RIC 2016
W14: Improving Confidence in Probabilistic Fracture Mechanics

Probabilistic Fracture Mechanics analysis of piping system under seismic loading

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1 Introduction

- The March 2011 accident at the Fukushima Daiichi nuclear power plant revealed the vulnerability of nuclear power plants against extreme external events such as earthquake and tsunami.
- Seismic margin assessment (SMA) and Probabilistic Risk Assessment (PRA) are primary methodologies used to assess seismic safety.
- Aging of component may have an effect on the seismic capacities and the fragility curves. However, the method to evaluate the effect has not been established yet.

2 Objective

- In order to understand how aging of piping affects its seismic fragility,
  - JAEA have been developing a PFM code PASCAL-SP* based on typical aging mechanisms and fracture mechanics models.
  - JAEA and S/NRA/R have investigated failure probabilities and fragility curves of aging pipes.**

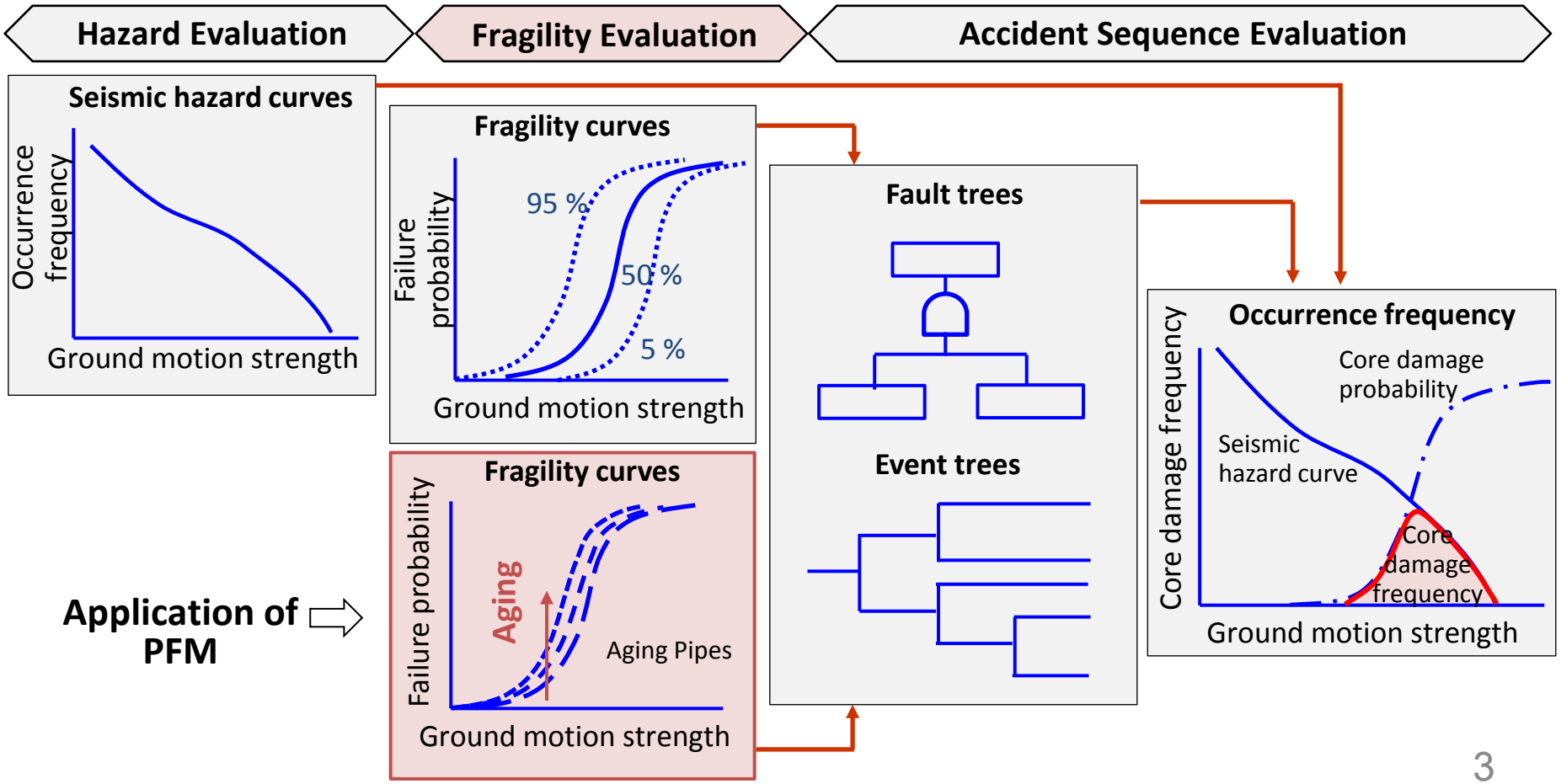
*H. Itoh, et. al., "User's Manuals of Probabilistic Fracture Mechanics Analysis Code for Aged Piping, PASCAL-SP," JAEA-Data/Code 2009-025,(2010)

**Y. Yamaguchi, et. Al., "Failure Probability Analysis of Aged Piping Using Probabilistic Fracture Mechanics Methodology Considering Seismic Loads," PVP2016-63801, ASME 2016 Pressure Vessels & Piping Conference, Vancouver, Canada

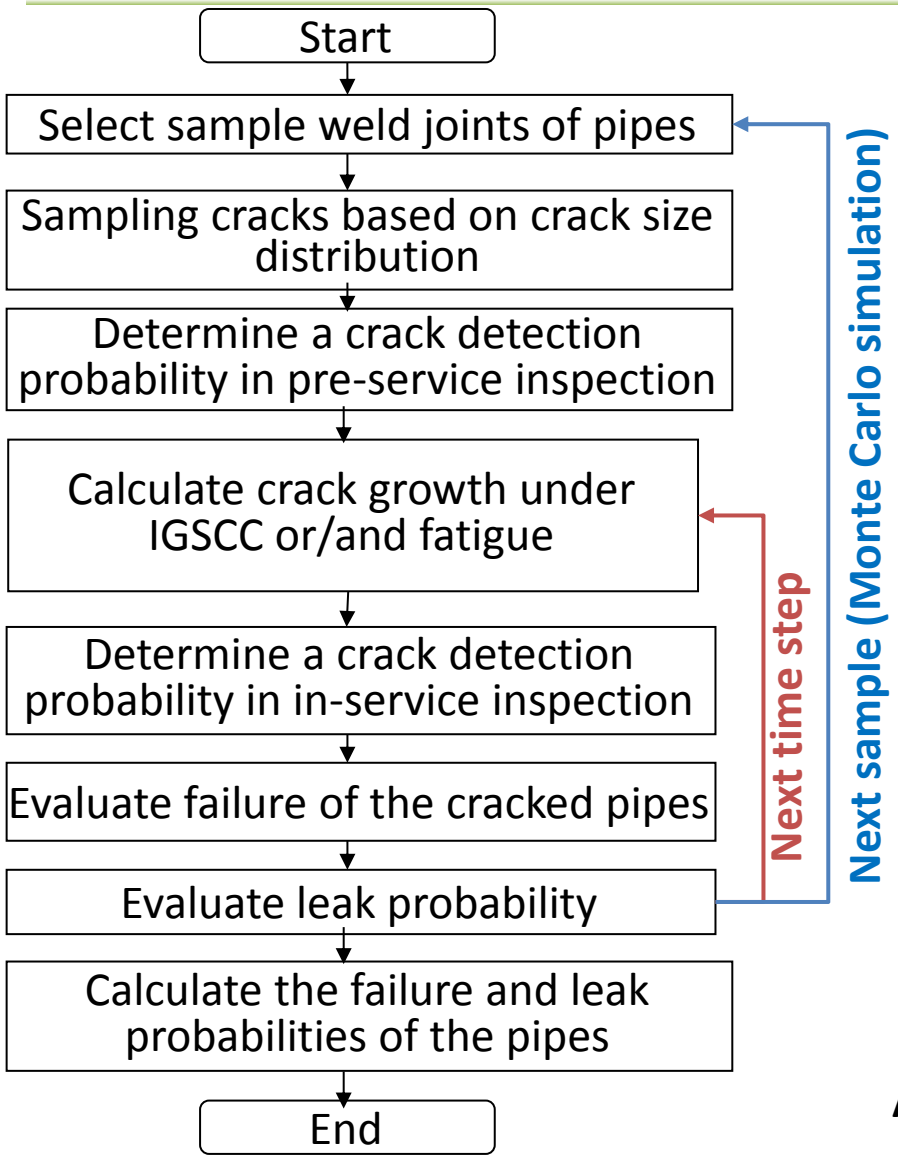
3 Scope of Analysis

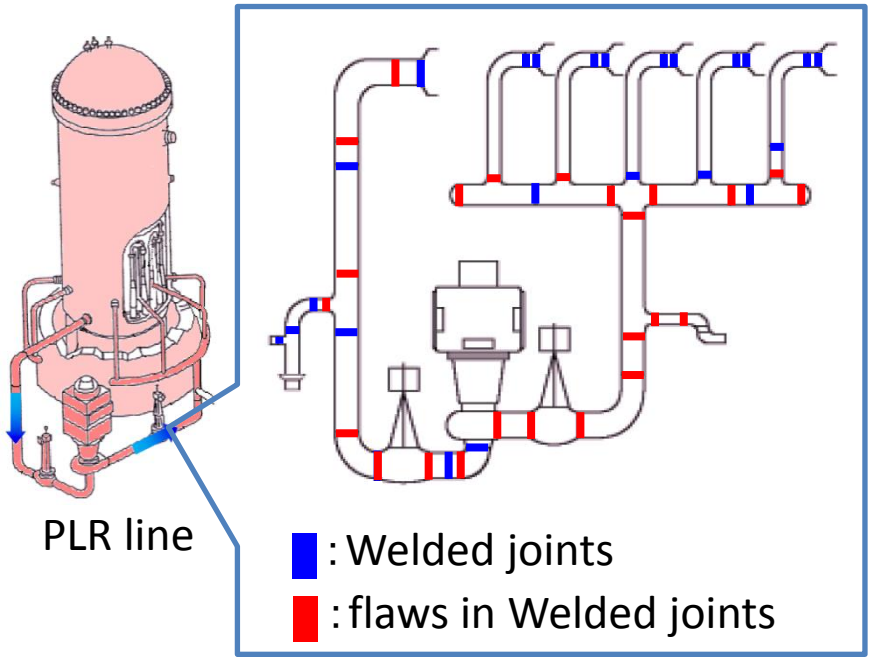
A PFM analysis code for aging pipes has been developed to evaluate failure probabilities and fragility curves.

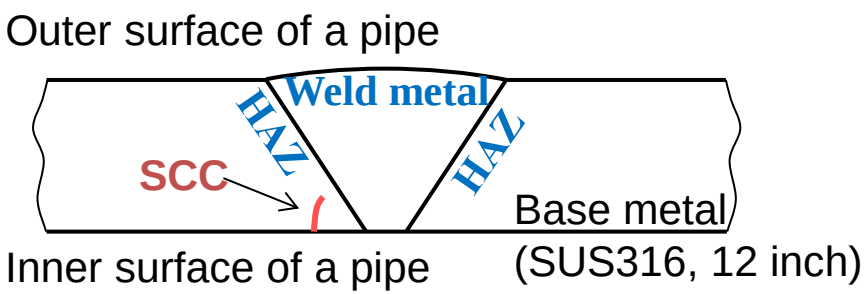
Process of seismic PRA



4-1 PFM Code Development*







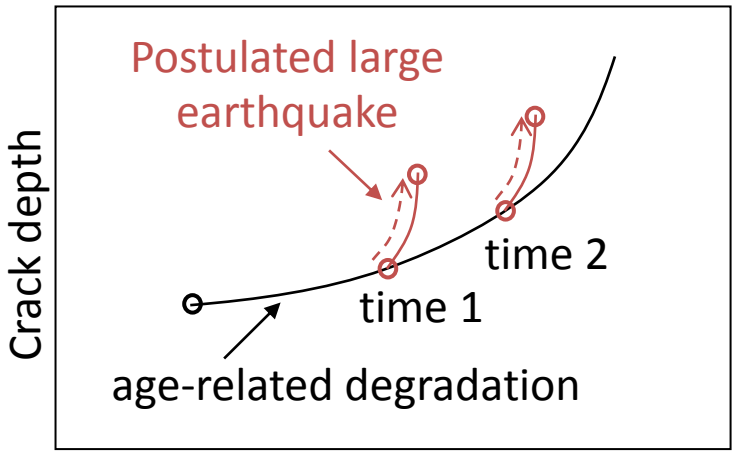
An Example of SCC detected in a BWR plant

4-2 PFM Code Development

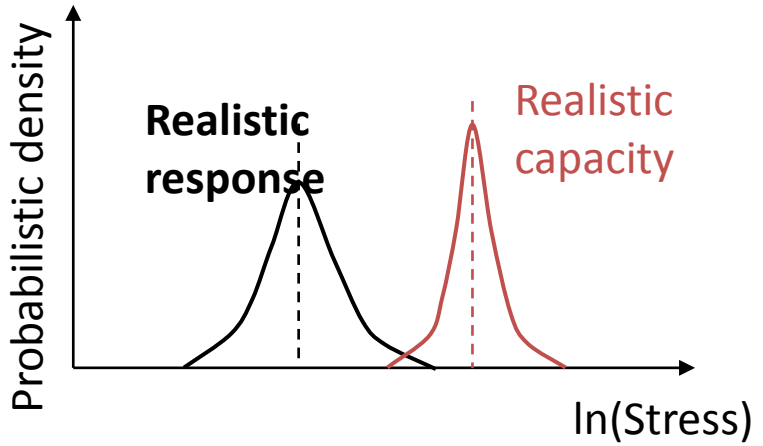
Stress analysis of seismic response

Consideration of

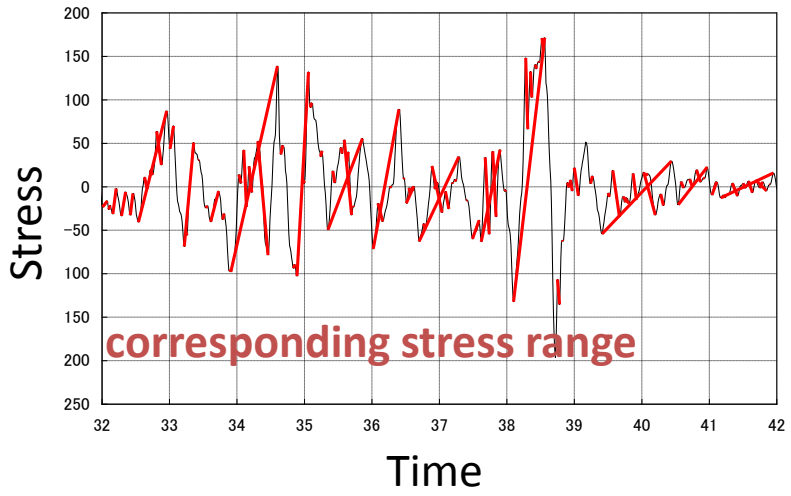
- uncertainty of seismic response
- seismic waveform
- equivalent cyclic stress
- main shock and aftershock



Crack growth analysis



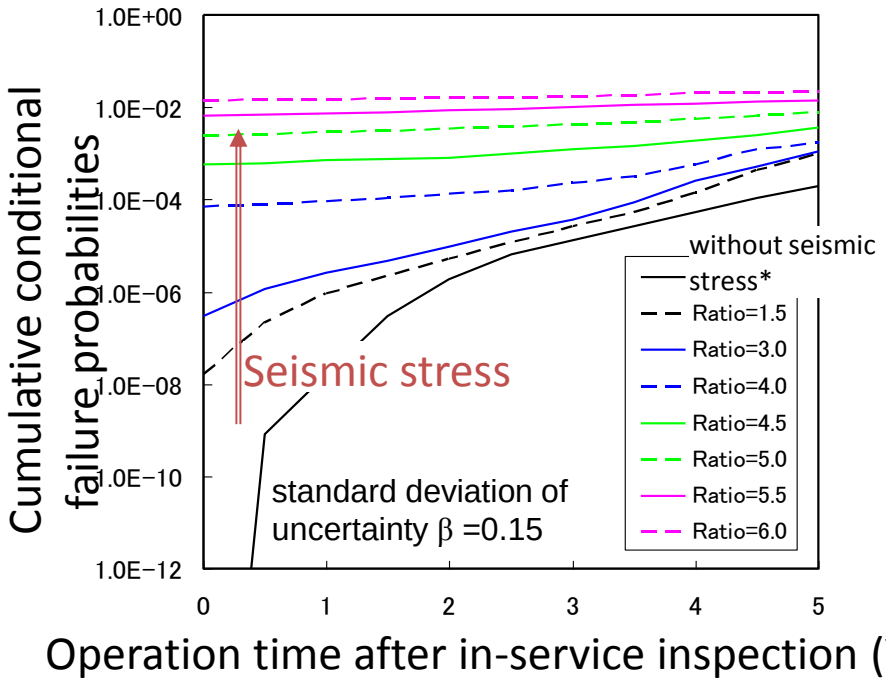
Uncertainty of seismic response stress



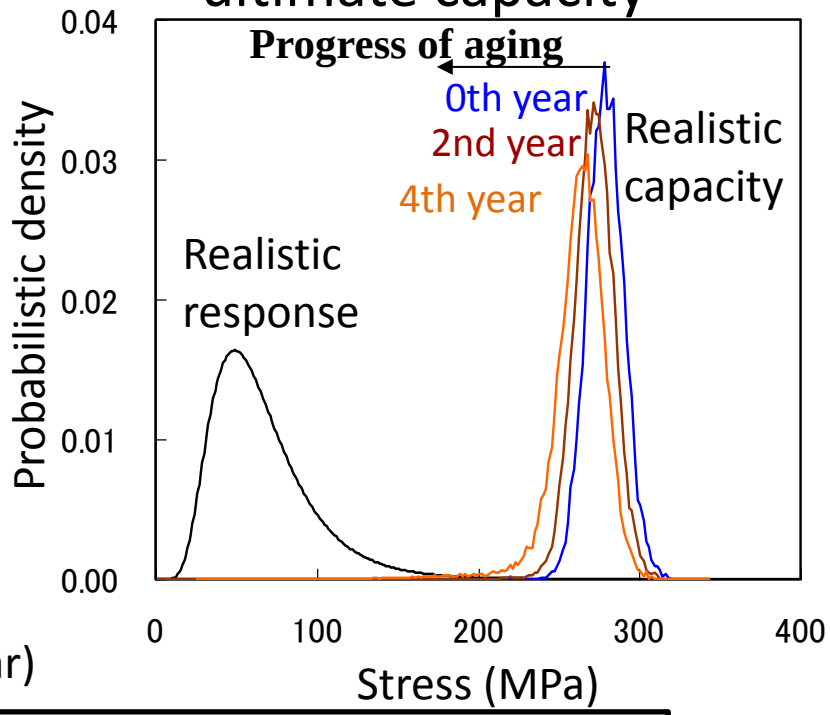
5-1 Example of Analysis Results

Using failure probability distributions analyzed by PFM, we obtained the probabilistic distribution of ultimate capacity for different operation years.

Failure probabilities



Probabilistic distribution of ultimate capacity



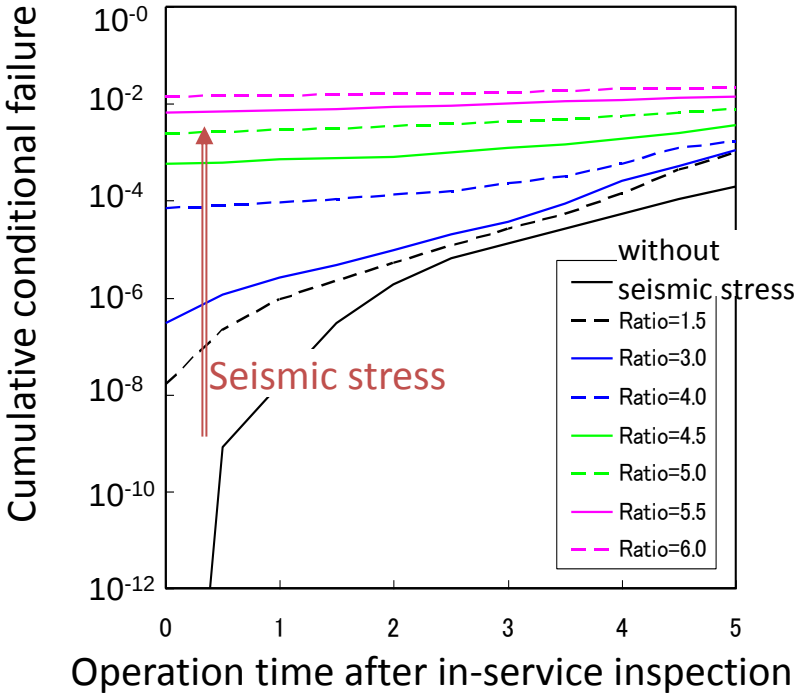
Aging of pipes has an effect on its realistic capacity.

* Stress Ratio : Bending stress caused by seismic motion, expressed as a ratio of reference value 45 MPa

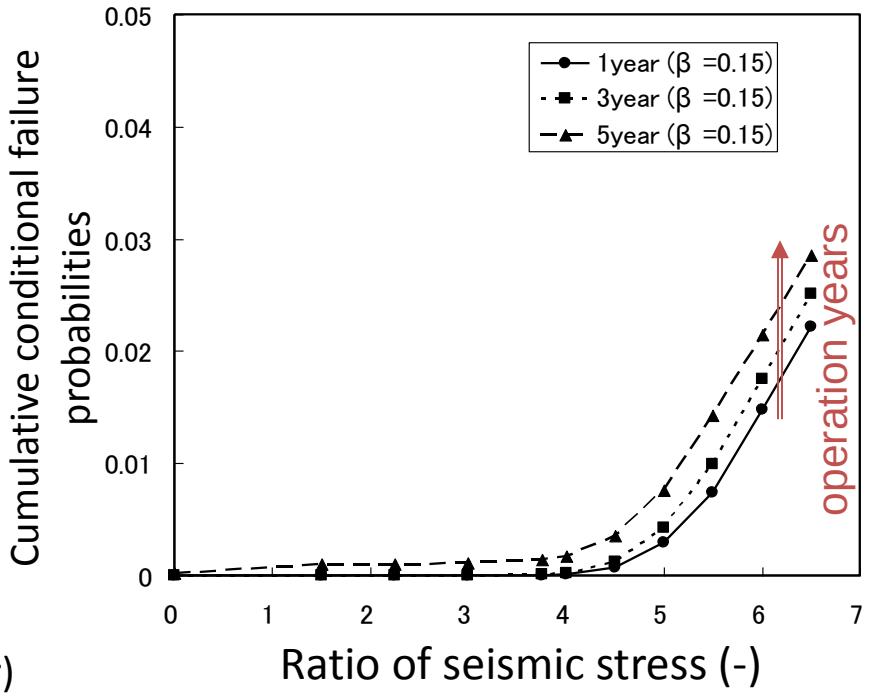
5-2 Example of Analysis Results

Using failure probability distributions analyzed by PFM, we obtained the fragility curves, which go up with the increase of operation years.

Failure probabilities



Fragility curves

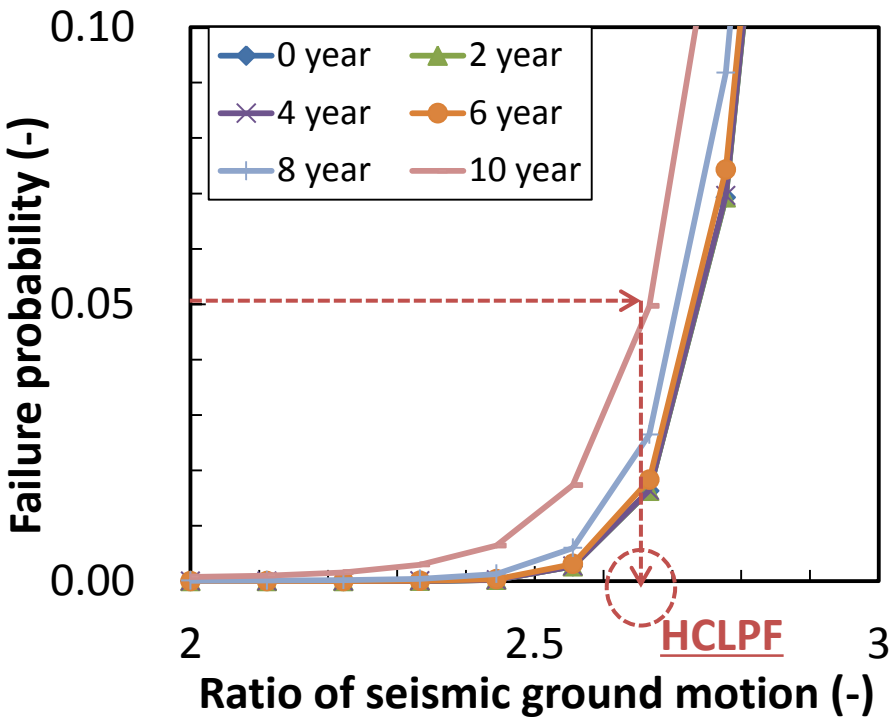


Aging effects are important for fragility evaluation, especially for pipes subjected to large seismic motion.

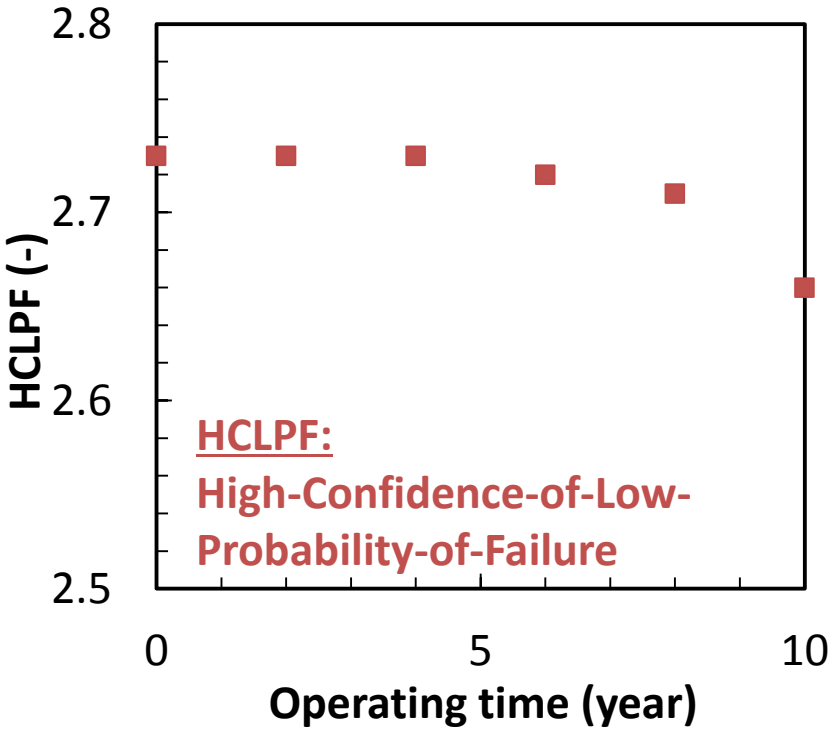
5-3 Example of Analysis Results

Using the fragility curves, we obtained the probability-based seismic margins, which decreases with lapse of time.

Fragility curves



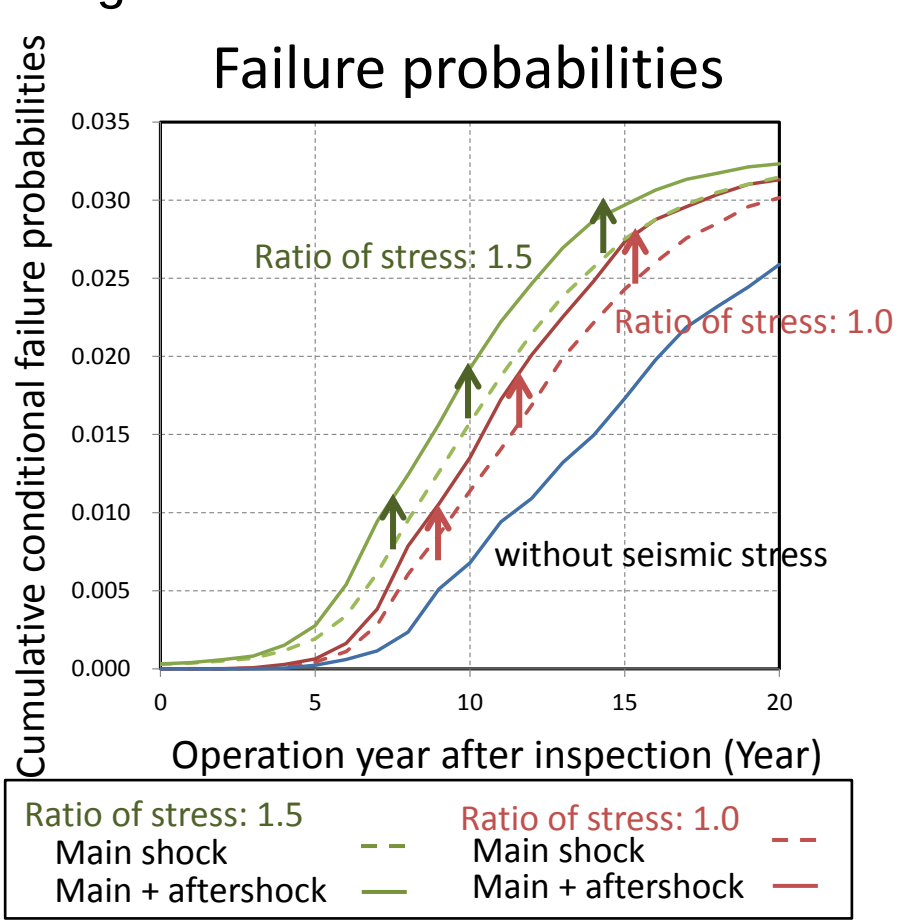
Probability-based seismic margin

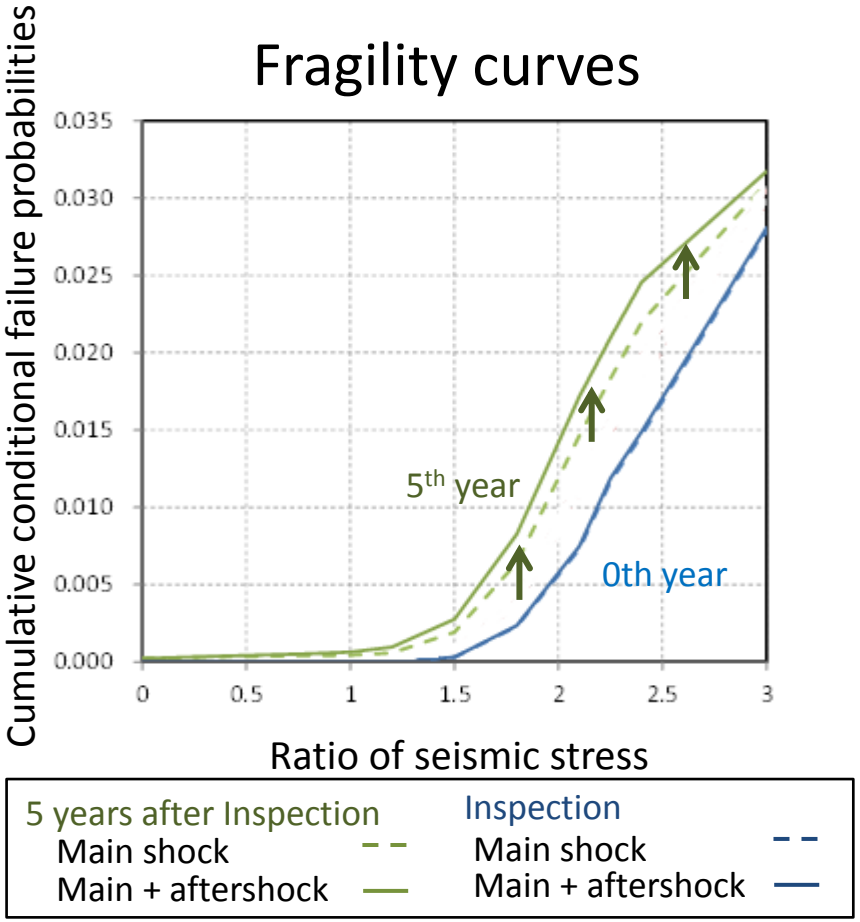


If appropriate measures are not taken, crack growth may cause a decrease in seismic margins.

5-4 Example of Analysis Results

The effect of an aftershock triggered by a main-shock with the same magnitude is evaluated.





In the case of aging pipes subjected to large seismic motion, aftershock also has an effect on failure probabilities.

Summary

- We have been developing the PFM code in order to perform seismic PRA for aging components.
- The results showed that crack growth by IGSCC and fatigue affects the probabilistic distribution of realistic capacity.
- By taking into account aging effects, we obtained fragility curves and seismic margins of pipes, which depends on operation years.