Quantification of importance

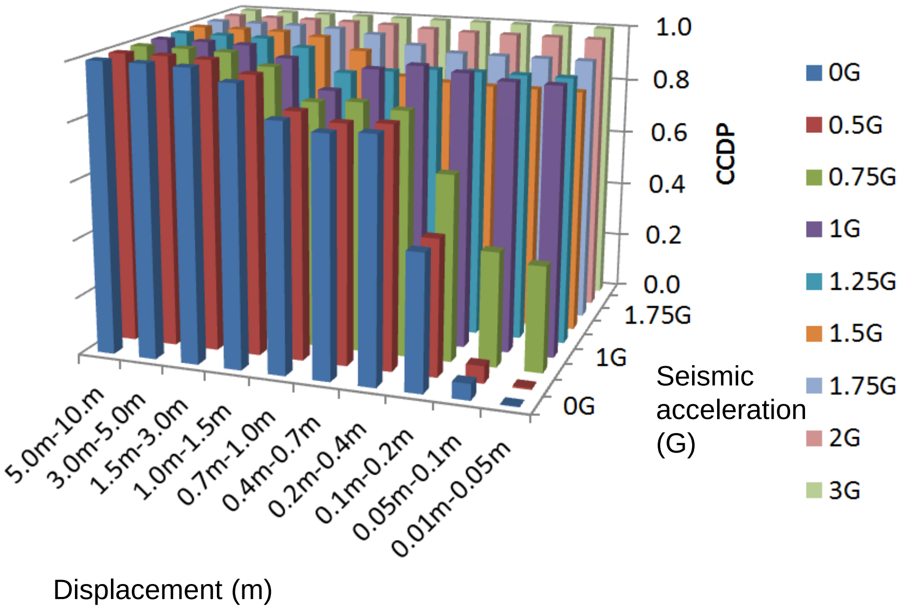
- Failure of over crossing pipings and cable trays have large contribution to risk
- Refinement of the fragility of these components are also important

no	Component	HCLPF (m)	FV importance
1	Cable tray (crossing buildings)	0.07	0.38
2	CCW pipings (crossing buildings)	0.07	0.11
3	Turbine building	0.24	0.11

Sensitivity study

The effect of seismic events on fault displacement risk has been investigated

- No information on occurrence frequency of combined seismic and fault displacement hazard.
- Variation of the conditional core damage probabilities (CCDPs) for given superposed seismic motion and fault displacement has been quantified.



Results

- CCDP is sensitive to the superposing seismic acceleration only at limited ranges of the combined hazard.

- If hazard analysis show the frequency of the combined hazard at that range is low, detailed analysis of combine hazard is not important.

Conclusion

- Quantification of accident sequences has been performed to confirm the feasibility of the methodology through application to a hypothetical plant.
- The analysis provides insights on important initiators, dominant accident sequences, important failure modes and range of fault displacement magnitude that has high contribution to risk.
- Concepts on how to consider the contribution of superposition of seismic acceleration have been examined.
- Improvements in the hazard analysis and fragility analysis is still necessary. Nuclear Risk Research Center of Japan in continuing research for improvements in this area.

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