



## Seismic Design of Korean Next Generation Reactor

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### Abstract

The objective of the Korean Next Generation Reactor(KNGR) seismic design is to develop a cost-effective standard design that can cover most of site characteristics in the world with the possible exception of extremely high seismicity area. This seismic design was based on the current state-of-the-art as well as the current Nuclear Regulatory guidance. This paper provides a summary on the design parameters used in the KNGR seismic design. In addition, this paper discusses seismic design requirements, selection of generic soil sites, selection of design control motions, and soil-structure interaction analyses for the KNGR Nuclear Island structures.

### 1. Introduction

The KNGR is a standard plant being developed by the KNGR Development Group (KNDG) as the next generation of nuclear power plants. This KNGR belongs to the Advanced Light Water Reactor(ALWR), having evolved from the Korean Standard Nuclear Power Plant(KSNP) in commercial operation at Ulchin, since KNGR incorporates a variety of technological and operational improvements to increase the reliability and safety margins.

The KNGR Nuclear Island(NI) consists of the Auxiliary Building, Outer Containment, Inner Containment, Internal Structures and Reactor Coolant System(RCS) (see Figure 1). The NI structures share one common basemat, the top of which is at EL. 55'-0". The plan dimensions of the basemat is 367 foot long by 296 foot wide. The exterior walls of NI structures are embedded about 53 foot, with finished grade at EL. 98'-8". Figure 2 shows the plan layout of the NI. All NI structures are made of reinforced concrete with Inner Containment Vessel of the prestressed concrete.

### 2. Seismic Design Requirements

One of the seismic design requirements for the plant is a Safe Shutdown Earthquake (SSE) of 0.3g. The spectral shape and the selection of the control motion are further discussed in Section 3. Operating Basis Earthquake(OBE) is not part of design basis for KNGR NI structures, since OBE is equal to one third of SSE(Appendix S to 10

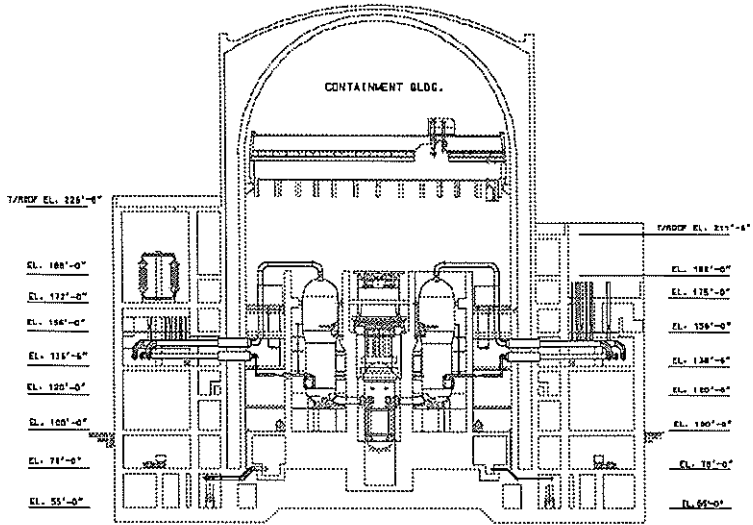


Figure 1. KNGR Nuclear Island, Elevation View

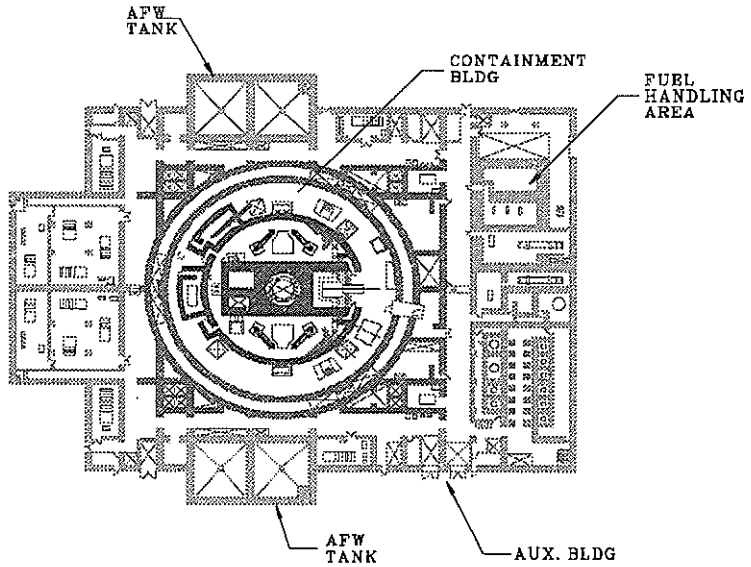


Figure 2. KNGR Nuclear Island, Plan View

CFR Part 50 [1]).

KNGR has established a Seismic Margin Earthquake(SME) level of 0.5g. That is, High Confidence of Low Probability of Failure(HCLPF) levels for essential structures and components to bring the plant into cold shutdown status is equal to or greater than 0.5g.

### 3. Selection of Control Motions

The project included two control motions in the KNGR seismic design basis: Control Motion Spectra 1 and 3, which were in contrast to ABB-CE System 80+ having taken into account of 3 design control motions(CMS1, CMS2, and CMS3) [2]. The Control Motion Spectrum(CMS) 2 was not included in the KNGR design basis, since it may lead to excessive conservatism. This would result in a high cost plant structures and equipment, which would be necessary only for the area of high frequency contents. Thus, for most sites not confronting to such high seismicity, the inclusion of CMS2 in the seismic design basis should be unnecessary.

Two control motions were chosen with the following thought process in support of design and standardization.

- Control Motion Spectrum 1 (CMS1) : This spectral shape is identical to the Regulatory Guide 1.60 spectrum [3]. It is considered in design to cover sites with deep soil deposits. The design based on this spectral shape satisfies the Korean Utility Requirements Document(KURD) [4] requirements for advanced nuclear power plant design.
- Control Motion Spectrum 3 (CMS3) : This is a rock outcrop spectrum, having been developed based on the recommendations of the NUREG/CR-0098 [5] primarily to cover lower frequency motions which may not be covered by CMS2 [2]. This widens the high frequency range to cover earthquakes with high frequency contents. The maximum spectral acceleration range is extended to 15 Hz, as opposed to 8 Hz which is used in NUREG/CR-0098 motions.

Both of the above Control Motion Spectra are shown in Figure 3. CMS3 is applied at the rock outcrop, whereas CMS1 is applied at the free-field ground surface. All both motions are applied to each of the site categories as defined below in order to develop the design basis of the plant.

The design spectra of both motions are anchored to 0.3g horizontal peak ground acceleration. For the vertical direction, CMS3 is anchored to a vertical peak ground acceleration of 0.2g(two thirds of the horizontal PGA). CMS1, being defined as a control motion for application at the free-field ground surface is defined to have a vertical peak ground acceleration of 0.3g, the same as the horizontal PGA.

### 4. Selection of Envelope of Soil Sites

Twelve generic soil sites and one rock site conditions were considered in ABB-CE System 80+ [2]. In contrast, eight generic soil sites and one rock site conditions were

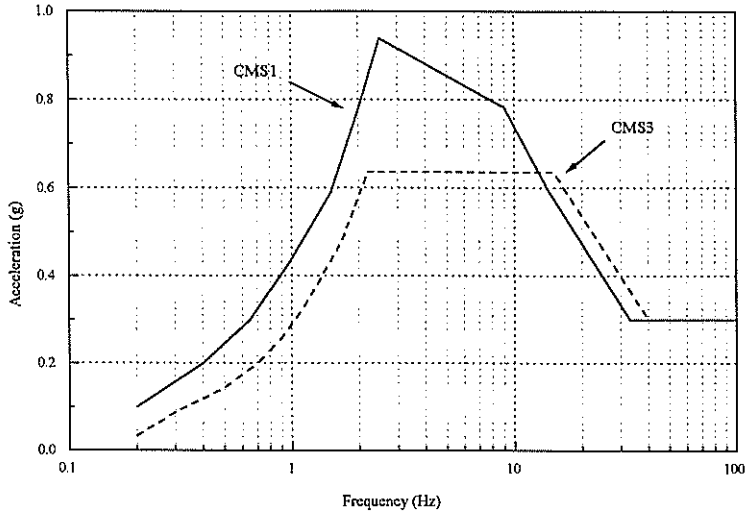


Figure 3. KNGR Control Motion Spectra Horizontal Direction, 5% Damping

considered to cover the site envelope characteristics of KNGR. One of the System 80+ soil categories (i.e., the soil case of 300 ft depth) was excluded since it was too deep to consider for possible KNGR construction sites and not governing in soil-structure interaction analyses of System 80+. The values of eight soil conditions were appropriately adjusted so as to reflect the soil conditions of KNGR construction sites and the soil conditions of System 80+.

The site parameter variations within these 9 conditions were chosen such that when combined with the effects of the 2 design control motions, the resulting free-field ground surface spectra would contain earthquake energy in all frequency ranges which are important in design of structures and components. Site conditions were chosen to cover sites with shear wave velocities as low as 1,000 fps, to rock site conditions.

The 3 site categories defined as A, B, and C, respectively was chosen. These correspond to depth of soil to bedrock values of 53', 100', and 200', respectively. Within each site category various soil property variations were chosen to cover the range of interest. At first, one case was chosen for site category A (namely, A-1), 4 cases for site category B (namely, B-1, B-2, B-3, and B-4), and 3 cases for site category C (namely, C-1, C-2, and C3). These 8 cases together with the rock case formed 9 site conditions chosen for the site envelope. Figure 4 shows all 8 soil site conditions used in the design basis of KNGR.

Figure 5 shows the envelope of free-field surface spectra resulting from the excitation

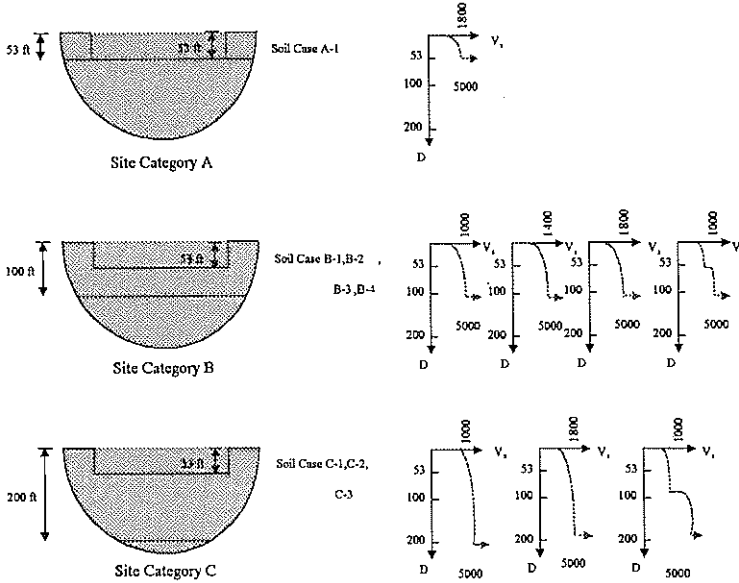


Figure 4. Generic Site Conditions used to Develop the Seismic Design Basis

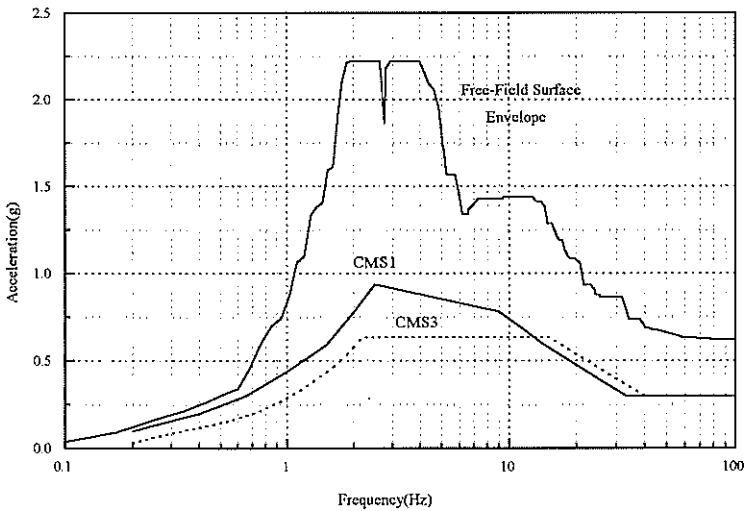


Figure 5. Envelope of Free-Field Surface Spectra Horizontal Direction, 5% Damping

of each of the above site conditions to rock outcrop control motion CMS3, for the horizontal direction. Superimposed on this figure is the original design control motion spectra(CMS1 and CMS3). As shown in this figure, the seismic design basis of KNGR is well in excess of the Regulatory Guide 1.60 requirements and the 0.3g free-field PGA, making the plant robust for construction even in areas of high seismicity.

### 5. Soil-Structure Interaction Analyses

Soil-Structure Interaction(SSI) analyses were performed in order to develop the seismic response of the KNGR for the site envelope. Lumped mass stick models were developed to model all the structures on the NI. This paper describes SSI analyses of NI structures. The stick model section properties were developed using finite element models. These stick models were "tuned" such that the mode shapes, frequencies, and mass participation factors matched those obtained from detailed three-dimensional finite element models. Figure 6 shows the SSI schematic system used for seismic analyses of KNGR NI structures.

All SSI analyses were performed using the SASSI computer program [6]. In addition, fixed-base analyses were performed to simulate the rock site conditions. Two fixed-base analyses were performed. First one is based on the traditional assumption that only the base of the structures is fixed. The second one assumes that both the base and sides of the structures within the embedded region were fixed, representing site conditions with concrete type backfill material. As such, a total of 8 SSI cases and 2 fixed-base conditions were analyzed for each of the 2 control motions(i.e., CMS1 and CMS3), which amounts to 20 analyses cases composing the seismic design basis of the KNGR. Figures 7 to 12 provide results of SSI analyses and cumulative stick shear force diagrams for Auxiliary Building and Containment Building

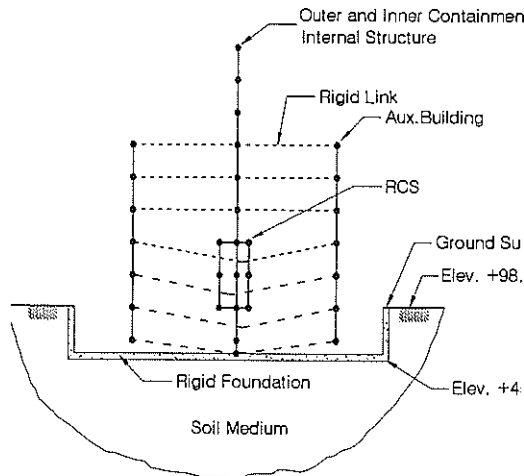


Figure 6. Schematic Representation of KNGR SSI System

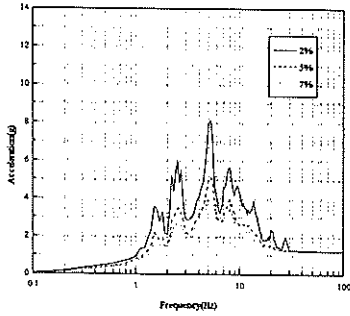


Figure 7. SSE Response Spectra, All Soil Cases, E-W, Auxiliary Building, EL.211.5'

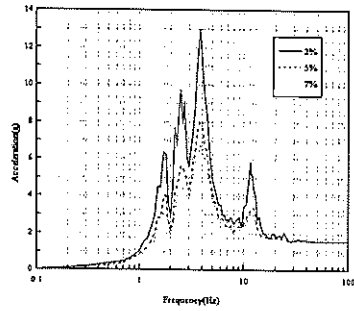


Figure 8. SSE Response Spectra, All Soil Cases, E-W, Inner Containment, EL.331.25'

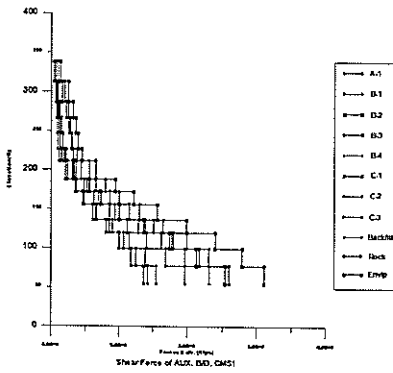


Figure 9. Cumulative Stick Shears of Auxiliary Building, CMS1 Motion, E-W

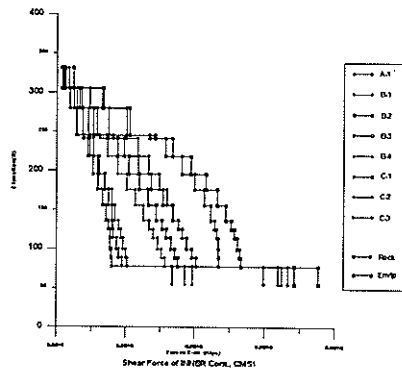


Figure 10. Cumulative Stick Shears of Inner Containment, CMS1 Motion, E-W

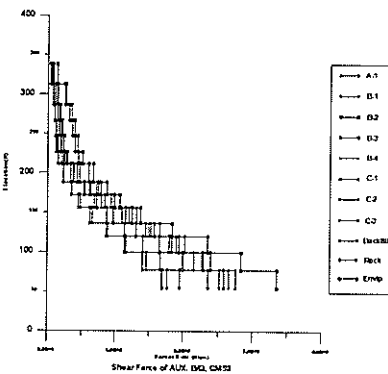


Figure 11. Cumulative Stick Shears of Auxiliary Building, CMS3 Motion, E-W

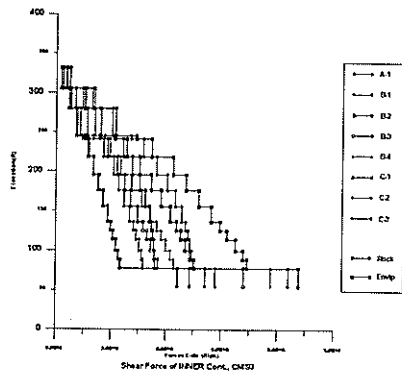


Figure 12. Cumulative Stick Shears of Inner Containment, CMS3 Motion, E-W

## 6. Conclusions

Conclusively, the following can be stated:

- The SSI analyses were performed in order to develop the seismic response of the KNGR for the site envelope.
- The KNGR design included 2 design control motions(CMS1 and CMS3) in the seismic design basis. CMS2 was excluded, because it may lead to excessive conservatism in KNGR seismic design.
- In order to cover an envelope of site conditions suitable for construction of the KNGR, the design considered 8 generic soil sites and one rock site conditions. This can sufficiently cover most of site conditions.
- The broadened in-structure FRS were developed and cumulative stick shear forces were extracted for NI structures. These are used in the seismic design of RCS and the static design of concrete structures.

## References

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