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Development of Three-dimensional Green's Function for Pressurizer Shell

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1. Introduction

The lifetime of nuclear power plant is mostly dependent on fatigue life of major components, and thus, the exact evaluation of fatigue life on major components is important to determine the continued operation [1~5]. In this paper, three-dimensional (3-D) stress and fatigue analyses are carried out. For this purpose, instead of conventional discrete subcomponents, a complex full geometry is considered. Then, temperature and mechanical stress transfer Green's functions are derived from finite element analyses employing unit input and applied to critical locations of pressurizer shell. Based on comparison of resulting stresses obtained from the Green's function and detailed 3-D finite element analysis (FEA), suitability of the three dimensional Green's function itself is investigated. Finally, prototype of fatigue life assessment results is provided and relevant ongoing activity is described.

2. 3-D Finite Element Analysis

2.1Finite element model

The finite element model was prepared to get the stress variation at concerned locations in pressurizer shell. Then, a series of FEA were performed by using the general-purpose finite element program, ANSYS [6].

Fig. 1 shows a 3-D finite element model, employed in the present work, which consists of 14,384 elements with 22,132 nodes. Two locations, bottom head to shell transition region (Point A) and the end point of surge nozzle (Point B), were selected as critical points for investigation.

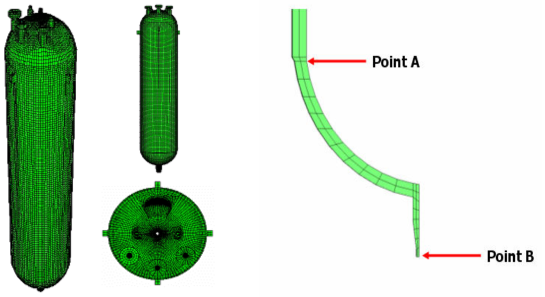


Fig. 1 The finite element model and two critical points

In order to verify the finite element model, hoop stress distributions at outer surface of shell is compared with those from well-known theoretical solution, as shown in Fig. 2, which showed a good agreement.

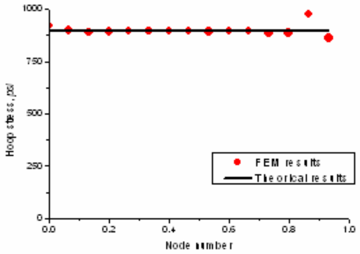


Fig. 2 Comparison of hoop stresses between finite element analysis result and theoretical solution

2.2 Design transient

For 3-D FEAs to develop Green's functions, typical design transients such as steady-states and heat-up & cool-down conditions were selected. Figs. 3 and 4 show the idealized pressure and temperature variations.

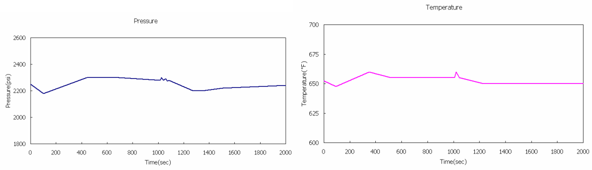


Fig. 3 Design transient A: steady-states condition

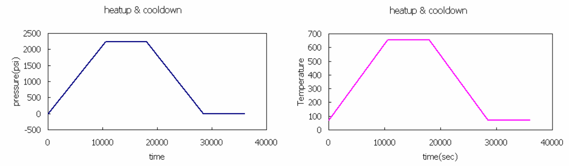


Fig. 4 Design transient B: heat-up & cool-down condition

3. Development of Green's Function

The stress at an arbitrary point of component can be divided into two parameters as following expression.

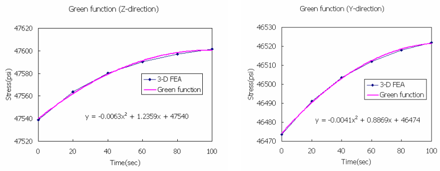
$$\sigma(t) = \sigma_P(t) + \sigma_T(t) \quad (1)$$

where, $\sigma_P(t)$ is the stress vector for primary loading condition such as weight, pressure, thermal expansion, etc. and $\sigma_T(t)$ is the stress vector due to thermal histories. The second term can be obtained by applying a Green's function according to the transient history. The Green's function is usually defined as the response of a system to a standard step input. The important property of the

Green's function is that, when suitably defined, it contains all essential information of the system. Combining Green's function with Duhamel's theorem, the change of thermal stresses at time τ due to a small change of the temperature boundary at time τ can be expressed as follows:

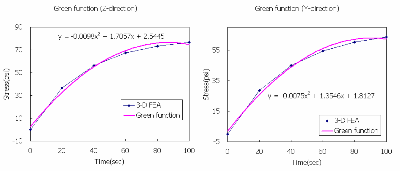
$$\sigma(t) = \int_0^t G(p, t-\tau) \frac{\partial}{\partial \tau} \phi(\tau) d\tau \tag{2}$$

where, *G(p, t)* is the stress transfer Green's function, which can be determined by using the unit step thermal loading. In this paper, individual Green's function is obtained at each direction. Figs. 5 and 6 depict representative Green's functions obtained at two critical points under two typical design transients.



(a) Point A (b) Point B

Fig. 5 Green's function of steady-states condition

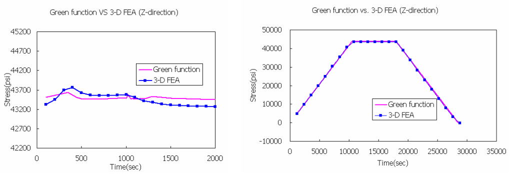


(a) Point A (b) Point B

Fig. 6 Green's function of heat-up & cool-down condition

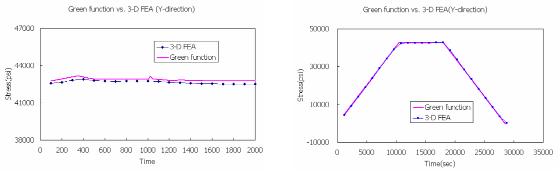
4. Verification of Green's Function by 3-D FEA

For verification, the stress distributions obtained from the twelve Green's functions were compared with those from detailed 3-D finite element analysis. At two critical locations, it showed a good agreement as depicted in Figs. 7 and 8.



(a) steady-states (b) heat-up & cool-down

Fig. 7 Comparison of stress distribution at Point A



(a) steady-states (b) heat-up & cool-down

Fig. 8 Comparison of stress distribution at Point B

5. Fatigue Life Assessment

The fatigue life assessment by using the verified Green's functions was also carried out at two critical points under both steady states and heat-up & cool-down conditions. For the assessment, appropriate S-N curve of carbon and low alloy steel designated in ASME Sec. III, was used. The resulting maximum alternating stress, allowable number of cycles and cumulative usage factor (UCF) under heat-up & cool-down condition are summarized in Table 1. The number of design cycle regarding the heat-up & cool-down condition was 500 and the CUF due to steady states condition was not considered since the corresponding alternating stress was less than endurance limit.

Table 1 Fatigue life assessment results at critical points

Variable	Point A	Point B
S_a (*ksi*)	36.7	45.93
$N_{allowable}$ (cycles)	17,142	9,000
CUF	0.029	0.056

6. Conclusion

In this paper, a method to assess fatigue life of pressurizer shell is proposed based on a 3-D Green's function. The specific Green's functions are verified through detailed 3-D finite element analysis and promising. At this time, an extended works are being carried out employing real operating data instead of typical design transients. The real operating data is generated by Korea Institute of Nuclear Safety (KINS) through a monitoring system named as Computerized technical Advisory system for the Radiological Emergency (CARE) [7].

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