Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Is Fuel Assembly Fine at BDBA Seismic Load?

Heung Seok KANG [a*], Kang Hee LEE [a], Kyung Ho YOON [a],
[b]*KAERI., PWR Fuel Technology Development Div., 989-111 Daeduk Daero., Yuseong-gu, Daejeon 34057*
[*]*Corresponding author: hskang@kaeri.re.kr*

1. Introduction

It was reported that Fukushima accident, 9.0 magnitude earthquake followed by significant tsunami, draws attention not only to severe accident but also Beyond Design Basis Accident (BDBA). It was known that the Peak Ground Acceleration (PGA) by the earthquake was recorded to be 0.561g that is beyond the design bases of the Dai-ichi NPP 2, 3, and 5. What would be the fuels and reactor internals if the tsunami did not occur? The question would be asked whether or not the integrities of the fuels and the reactor internals are alright after the severe shock, and whether or not the NPPs were continuously operated.

After Fukushima accident, IAEA and OECD/NEA speak aloud recommendation on Design Extension Condition (DEC) for some of current BDBA accidents, and thus, some of the current BDBA to be obviously included in design conditions.

In this study, 1) we will review on 2011 Fukushima accident from the earthquake point of view, before great tsunami, 2) on the analysis procedure for seismic accidents, of which the main frame was established several decades ago, 3) on possible issue on current design method, and 4) on practical way to solve the design issues and to reflect a beyond design basis seismic accident in DEC

2. 2011 Fukushima Seismic Accident

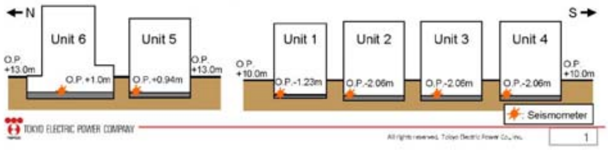
As of January 2016, NPPs of 439 are operating to produce electricity [1], and 20 % of them are operating in the area of significant seismic activity [2].

Since earthquake officially recorded, the most severe one was 1960 Chile earthquake that was known to be 9.6 magnitude. 2013 Fukushima earthquake was recorded as 9.0 magnitude that was the fourth worst one recorded ever. It is known that there was a foreshock of 7.3 magnitude before the main shock, followed by a lots of aftershocks over 7.0 magnitude for several days. It was reported that Fukushima Dai-ichi NPPs were safely shutdowned when PGA reached at design bases before great tsunami caused catastrophic disaster. It was also reported that some of measured PGAs exceeded the design basis earthquake: the observed PGA of unit 2 was 0.561g that was beyond design basis by 26%. Design bases and recorded PGAs at Fukushima Dai-ichi NPP are summarized in Table 1.

Table 1. Records of PGA Observations at Fukushima Dai-ichi NPPs [3]

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal)					Static horizontal acceleration (Gal)
				New design-basis seismic ground motion Ss			Original design-basis seismic ground motion		
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	460	447	258	487	489	412	245		470
Unit 2	348	550	302	441	438	420	250		
Unit 3	322	507	231	449	441	429	291	275	
Unit 4	281	319	200	447	445	422	291	283	
Unit 5	311	548	256	452	452	427	294	255	
Unit 6	298	444	244	445	448	415	495	500	

* ☐ indicates the observed value was beyond the response of Ss, the others were under the response of Ss.



What happened to Fukushima NPP if the tsunami did not mess up? Were fuel assemblies and reactor internals fine so that the NPP can continuously operate without any problem? The same question may be asked for OPR-1000 and APR-1400 assuming that the NPPs experienced BDB seismic accident.

3. Current Analysis Procedure for Seismic Analysis

3.1 Design Procedure and computer Code

When Korea performed the joint design with ABB-CE for YGN 3 &4, fuel assembly mechanical design procedure are as follows:

(1) coupled containment building and RCS (coarse model)
(2) RCS (SG + Reactor Vessel) model to get reactor vessel motion
(3) Reactor vessel internals and fuel model to obtain horizontal & vertical core plate motions: simplified FA model
(4) Detailed core model: detailed spacer grid model
(5) FA stress analysis: FA deflection shape & impact load analysis

For step (3) and (4), CESHOCK code is utilized. In step (4), DSHAPE code searches the CESHOCK output for the displacement shapes which correspond to those of peak displacement, peak shear force and peak bending moment. The FORCE code determines the max. one-sided and through-grid impact loads for every grid in the model. The PULSE code examines the one-sided and through-grid impact force time histories. Those three codes are a kind of post processing codes of CESHOCK.

3.2 Seismic Load Path to FA

When a seismic accident occurs, seismic load path from ground motion to fuel assemblies may list briefly as follows:

1) FA Upper End Fitting (UEF)

Ground motion → Supports below Cold Leg Flange → R.V. Flange→Upper Guide Structure→Tube Sheet Tube on FA Alignment Plate → FA UEF

2) FA Lower End Fitting (LEF)

Ground motion → Supports below Cold Leg Flange R.V. Flange → Core Support Barrel →Lower Core Support Plate → FA LEF

4. Possible Issues on Current Design Method

Design procedure and code system had been established several decades ago including basic characteristic test data of FA by test method.

The characteristic test data for FA model is obtained from air test so far. The data includes vibration modes, damping at each mode, FA-to-shroud and FA-to-FA restitution, grid characteristic data such as crush strength, and load-to-time characteristics during one-sided and through-grid load. Since FA is operating in coolant flow, the characteristic tests should be carried out under water at least or in flowing water.

Now, everyone knows that BDB accident can occur as observed in NPPs at Fukushima. It is very important to know how much real margin could have for FA integrity at Operating Basis Earthquake (OBE) and Safety Shutdown Earthquake (SSE, 0.2g for OPR-1000, 0.3g for APR-1400). Currently, design margin and safety margin are decided according not to real test, but to analysis based on many assumptions. Two ways are possibly suggested to verify real design and safety margins as shown in Fig.1: one is a direct way to perform a real test with real specimen, the other is indirect way to verify design code with a reduced-scale tests [4].

In addition to the design and safety margin that are necessarily verified, since the current design codes are valid in design limit, Code Validation and Verification (Code V&V) may be mandatory to utilize them beyond the design limit into DEC. A reduced scale tests may be performed for the code V&V.

Considering that FA is burning up under the circumstance of pressurized hot water flowing high velocity up to 6 m/s, fluid-structure-interaction (FSI) should be reflected into FA model.

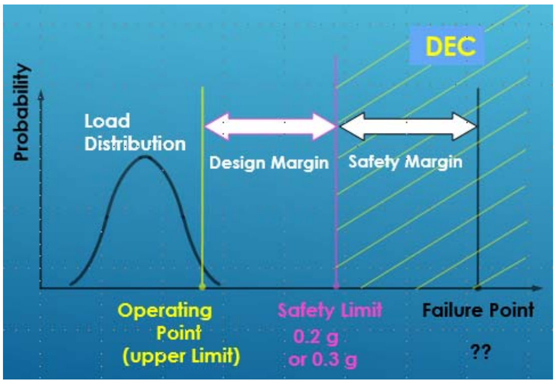


Fig. 1 Design and Safety Margin

5. Conclusions

In this study, we have reviewed seismic analysis procedure and tests for FA mechanical integrity. We may give some recommendation to incorporate BDB seismic accident into DEC as follows:

1) FA characteristic test considering realistic boundary conditions
2) Implementation of FSI into analysis models
3) Verification test to confirm design and safety margin
4) Improvement of design codes to reflect the modern computer capability.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) funded by the Korea government (MSIP) (NRF-2012M2A8A5025825)

REFERENCES

[1] World Nuclear Association, Website: www.world-nuclear.org/information-library/facts-and-figures/world-nuclear-power-reactor-and-uranium-requireme.aspx, Jan. 1, 2016.1.

[2] World Nuclear Association, Website: www.world-nuclear.org/information-library/sefety-and-security/safety-of-plants/nuclear-power-plants-and-earthquake.aspx. Mar. 8, 2016.

[3] IAEA Mission Report, "The great east japan earthquake expert mission: IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NOO Accident Following the Great East Japan Earthquake and Tsunami", Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai Dai-ni NPP, Japan, 24 May – 2 June 2011.

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[4] USNRC Report, "An integrated structure and scaling methodology for sever accident technical issue resolution", NUREG/CR-5809, EGG-2659, Rev/04, Feb. 29, 1992.