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A methodology for calculation of thermal stress based on Green's function and artificial neural network

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1. Introduction

Recently, many nuclear reactors are being operated beyond their design life or will be approaching their life. During the long term operation, various degradation mechanisms are occurred. And, fatigue damage caused by operational loads is the one of important damage mechanisms in NPPs. To monitor the fatigue damage of major components, fatigue monitoring system (FMS) has been installed. Most of FMS have used Green's function approach (GFA) to calculate the thermal stresses rapidly. However, because the temperature-independent material properties are used in the existing GFA, it cannot be directly used when the temperature-dependent material properties are considered [1]. So, in this paper, the modified Green's function which can consider temperature-dependent material properties is proposed by using an artificial neural network (ANN). To verify the modified GFA, thermal stresses by the proposed method are compared with those by finite element analysis (FEA) at the transition wall of a vessel.

2. Theoretical background

Kuo et. al. proposed the thermal stresses calculation method using transfer matrices and Green's function to calculate the thermal stresses[1]. According to this method, so-called GFA, the thermal stresses at an arbitrary location can be defined as Eq. (1).

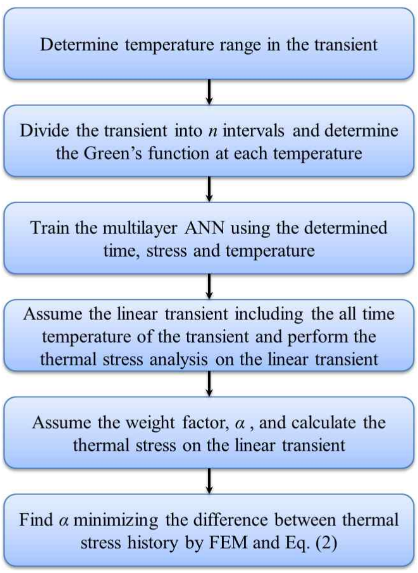


Fig. 1 The procedure to determine the Green's function

$$\sigma_{th}(t) = \int_0^t G(t-\tau)\frac{\partial}{\partial \tau}\phi(\tau)d\tau \qquad (1)$$

where $G(t)$ is a Green's function for the thermal stresses at arbitrary location and $\Phi(t)$ is the coolant temperature for a transient operation. Green's function is defined as a stress variation at the arbitrary point when the coolant temperature is increased as a unit step. However, the existing GFA cannot calculate the thermal stresses considering a change of material properties with a temperature variation because the temperature-independent material properties are used when the Green's function is determined. So, in this paper, the modified Green's function which can consider the temperature-dependent material properties is proposed by using an artificial neural network (ANN).

Fig.1 shows the procedure of proposed method. First of all, temperature range of the arbitrary transient is determined. The all range of the transient is divided into n intervals, and the Green's function at the each temperature is determined using finite element method (FEM). When the Green's functions are determined by FEM, temperature-dependent material properties are used. An ANN which is composed of multilayer is trained by using the determined Green's functions. Then, as Eq. (2), the relationship among time, stress and temperature can be modeled as the trained network, $G_{ANN}(t, T)$. And, thermal stress at specific time and temperature can be predicted using this network, modified Green's function. After that, the linear transient which can include the all temperature and time of the transient is assumed.

$$\sigma_{th\_new}(t) = \int_0^t \alpha \cdot G_{ANN}(t-\tau, T)\frac{\partial}{\partial \tau}\phi(\tau)d\tau \qquad (2)$$

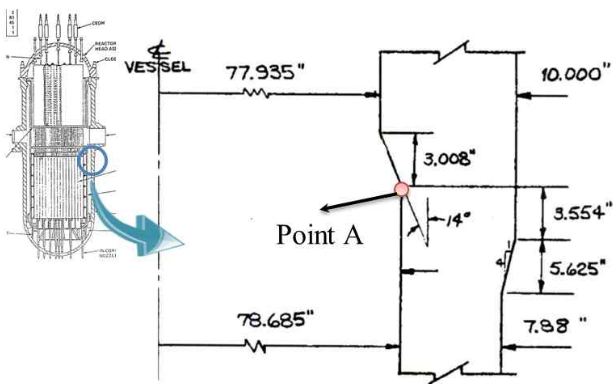
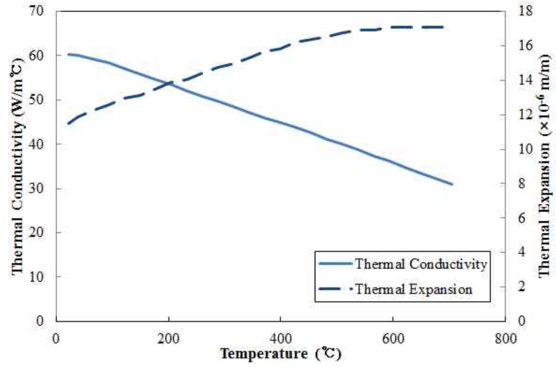
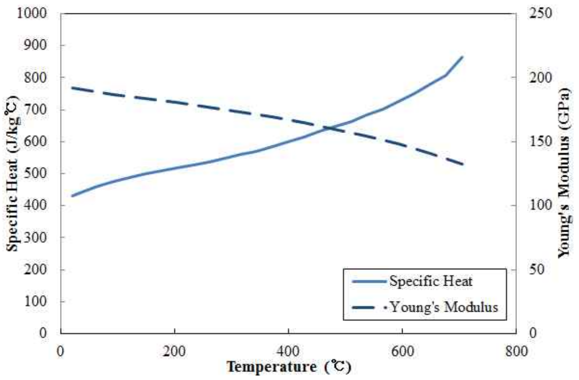


Fig. 2 The geometry of transition wall



(a) Thermal conductivity and Expansion



(b) Specific heat and Young's modulus

Fig. 3 Material properties as a function of temperature

And the thermal stress analysis on the linear transient is performed. The next step is to assume weight factor, α in Eq. (2), and to calculate the thermal stresses on the linear transient using Eq. (2). And then, find α minimizing the difference between thermal stress history by FEM and Eq. (2). If α is determined, the thermal stress history on the arbitrary transient at the critical point can be calculated by Eq. (2)

3. Verification

As shown in Fig. 2, the transition wall of the reactor pressure vessel (RPV) is selected as the interesting component. And, the critical location is the point A. For the modeling, an axisymmetric finite element (FE) model is used. And heat transfer by the convection is occurred at the inner surface of the transition wall and the film coefficient value is 630.5W/(m^2℃). And the outer surfaces of the wall are assumed to be thermally insulated. Carbon steel (SA508) is used as the material of vessel wall. Fig. 3 represents material properties as a function of temperature. To verify the modified Green's function, thermal stresses by the proposed method are compared with those by FEA at the point A. Fig. 4 presents the assumed and linear transient. The temperature range of these transients is from 25℃ to 385℃ and the Green's function at intervals of 25℃ is determined using temperature-dependent material properties. And then, the ANN is trained using thermal stress values of each Green's function.

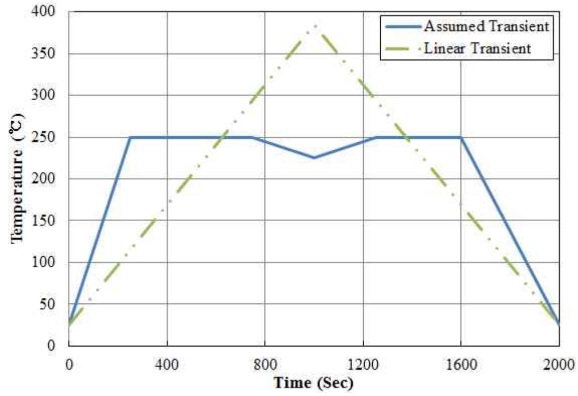


Fig. 4 Transient history at the inner surface

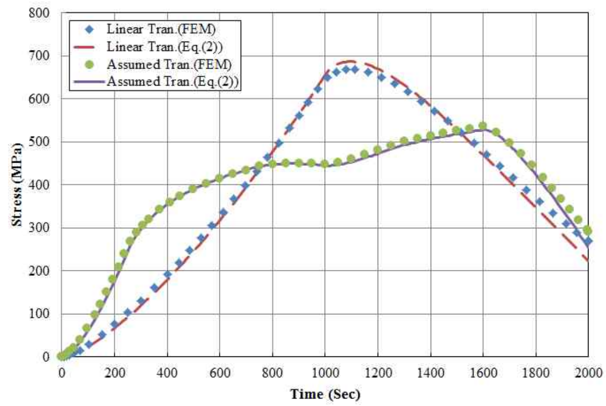


Fig. 5 Thermal stress comparison between the modified method and FEM

At the point A, the equivalent stresses are obtained and Fig. 5 shows the comparison results of equivalent stresses for the transients. When thermal stresses on the linear transient by FEM are compared with those by Eq. (2), α minimizing the difference between thermal stress histories is 0.9339. Thermal stress analysis on the assumed transient is performed using the determined weight factor. As shown in Fig. 5 when results by new method are compared with those by FEM, the results between two methods show a good agreement.

4. Conclusions

In this paper, the modified Green's function considering temperature-dependent material properties is proposed by using neural network. To verify the proposed method, thermal stresses by the modified Green's function are compared with those by FEM and the results between two methods show a good agreement. Finally, it is anticipated that more precise fatigue evaluation is performed by using the proposed method.

REFERENCES

[1] H. Zhang, Y. Xiong, C. Nie, D. Xie and K. Sun, A methodology for online fatigue monitoring with consideration of temperature-dependent material properties using artificial parameter method, Journal of Pressure Vessel Technology Vol. 134, pp. 011201.1-011201.6, 2012.