Draft for KINS Regulatory Guide on Seismic Isolation System of Nuclear Power Plant Structures

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1. Introduction

After the Kashiwazaki-Kariwa nuclear power plant (NPP) in Japan was seriously affected by the Niigatagen-chuetsu-oki earthquake (16 July 2007, Mw 6.6), the efforts have actively been made to enhance the seismic safety of NPPs. As a part of these efforts, applying a seismic isolation system to NPP structures is being seriously considered and researched in several countries.

To date, only a few NPPs including 4 units in France and 2 units in Republic of South Africa have adopted the seismic isolation systems. However, France recently adopted seismic isolation systems to research reactors under construction such as Jules Horowitze and ITER, and countries such as Japan and US are pushing forward to develop seismic isolation systems for commercial NPPs. Accordingly, regulatory organizations in the US and Japan such as US NRC and JNES have been performing researches for the preparation of regulatory guides on seismic isolation systems [1]. Using the research results, JNES recently distributed a regulatory guide for a seismic isolation system [2]. In Korea, the joint research team including KEPCO E&C, KHNP, KAERI, and EESK has performed a research on applying a seismic isolation system to the APR 1400 system since 2011. In response to this movement, Korea Institute of Nuclear Safety (KINS) is conducting an independent research project to provide a regulatory guide (RG) on seismic isolation systems for NPP structures [3].

In this paper, the framework on a draft KINS RG addressing design, analysis, manufacture, installation, maintenance, and performance evaluation of isolators, isolation systems and isolated structures is presented. The draft RG has been developed based upon domestic and overseas industrial codes & standards, regulatory documents and the related research information available to date.

2. Development of KINS Regulatory Guide

The final objective of the KINS research project is to establish the KINS RG on seismic isolation systems for NPP structures. In this section, the research process, the development of draft and main requirements in the KINS RG are described.

2.1 Research process for developing KINS RG

The research process for developing the KINS RG on seismic isolation systems for NPP structures is as follows:

Step 1 : Investigation and analysis of domestic and overseas industrial codes & standards and regulatory documents
Step 2 : Identifying anticipated safety issues on seismic isolation systems
Step 3 : Identifying severe regulatory requirements through enveloping process of industrial codes & standards and regulatory documents
Step 4 : Preparation of draft for the KINS regulatory guide
Step 5 : Collection of public comments on the draft from independent industrial circles and related research institutes
Step 6 : Finalization of the KINS regulatory guide on seismic isolation systems for NPP structures

The research results for Steps 1 and 2, especially anticipated safety issues on seismic isolation systems, were described in Choi et al. [4] in detail. This paper concentrates on Steps 4 and 5. Steps 5 and 6 are the future works in this study.

2.2 Development of draft KINS RG

Considerable efforts were dedicated to developing the draft KINS RG. Regulatory documents and industrial codes & standards applicable to seismic isolation systems were investigated and regulatory requirements addressing design, construction and operational needs for seismic isolation system were drawn up as severe as possible based on the envelop of the investigated requirements.

Overseas regulatory documents for seismic isolation systems include the NUREG report by US NRC [1] and the JNES regulatory guideline [2]. Industrial codes & standards can be categorized as Korean design

standards including the design code for highway bridges [5] and design of seismic isolated structures [6], and overseas design standards including ASCE 4-13 [7], ASCE 7-10 [8], IAEA technical report [9], AASHTO [10] and ISO 22762 [11].

The overall frame of the draft KINS RG applies the NUREG report issued by US NRC correspondingly. The draft is divided into ten major chapters which are (1) Introduction, (2) Scope, (3) Performance expectation, (4) Isolators and isolation systems, (5) Design of isolated structure, (6) Seismic analysis of isolated structure, (7) Test of isolators, (8) Quality and Maintenance of isolators, (9) Additional considerations on design and operation, and (10) References. The detailed contents and the corresponding enveloping status of the regulatory documents and industrial codes & standards applicable to seismic isolation systems are tabulated in Table 1.

2.3 Main recommendations in draft KINS RG

Main recommendations in the draft KINS RG are as follows:

(1) The performance expectations for the elements of seismically isolated structures including seismic isolation systems, superstructures, umbilicals and moats are determined based on the NUREG report. Ground motion levels are separately defined by a design basis earthquake and a beyond design basis earthquake.
(2) Through the review of mechanical characteristics, performance requirements, load resistance ability, and lateral resiliency of isolators and isolation systems, the related requirements are drawn.
(3) Through the review of the structural plan, isolators, hard stops, and design displacement and load for above and beneath structures, systems and components from isolation interface, the related requirements for designing the isolated structures are drawn.
(4) Concerning the seismic analysis of isolated structures, the requirements for the time domain, frequency domain and multistep analyses are presented and the necessary items for mathematical modeling are identified.
(5) Concerning the prototype and the production tests of isolators, the requirements for specimen, record, procedure, and compatibility for the tests are identified.
(6) Through the review of the inspection, replacement, quality assurance, and maintenance requirements, the related regulatory requirements are identified.

3. Concluding Remarks

As noticed, while the concept of seismic isolation is not new and the technique has been applied to thousands of civil engineering structures worldwide, a full scale application to an NPP structure is rare and technical guides for ensuring the safety is needed.

In this paper, the framework on a draft KINS RG addressing design, analysis, manufacture, installation, maintenance, and performance evaluation of the isolators, isolation systems and isolated structures is presented.

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Table I: Envelop of the regulatory items for industrial codes & standards, regulatory documents

#	Regulatory items	NUREG [1]	JNES-SS-1102 [2]	ASCE 4-13 [7]	ASCE 7-10 [8]	IAEA [9]	Overseas	Domestic
1	**Introduction**	1	1		17.1.1	1, 2.0		[5] 6.9.2
2	**Scope**	1.3	2	7.7.1	17.1	2.1	[10] 1, [11] 1	[5] 6.9.1.1 [6] 0101.2
3	**Performance expectations**	8	4	7.7.1, C7.7.1				
4	**Isolators and isolation systems**							
4.1	General requirements	3.1, 3.2		7.7.2.1.1				
4.2	Isolator	3.3	4.1	7.7.2.2, C7.7.2.2			[11] 5	[6] 0302
4.2.1	Mechanical characteristics	4	4.2	7.7.2.2.1, C7.7.2.2.1		Annex iii.1		
4.2.2	Performance requirements	3.3	4.2	7.7.1, C7.7.1		4.3.2	[11] 6, 7	[6] 0303.1, 0303.2
4.3	Isolated system		5.3.2	7.7.2.1	17.2.4.1~5			
4.3.1	General requirements	3.2, 5.1, 9.1		7.7.2.1.1		3.2	[10] 8.1, 8.2	[5] 6.9.8.1~5 [6] 0401, 0402, 0404
4.3.2	Load resistance ability	5		7.7.2.1.2, C7.7.2.1.2	17.2.4.6, 17.2.4.7			
4.3.3	Lateral resiliency	3.4		7.7.2.1.3, C7.7.2.1.3	17.2.4.4			
5	**Design of isolated structure**							
5.1	Structural plan	3.5	4.3, 5.1			4.4.1, 4.5		[6] 0404
5.2	Design displacement and load	8, 9.1.3, 9.1.4	5.2	7.7.5.1, C7.7.5.1		4.4.1, 4.4.5, 4.4.6, 4.6		
5.2.1	Isolator	8.2, 8.3	5.3.2	7.7.5.2, C7.7.5.2	17.2.4	4.3		
5.2.2	Hard stop	8.2, 9.1.5		7.7.5.3, C7.7.5.3				
5.2.3	SSC above the isolation interface	8, 3.6	5.2.3, 5.2.4, 5.4.1, 5.4.2, 5.5	7.7.5.4, C7.7.5.4	17.2.6.1, 17.6.4.2, 17.6.4.4	4.4.7, 4.4.8, 8.2		
5.2.4	SCs across the isolation interface	8.3	5.2.4, 5.3.2	7.7.5.6, C7.7.5.6	17.2.6.2			
5.2.5	Structures beneath the isolation Interface	9.1.2		7.7.5.5, C7.7.5.5	17.2.6.3, 17.6.4.1			
6	**Seismic analysis of isolated structure**							
6.1	General requirements	7.1.1	6.1			4.1, 6		
6.2	Input seismic motions			7.7.3	17.3, 17.6.3.2	4.2, 4.4.2, 5	[10] 4	
6.3	Analysis Method	7.1.2~4	5.3.2~4, 6.2~4	7.7.4.1, C7.7.4.1	17.4	4.4.4	[10] 7	[5] 6.9.7
6.3.1	Time domain method	7.1.2		7.7.4.1.2, C7.7.4.1.2	17.4.2.2, 17.6.3.4		[10] 7.4	[5] 6.9.7.5
6.3.2	Frequency domain method	7.1.3		7.7.4.1.3, C7.7.4.1.3	17.4.2.1, 17.6.3.3		[10] 7.2, 7.3	[5] 6.9.7.3~4
6.3.2	Multistep method	7.1.4		7.7.4.1.4, C7.7.4.1.4				
6.4	Mathematical modeling	7.2	4.3	7.7.4.2, C7.7.4.2	17.6.2	4.4.3		
6.4.1	General requirements	7.2.1		7.7.4.2.1, C7.7.4.2.1	17.6.4.3			
6.4.2	Modeling of isolators	7.2.2, 7.2.3	5.3.2	7.7.4.2.2~4, C7.7.4.2.2~4	17.6.2.1		[10] 14, 16	[5] 6.9.7, [6] 0502

Table I: Envelop of the regulatory items for industrial codes & standards, regulatory documents (Continue)

#	Regulatory items	NUREG [1]	JNES-SS-1102 [2]	ASCE 4-13 [7]	ASCE 7-10 [8]	IAEA [9]	Overseas	Domestic
7	**Test of isolators**							
7.1	General requirements	9.2.2	7.1	7.7.7.1, C7.7.7.1	17.8.1			
7.2	Prototype test	9.2.2		7.7.7.2, C7.7.7.2	17.8.2		[10] 13.2, [11] 5	[5] 6.9.8.4
7.2.1	Test specimen	9.2.2		7.7.7.2.1, C7.7.7.2.1			[10] 13.2.1	
7.2.2	Test records	9.2.2		7.7.7.2.2, C7.7.7.2.2	17.8.2.1			
7.2.3	Test method	9.2.2		7.7.7.2.3, C7.7.7.2.3	17.8.2.2~7			
7.3	Production test	9.2.2		7.7.7.3, C7.7.7.3			[10] 13.3, [11] 6	[5] 6.9.8.4, [6] 0303.3
7.3.1	Test specimen	9.2.2		7.7.7.3.1, C7.7.7.3.1			[11] 8	
7.3.2	Test records	9.2.2		7.7.7.3.2, C7.7.7.3.2				
7.3.3	Test method	9.2.2		7.7.7.3.3, C7.7.7.3.3				
8	**Quality and maintenance of isolators**							
8.1	Inspection and replacement	9.3.1	5.3.5, 8	7.7.2.1.6, C7.7.2.1.6	17.2.4.8	3.3, 3.4, 7.3		
8.2	Quality control	9.2.1, 9.2.3	7.1, 7.2	7.7.2.2.2, C7.7.2.2.2	17.2.4.9	7.1, 7.2	[10] 15, 17, [11] 11	
8.3	Maintenance	9.3.2~5	5.3.5			7.3		
9	**Additional considerations on design and operation**							
9.1	Other external events	9.1.3						
9.2	Accident conditions and emergency response	9.1.4						
9.3	Moat cap design	9.1.5						
9.4	Peer review	9.1.6						
9.5	Additional seismic monitoring equipment	9.3.2						
9.6	Basemat and foundation design	9.1.2, 9.3.3						
9.7	Operating temperature	9.3.5						
10	**References**							