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Comparison of Elastic and Nonlinear Time-History Analyses for Nuclear Power Plant

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1. Introduction

The seismic safety assessment of nuclear power plants relies heavily on accurately estimating the structural response under earthquake loading. To date, most structural analyses of nuclear facilities have been performed within the elastic range, and linear time history analysis (LTHA) has been the standard tool in probabilistic safety assessment (PSA) and seismic performance evaluation. While this approach offers computational efficiency, it has inherent limitations, as actual earthquake excitations may induce inelastic behavior, leading to either underestimation or overestimation of structural responses.

Traditional attempts to account for inelastic effects have primarily relied on empirical factors, such as the inelastic absorption factor or equivalent linearization methods. However, these indirect approaches often lack generality and may not capture the nonlinear characteristics of complex structures under varying seismic conditions. In particular, auxiliary buildings in nuclear power plants, which exhibit irregular configurations and diverse boundary conditions, require direct nonlinear simulations to accurately capture their seismic response.

This study aims to compare the results of linear and nonlinear time history analyses under identical conditions for a representative nuclear power plant auxiliary building. Special attention is given to critical response parameters, including changes in natural frequencies, differences in response spectra, inter-story drift ratios, and residual deformations. By quantifying the discrepancies between linear and nonlinear analyses, this work provides essential insights into the limitations of current elastic-based evaluations and contributes to the development of more realistic and reliable seismic performance assessment methodologies for nuclear structures.

2. Analysis model

The auxiliary building of APR1400 was used for analysis. Figure 1 shows the model in Abaqus program. A structure composed of orthogonal walls, such as an auxiliary building, can be regarded as a representative system that exhibits a combined response of membrane and bending behavior when subjected to lateral loads such as seismic excitations. Therefore, a layered shell element was employed for the modeling. The material models for concrete and reinforced bar were concrete damage model and bi-linear model, respectively.

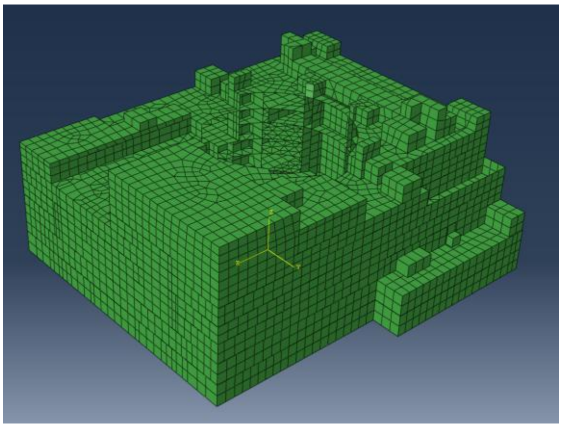

Figure 1. Auxiliary building of APR1400

The input ground motion was generated as an artificial earthquake record, following the spectrum specified in NUREG-0098, with the Gyeong-ju earthquake adopted as the seed motion.

For the linear elastic analysis, the input ground motion was scaled to a peak ground acceleration (PGA) of 0.3g. In contrast, the nonlinear analysis was performed using input ground motions scaled to PGAs of 0.3g, 0.5g, and 0.7g.

3. Analysis results

Figure 2 shows the floor response spectra at the center of each floor and comparison of floor response spectra between elastic and nonlinear analysis according to frequency. The comparison shows the ratio of elastic and nonlinear analysis

At a PGA of 0.3g, the structure exhibited an almost elastic response, and thus no significant difference was observed between the results of linear elastic and nonlinear analyses. However, as the input PGA increased, discrepancies between the two analyses became evident. Overall, the nonlinear analysis results showed smaller response amplitudes in the vicinity of the natural frequency range compared to the linear elastic analysis.

Using the 0.7g case as a reference, the nonlinear (NLTHA) and linear elastic (LTHA) responses by plotting the ratio EL/NL over frequency for four representative locations was compared.

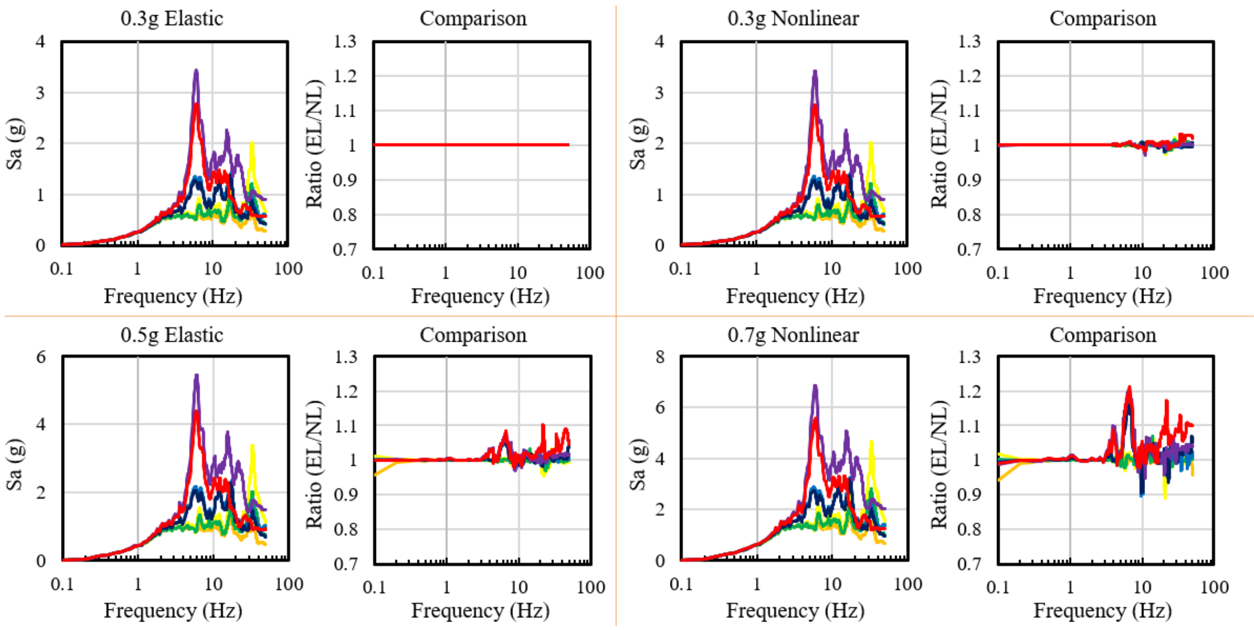

Figure 2. Floor response spectra of each floor and comparison between elastic and nonlinear time history analysis.

Area 1 (horizontal direction, high level of auxiliary building): Around the first-mode band (5–5.7 Hz) the elastic analysis results was greater than the elastic result by over 10%. This local amplification is consistent with slight modal drift and stiffness degradation near first yield, which increases the response close to resonance.

Area 2 (horizontal direction, corner of upper region ~172 ft): In the high-frequency range (>15 Hz) the nonlinear response is clearly greater than the elastic one. Energy dissipation and microcracking induce the high-frequency content at this elevation.

Area 3 (vertical direction, slab element): At the high frequency band, in the case of nonlinear analysis, comparison result shows 10% less than that of elastic analysis. Vertical response is sensitive to local stiffness changes of slabs and wall–slab interaction, which can shift and amplify peaks in this band.

Area 4 (vertical direction, large area): A broad band (≈5–25 Hz) exhibits amplification ≥10% and up to ~50% in the elastic results. This indicates distributed nonlinear mechanisms (e.g., cracking, contact/open-close effects at openings) that couple with vertical modes over a wide frequency range.

4. Conclusions

This study investigated the seismic response of a nuclear-related auxiliary structure considering both elastic and nonlinear time history analyses. Artificial ground motions were generated using the Gyeong-ju earthquake as a seed motion, scaled to match the NUREG-0098 design spectrum. For the elastic analysis, the input PGA was set to 0.3g, while for the nonlinear analysis, three intensity levels (0.3g, 0.5g, and 0.7g) were applied. The results of both methods were compared in terms of floor response spectra and the frequency-domain characteristics of structural response.

The ratio EL/NL > 1 in most frequency bands, indicating that elastic analysis generally overestimates the nonlinear response (conservative).

However, in some localized high-frequency vertical responses, the ratio drops to ≈1 or slightly below, showing that elastic analysis may underestimate the response.

Therefore, the conservatism of elastic analysis depends on frequency and location, and nonlinear effects should be considered for accurate evaluation.

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REFERENCES

[1] Lubliner, J., Oliver, J., Oller, S., & Sancho, J. M. (1989). A plastic-damage model for concrete. International Journal of Solids and Structures, 25(3), 299–326

[2] U.S. Nuclear Regulatory Commission. (1978). NUREG/CR-0098: Development of criteria for seismic review of selected nuclear power plant structures, systems, and components. U.S. Nuclear Regulatory Commission.