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Original Article

# INTEGRITY ANALYSIS OF AN UPPER GUIDE STRUCTURE FLANGE

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ABSTRACT

The integrity assessment of reactor vessel internals should be conducted in the design process to secure the safety of nuclear power plants. Various loads such as self-weight, seismic load, flow-induced load, and preload are applied to the internals. Therefore, the American Society of Mechanical Engineers (ASME) Code, Section III, defines the stress limit for reactor vessel internals. The present study focused on structural response analyses of the upper guide structure upper flange. The distributions of the stress intensity in the flange body were analyzed under various design load cases during normal operation. The allowable stress intensities along the expected sections of stress concentration were derived from the results of the finite element analysis for evaluating the structural integrity of the flange design. Furthermore, seismic analyses of the upper flange were performed to identify dynamic behavior with respect to the seismic and impact input. The mode superposition and full transient methods were used to perform time–history analyses, and the displacement at the lower end of the flange was obtained. The effect of the damping ratio on the response of the flange was also evaluated, and the acceleration was obtained. The results of elastic and seismic analyses in this study will be used as basic information to judge whether a flange design meets the acceptance criteria.



## 1. Introduction

Reactor vessel internal (RVI) assemblies are part of the reactor coolant system and are located inside the reactor pressure vessel. The RVIs are long-lived passive structural components. The intended functions of RVIs are to support core cooling, enable control rod insertion, and maintain the integrity of the fuel [1]. The RVI components are largely classified into three categories: (1) the core support barrel (CSB), (2) the lower support structure (LSS) and core shroud (CS), and (3) the upper guide structure (UGS) [2]. The UGS assembly is located above the reactor core within the CSB. The functions of UGS assembly are to provide alignment and support of the fuel assemblies, to maintain the control element assembly (CEA) shroud spacing, to prevent the movement of the fuel assemblies in the event of a severe accident condition, and to protect the control rods from a cross-flow effect [1]. The UGS flange has a key functional role in the UGS assembly supporter.

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During the operation of the reactor, the upper part and lower part of UGS flange are in contact with the closure head of the reactor vessel and the hold-down ring, respectively.

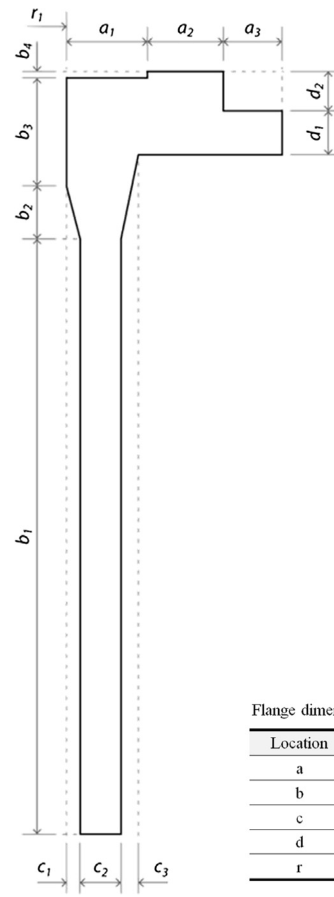
After the Fukushima accident, more attention has been focused on the safety and availability of important components and the system of nuclear power plants under internal accidents and extreme disasters [3]. In particular, the integrity of RVIs is critical to the safe operation of a nuclear power plant. Therefore, the American Society of Mechanical Engineers (ASME) Code classifies RVIs as independent components [i.e., the core support structure (CSS)] and requires certified detail stress reports to prove safe operation during the design life [4]. The ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, defines the stress limits on the membrane and bending stresses for the CSS components [5]. The membrane and bending stresses along some selected sections are calculated from a numerical model and compared to the ASME Code requirements [4]. Allowable stress intensities of RVIs should not exceed the design limits specified in the ASME Code, which are expressed by the design stress intensity values (i.e., $S_m$) [5]. To compare the allowable stress intensities and the design criteria, the elastic analysis for internal structures are needed in the design process. Furthermore, a response analysis undergoing dynamic behaviors with respect to the seismic or impact inputs should be conducted during the design process to secure the safety of the RVIs [6]. In general, lumped mass stick models are used to perform seismic analysis. However, the full three-dimensional (3D) finite element (FE) model was used in this study. The stress intensity distributions under impact and seismic excitation can assess the structural integrity of the RVIs. Based on the results, the RVIs could be manufactured from a design specification that reflects the elastic analysis results with the appropriate design loads.

In this study, the elastic and seismic analysis results of the UGS upper flange for Korean pressurized water reactor (PWR) nuclear power plants are presented for integrity verification, based on the presence of various internal and external loads. The distribution of stress intensities of the flange FE model was analyzed under eight types of design load combinations, which increase in the steady state. Furthermore, the seismic and impact analysis were performed with different damping types and ratios. The analysis results were applied to assess the structural integrity of the UGS upper flange during normal operation, impact, and seismic excitation.

## 2. Elastic analysis

### 2.1. Upper guide structure upper flange geometry and analysis model

The method applied in the elastic analysis included a calculation of the structural response using a two-dimensional (2D) FE model. Fig. 1 presents the detailed geometry of the UGS upper flange. The dimensions are based on the design specification of the UGS upper flange in commercial Korean standard nuclear power plants. The meshes of the geometric modes were generated using the structural analysis program, ANSYS version 14.5 (ANSYS Inc., Canonsburg, PA, USA). PLANE 25 element was used to calculate the distribution of the stress




Flange dimensions (in.)

| Location | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| a | 6.316 | 5.746 | 4.375 | |
| b | 45.00 | 4.500 | 8.000 | 0.500 |
| c | 1.062 | 3.000 | 1.190 | |
| d | 3.250 | 3.000 | | |
| r | 64.438 | | | |

**Fig. 1 – Dimensions of the upper guide structure upper flange.**

intensities. Fig. 2 presents the 2D FE model. There were 1,409 nodes in the generated analysis mode. This study assumes that the UGS upper flange is fabricated of Type 304L stainless steel. The corresponding material properties are shown in Table 1.

### 2.2. Boundary condition and applied load cases

When evaluating the accurate structural response, constraints are important factors because they limit the strain on structures and affect their stiffness [7]. The lower surface of the UGS upper flange is arrested in the hold-down ring and the upper flange of the CSB assembly. The upper end of the flange is in contact with the closure head of the reactor vessel. As a result, the degrees of freedom (DOF) in the vertical and circumferential direction at the UGS assembly are fixed [7].

The rules and guidelines of ASME Boiler and Pressure Vessel Code, Section III, Subsection NG, can be used in the elastic analysis of the RVI components. An important feature of this method is the combination of all possible loads to which the RVI components are subjected. For example, the design loadings that are used when determining the component stress analysis are the following: (1) the differential pressure resulting from coolant flow; (2) the weight of the structure; (3) the superimposed loads from other components;