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Seismic Probabilistic Risk Analysis of Transmission Systems for Kashiwazaki-Kariwa NPS using Deaggregation Hazard taking account of Non-Specified Source Faults

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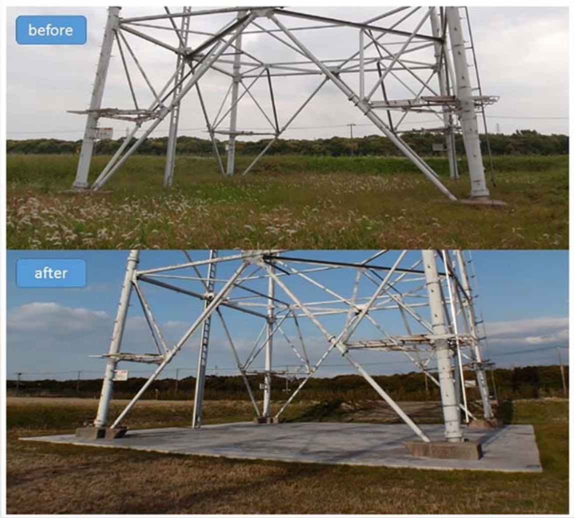
Background and Objectives

- In Japan, there are 3 cases of LOOP due to earthquakes.
  - 3/11/2011 Tohoku-Pacific Ocean Earthquake: Fukushima-Daiichi, Fukushima-Daini
  - 4/7/2011 Miyagi-oki Earthquake: Higashidori(under construction), Rokkasho Reprocessing Plant
  - 9/6/2018 Iburi Earthquake: Tomari
- The damage caused by Tohoku-Pacific Ocean Earthquake is as follows
  - 1 transmission tower collapse
  - Many insulators placed on the transmission tower were damaged



Background and Objectives

- In conventional KK-NPS's PRA, LOOP was modeled by the fragility of the most vulnerable equipment in the NPS (i.e. ceramic insulator), but the representativeness to the external power grid is an issue.
- Seismically-induced LOOP outside the NPS can be basically handled by the internal event PRA, but there is also a issue in dealing with frequentist method (i.e. the more the earthquake doesn't occur, the more the probability of occurrence increases in theory).
- There is a option to use generic fragility, however there are also plant-specific aspects in the grid.
- U.S. conventional fragility may be conservative.

	KK (Ceramic Insulator)	U.S. Conventional Fragility
Am	0.91	0.30
βr	0.24	0.30
βu	0.22	0.45
HCLPF	0.43	0.09
Failure frequency [/year] (with KK site Hazard)	1.1E-4	4.6E-3

IS THIS REALISTIC…?

SCOPE

- 3 power supply routes containing 5 lines (one route of which has a substantially different direction)

Power lines	Capacity
“Route A-1” 500kV Shin Niigata Power Line	4139MW × 2 lines
“Route A-2” 500kV Minami Niigata Power Line	4139MW × 2 lines
“Route B” Arahama power Line (Tohoku Electric Power Company)	118MW × 1 line

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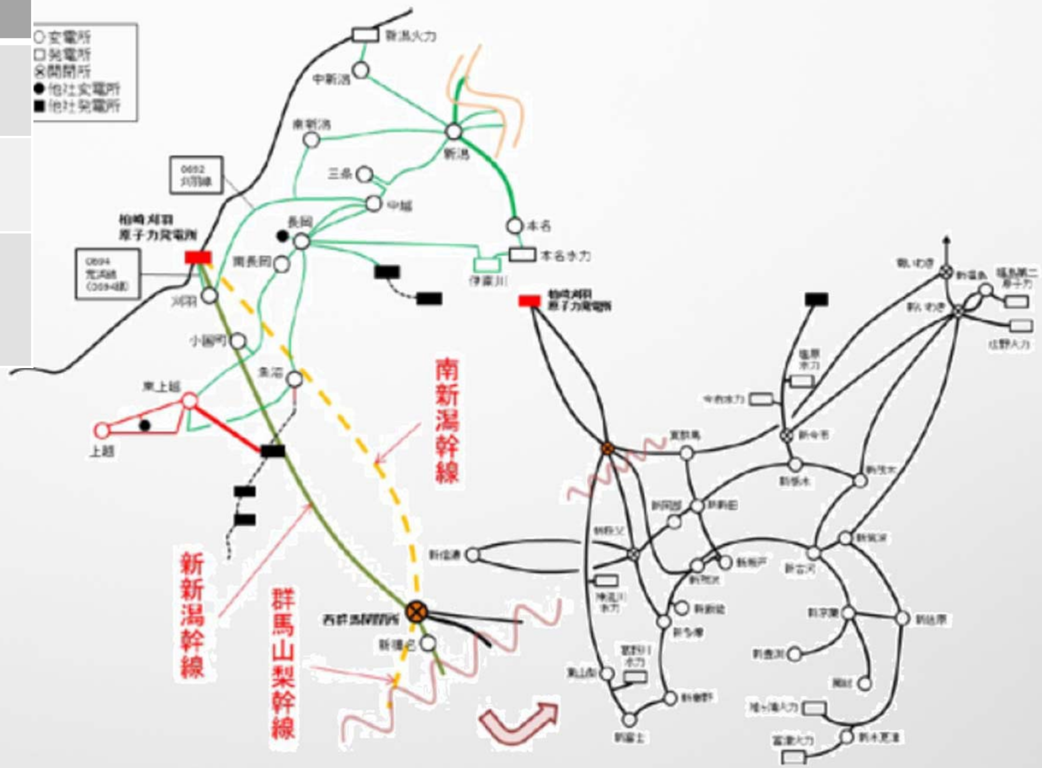
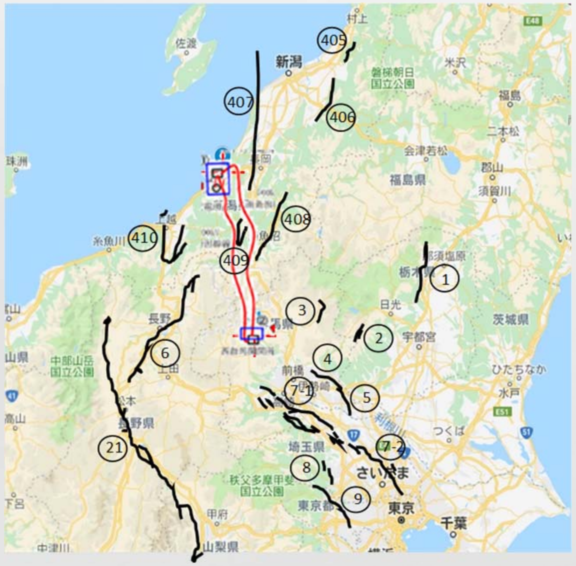


SEISMIC HAZARD ANALYSIS
– Specified Source Faults

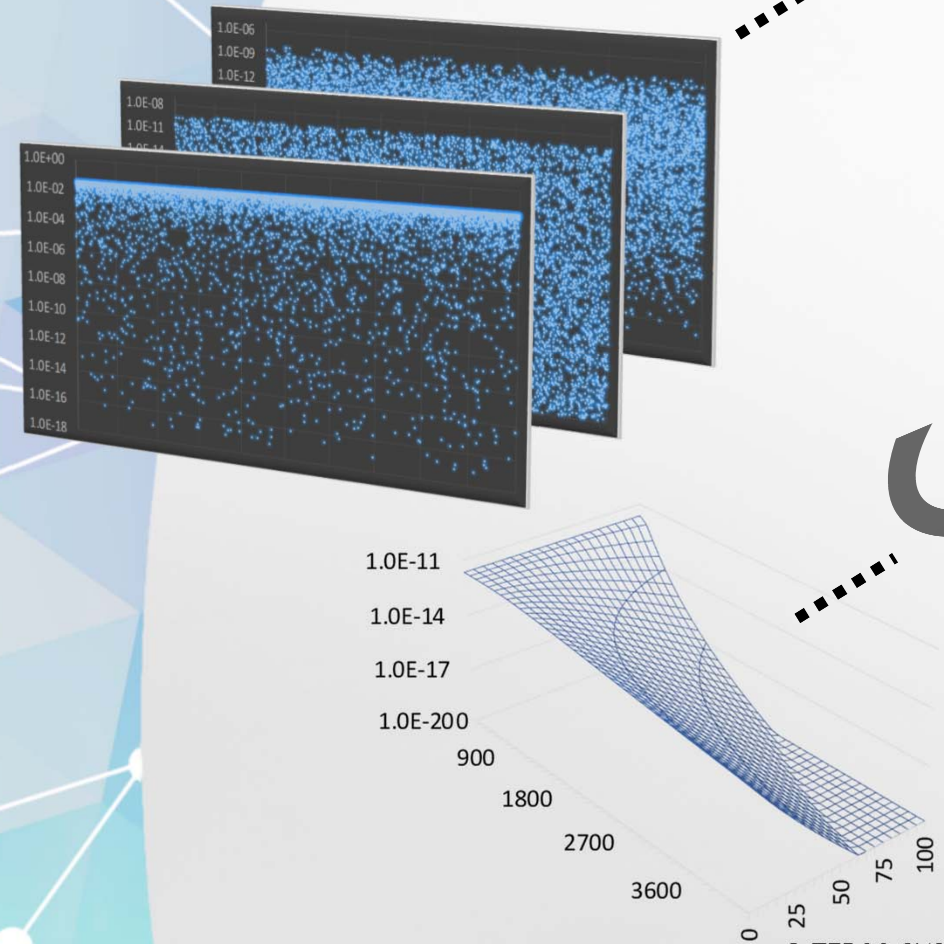
- Considered the characterization of each source fault, ground motion attenuation, and site amplification.
- Developed the three-dimensional hazard of annual frequency of exceedance, distance and gal separated for each source faults.
- Major seismic faults are identified by literature surveys.
- Evaluated 16 faults (24 sections) within 100km
  - Offshore faults were excluded from this survey because the on-site facilities are relatively representative.

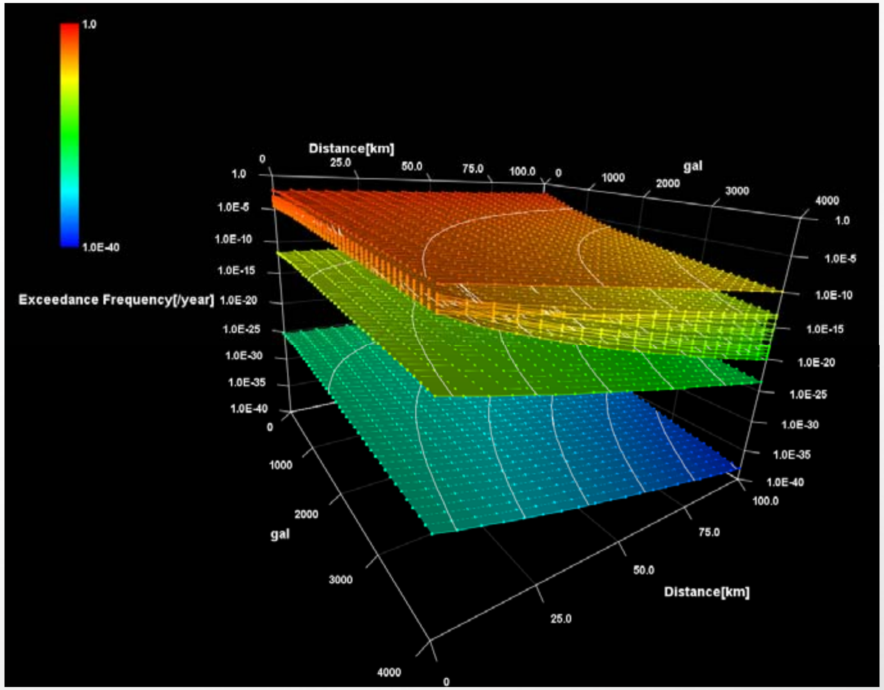


[Example]

No.	Active Source Fault Name	Length	Mw	Mean Recurrence Interval	Latest Faulting Event	Model
1	Sekiya Fault	38	7.1	2600-4100	14^{th} -17^{th} century	BPT
6	Western Boundary Fault Zone of the Nagano Basin	74	7.5	3000	-	Poisson
21	ISTL (Itoigawa-Shizuoka Tectonic Line) Fault Zone	158	8.0	600-800	800-1200 years ago	BPT

Occurrence Probability / Ground Motion Attenuation Relation / Amplification near Ground





Occurrence Probability / Ground Motion Attenuation Relation / Amplification near Ground

- Occurrence probability：BPT / Poisson process

  BPT: $f(t;\mu,\alpha)=\{\mu/(2\pi\alpha^2 t^3)\}^{1/2}\exp\{-(t-\mu)^2/(2\mu\alpha^2 t)\}$

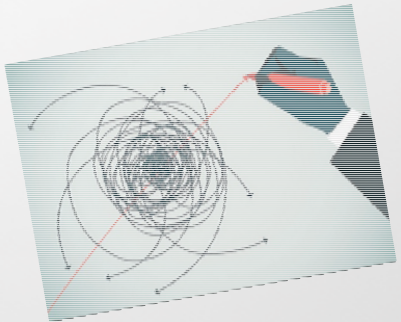
  Poisson: $f(t)=e^{-t/\mu}/\mu$

  - Calculated using the Monte Carlo method assuming a uniform distribution based on the estimated width of the mean recurrence interval and of the latest faulting event period. (iteration: 1,000,000 times)
  - Aperiodicity Value α : 0.24
- Mw is estimated from the fault length by empirical formula (Matsuda(1975), Central Disaster Management Council in Japan(2005))
- Attenuation Relations for Peak Ground Acceleration: Si and Midorikawa (1999)

$$b = aM_w + hD + \sum d_i S_i + e + \varepsilon$$

Table 7. The results of the regression analysis with constraint (Using Equivalent hypocentral distance)

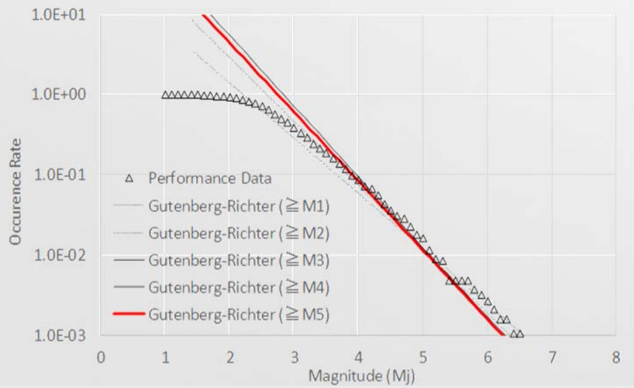
a	h	d: Crustal	d: Inter-plate	d: Intra-plate	e
Peak ground acceleration					
0.50	0.0036	0.00	0.09	0.28	0.60
Peak ground velocity					
0.58	0.0031	0.00	0.06	0.16	-1.25

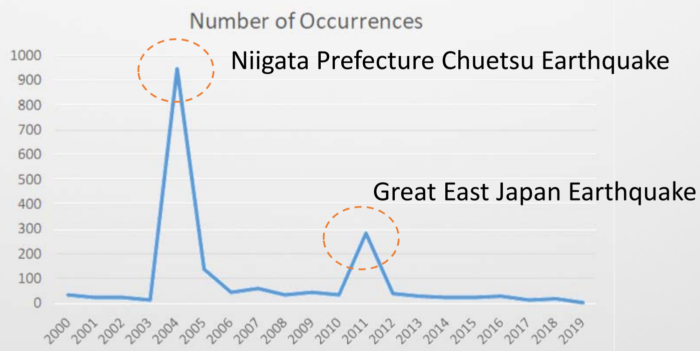


- Evaluation considering uncertainty using a logic tree that is normally implemented in PSHA is out of scope of this study.

SEISMIC HAZARD ANALYSIS
– Non-Specified Source Faults

- Evaluate as "Non-Specified Source Faults" to include smaller earthquakes for which there is insufficient information about source faults.
- Evaluation using conventional Gutenberg-Richter (G-R) law with magnitude data.
- Carried out statistical analysis for earthquakes that occurred in the land area of Niigata Prefecture, where power transmission networks exist.
- To ensure the uniformity of data accuracy, the data collection period was set as 1/1/2000 – 3/31/2019. 1872 earthquake data were analyzed and the occurrence frequency of exceedance was evaluated.
- The upper limit of Mj was set to 7.4 (Shimazaki (2009))





Fragility

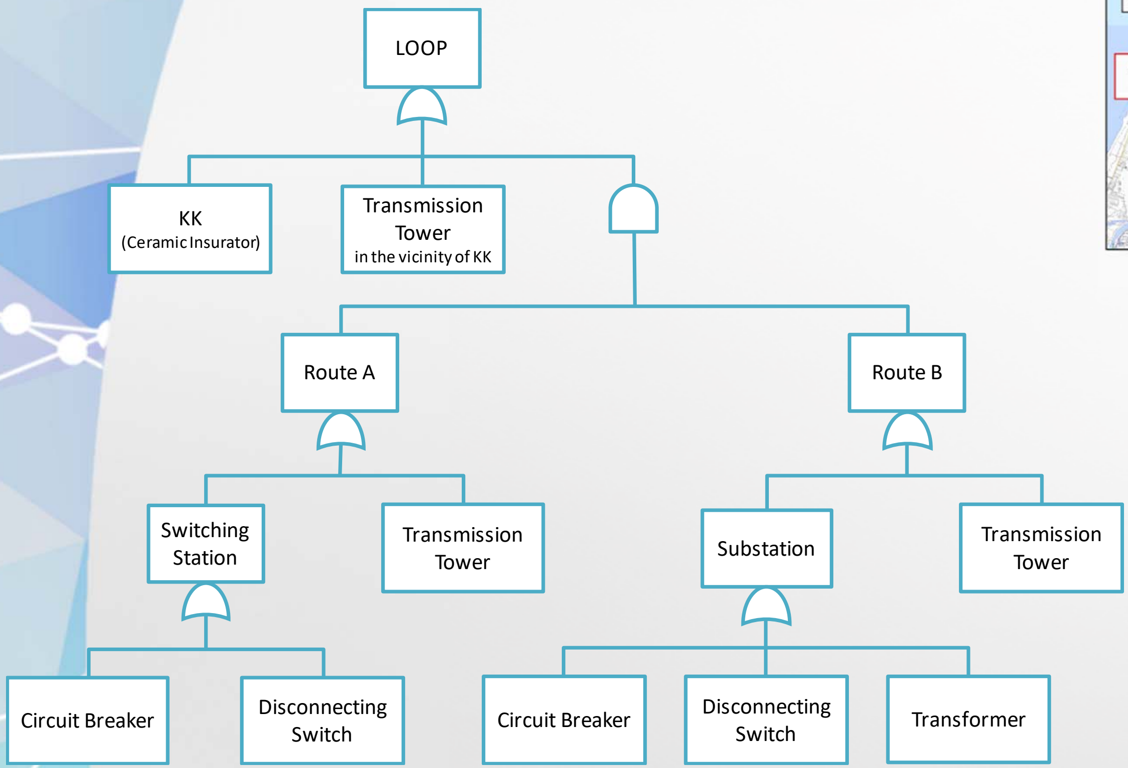
- Oikawa et al. (2001)
  - The following fragility list based on damage performance data before 1979 was developed.
  - Moreover, It has been proposed to apply a factor of 2 to evaluate the fragility after 1980.

Table 4 Seismic Capacity of Electrical Equipment in Substations Manufactured before 1979

	Higher than 187kV							All Voltage Class
	Transformer	Circuit Breaker	Disconnecting Switch	Lightning Arrester	Instrument Transformer	Power Capacitor	Shunt Reactor	Transmission Tower
Median [Gal]	340	620	480	550	550	790	610	770
β_r	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.32
β_u	0.36	0.19	0.20	0.13	0.13	0.11	0.32	0.20
β_c	0.46	0.35	0.35	0.32	0.32	0.31	0.43	0.38
	Lower than 187kV							
	Transformer	Circuit Breaker	Disconnecting Switch	Lightning Arrester	Instrument Transformer	Power Capacitor	Shunt Reactor	Neutral Grounding Resistor
Median [Gal]	500	1010	780	830	830	790	610	600
β_r	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
β_u	0.20	0.16	0.38	0.13	0.13	0.11	0.32	0.20
β_c	0.35	0.31	0.48	0.32	0.32	0.31	0.43	0.35

System Analysis

❐ Fault Tree



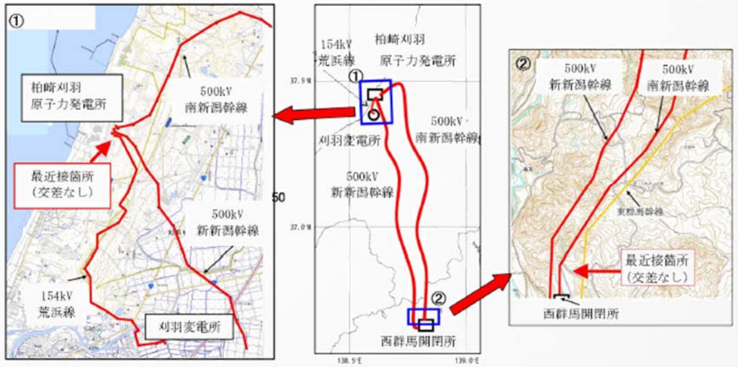
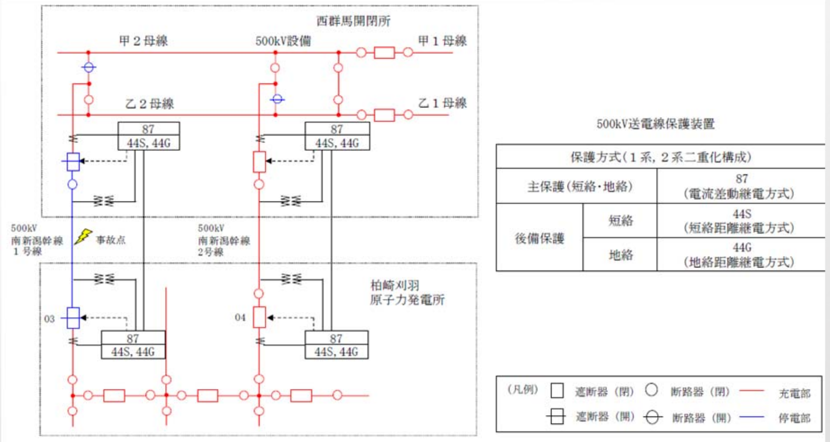


図 4　500kV 新新潟幹線・500kV 南新潟幹線・154kV 荒浜線のルート

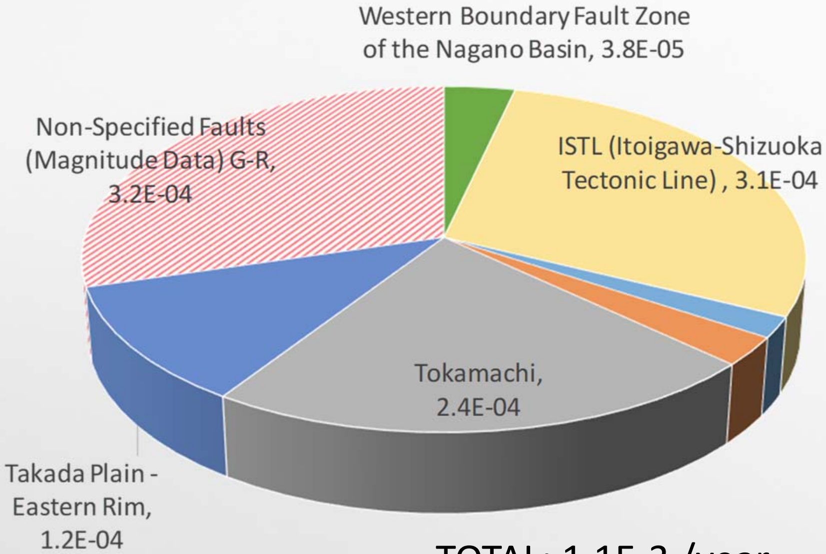


保護方式(１系，２系二重化構成)		
主保護(短絡・地絡)		87 (電流差動継電方式)
後備保護	短絡	44S (短絡距離継電方式)
	地絡	44G (地絡距離継電方式)

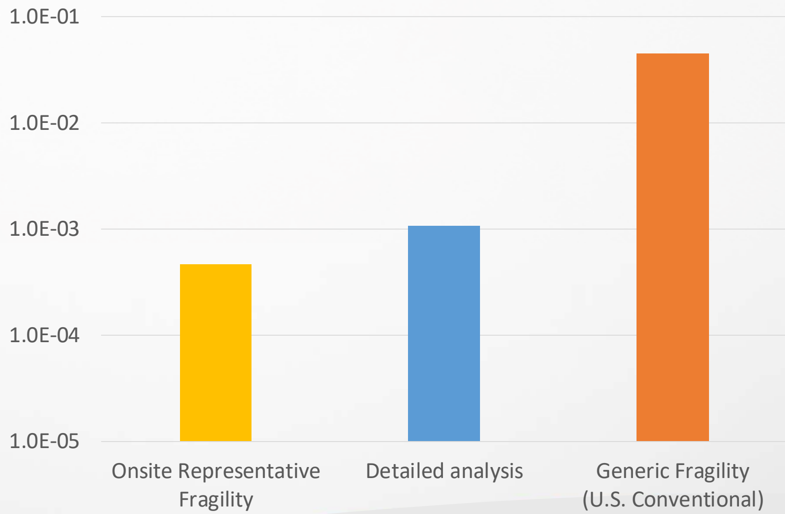
(a) 500kV 南新潟幹線 1 号線故障時

Results

LOOP Frequency

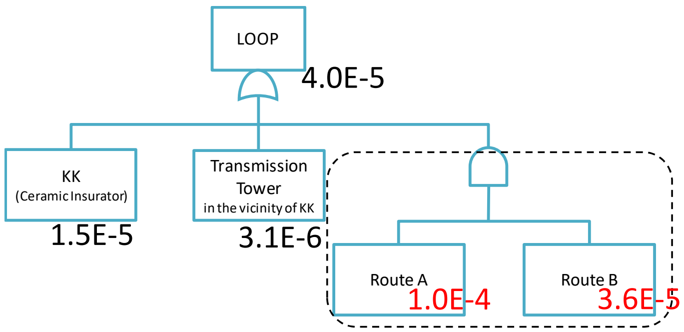


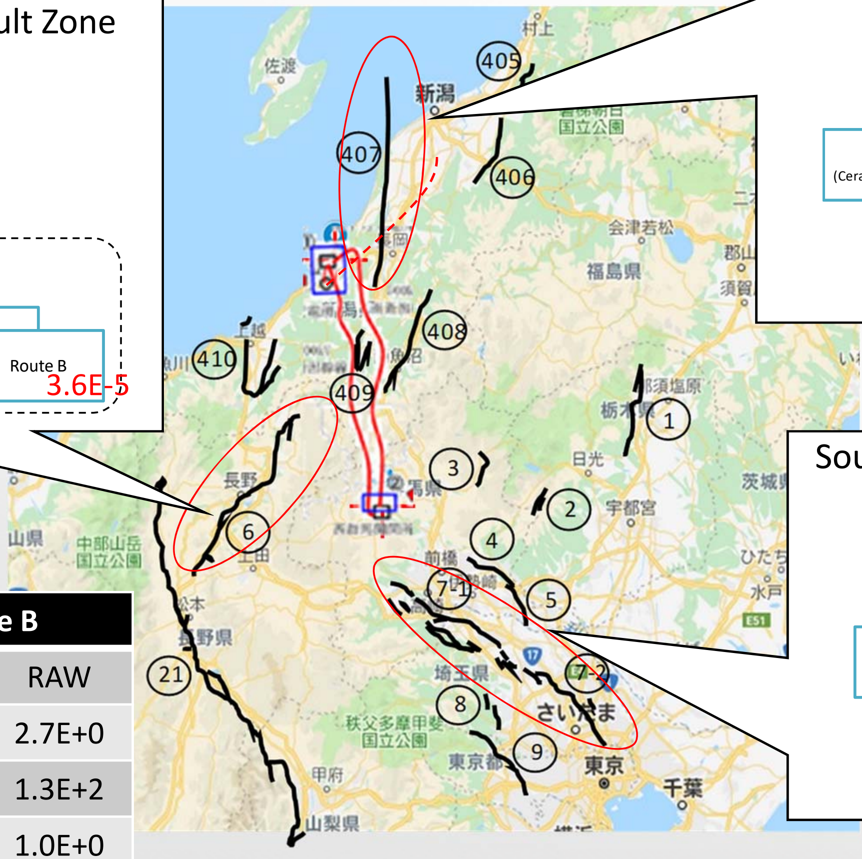
TOTAL: 1.1E-3 /year



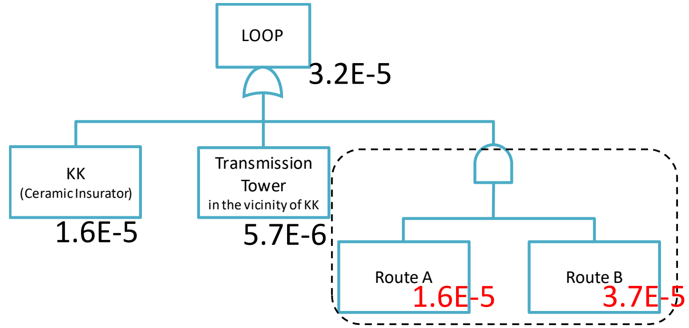
Results

Source Fault #6: Western Boundary Fault Zone of the Nagano Basin

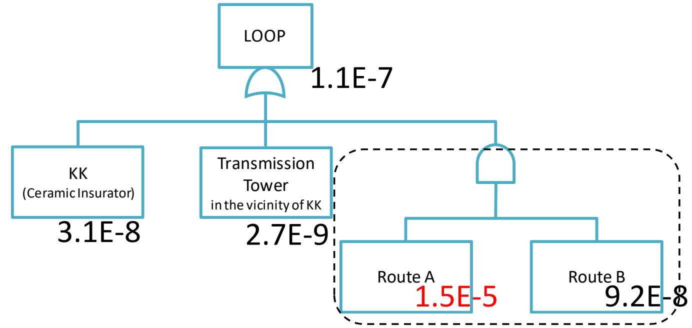




Source Fault #407: Fukaya and Ayasegawa



Source Fault #7: Fukaya and Ayasegawa



#	Route A		Route B	
	FV	RAW	FV	RAW
6	5.7E-1	8.7E+0	5.7E-1	2.7E+0
7	7.1E-1	1.0E+0	7.1E-1	1.3E+2
407	2.0E-1	1.8E+0	2.0E-1	1.0E+0

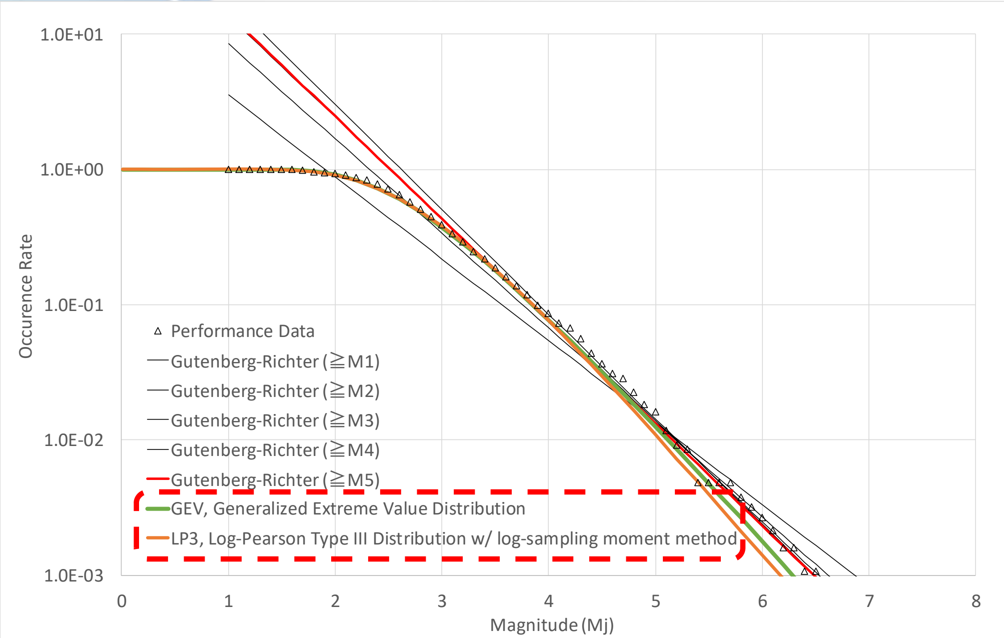
Hazard Curve Sensitivity
- Non-Specified Source Faults

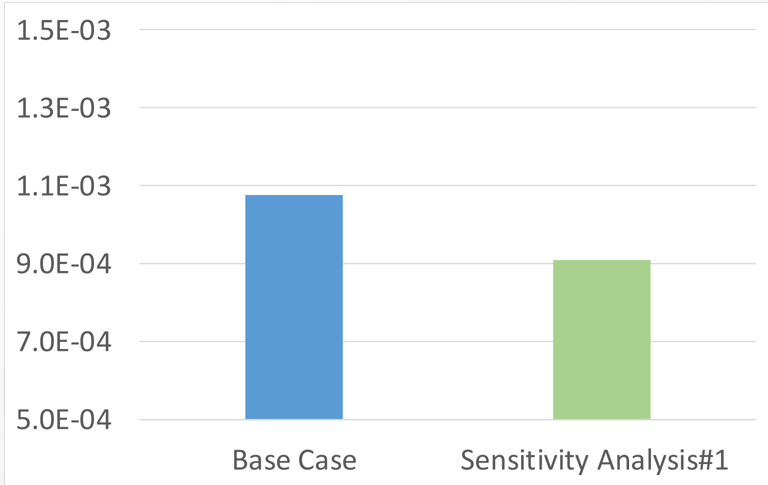
- Since the equipment such as insulators could be seismically more vulnerable than the high seismic design category equipment of nuclear power plants, the accuracy in the low acceleration region is important.
- For non-specified source faults, the sensitivity analysis by extreme value analysis using the method of moments was conducted in addition to the evaluation based on the conventional Gutenberg-Richter law with magnitude data.

	Method	Performance Data
Base Case	Gutenberg-Richter law	Magnitude
Sensitivity Analysis #1	Extreme Value Evaluation using the method of moments	Magnitude
Sensitivity Analysis #2	Extreme Value Evaluation using the method of moments	JMA Measuring Seismic Intensity

Sensitivity Analysis #1
- Non-Specified Source Faults

- INDEX: Magnitude

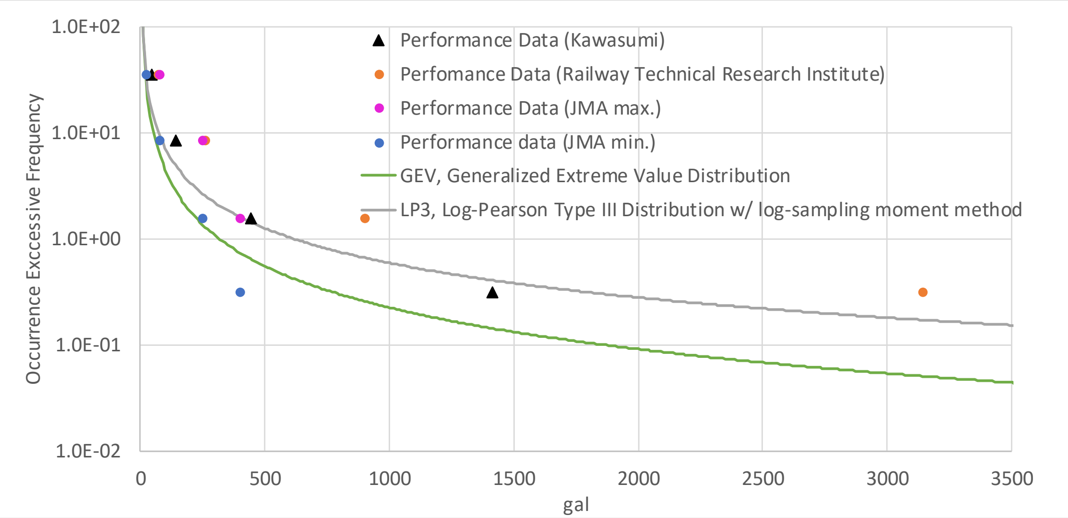




- The G-R law's misfit in the low acceleration region is thought to be due to undetectable earthquakes. However, we assumed that samples were obtained equivalently from the population, and the sensitivity study was conducted by using a distribution form more consistent with the data

Sensitivity Analysis #2
- Non-Specified Source Faults

- INDEX: JMA's Measuring Seismic Intensity
  - Trial to evaluate the damage hazard of the power transmission network from the viewpoint of damage performance data rather than the information on the source faults.
  - This has the merit that the distance attenuation related- and site ground related- uncertainty are taken into account from the start.



- The classification class was too rough and it was not a realistic evaluation.
- SLSC (Standard Least Squares Criterion)
  - GEV: 0.152
  - LP3: 0.202

Summary

- It was confirmed that the evaluation of the site's facilities alone was insufficiently representative with respect to the frequency of LOOP occurrence, but its impact was limited (about 2.3 times the frequency of LOOP occurrence).
- In particular, the contribution from non-specified source fault's seismic motions is large, and the conventional G-R law evaluation may be conservative in the low-acceleration region when the fragility to be evaluated is relatively small, as in the present case.
- For LOOP generated by source fault far from the power plant, the power plant facilities are likely to be healthy and the impact on the CDF is likely to be relatively small (generally considered a level that can be evaluated using an internal event PRA model rather than seismic PRA).

Future Work

- Expansion of Evaluation Range of Specified Source Fault
- Sensitivity Analysis by Changing Correlation
- Refinement of PSHA

Thank you for your kind attention

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