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ASSESSMENT OF DESIGN MARGIN OF FATIGUE OF RPV BASED ON OPERATING DATA

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1. Introduction

Reactor Pressure Vessel (RPV) is designed as such that it is compliance with the requirements of the construction code throughout its design life. In the course of the detailed design by analysis, stress analysis is performed in accordance with design basis thermal cycles.
These design basis thermal cycles are set for design of RPV, so both temperature and pressure changing ratios are considered to be set to be conservative compared with those measured in operating plants. And stress resulting from these thermal cycles is also considered conservative. If that's true, then that means that even though design basis cumulative usage factor (CUF) shows some higher value, the actual CUF evaluated based on actual plant data is very low.

To evaluate the actual CUF of a specific RPV based on its operating experience is one of the most important items for plant life extension (PLEX) of nuclear power plant. For that object, it is necessary to set the optimum analytical condition to evaluate the actual stress resulting from actual phenomena. As a first step of finding optimum analytical condition, numerical analysis by 2D Finite Element Analysis (FEA) based on actual plant data has been carried out. By adjusting boundary condition of the analysis, then, temperature distribution similar to the measured one could be obtained.
As a result, for some events such as start-up and shutdown, some extent of conservatism was found in the design basis analysis compared with the one obtained from actual process data.

On the other hand, if actual CUF of a specific RPV based on its operating experience is calculated by FEA method, which is widely applied in these days, it takes longer time and much cost. So from the commercial stand point of view, current evaluation technique is not practical. To save time and cost, simplified evaluation technique is needed to develop.
Considering the licensing problem, this kind of evaluation technique should be as such that the results obtained by this technique should give close to the exact value or at least a little bit conservative value. There are some techniques already proposed and applied for the plants, but we think no technique verifies that the procedure does not give unconservative results. We are establishing simplified procedure that gives very close to exact value but never gives unconservative value.
This paper describes the assessment of design margin of RPV taking the feedwater nozzle and support skirt as representatives of RPV of Boiling Water

Reactor (BWR) , which are considered to be critical among other parts, and development of simplified evaluation procedure.

2. Evaluation Procedure

The evaluation procedure is shown in Fig. 1. As shown in the figure, actual CUF against specific operating condition and/or transient was evaluated in accordance with the steps described below:

(1) Comparison between temperature obtained based on design basis analytical method and the one measured in plant.
(2) Optimization of boundary condition of the analysis.
(3) Get CUF by FEA
(4) Evaluation of design margin by comparing CUF obtained in step (3) above and the one obtained by design basis.

Each item is discussed in the next paragraph.

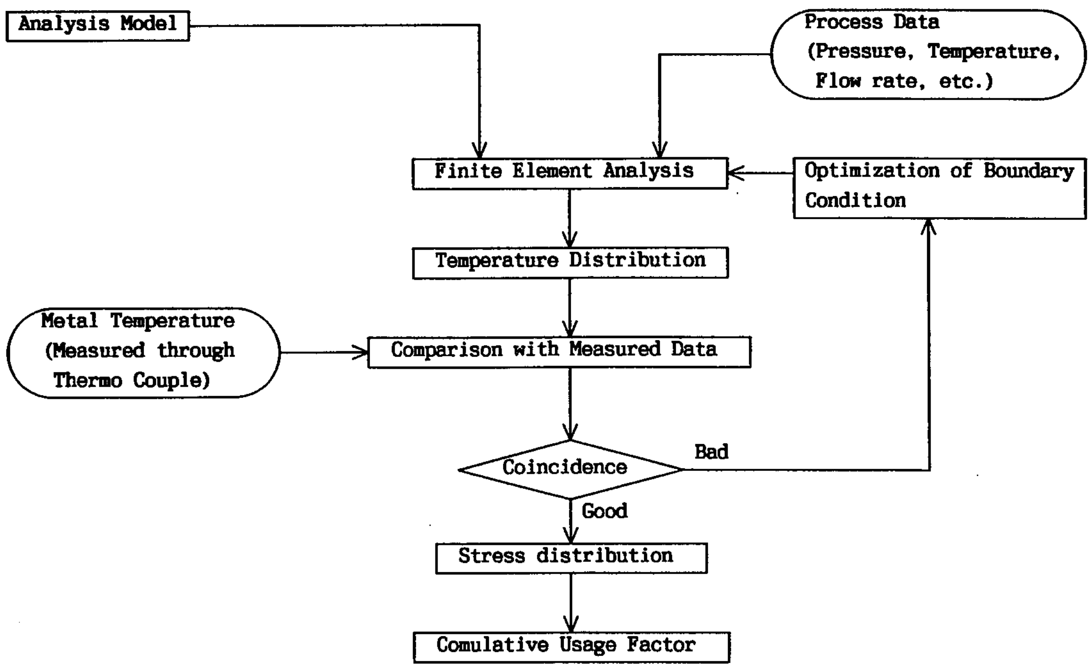
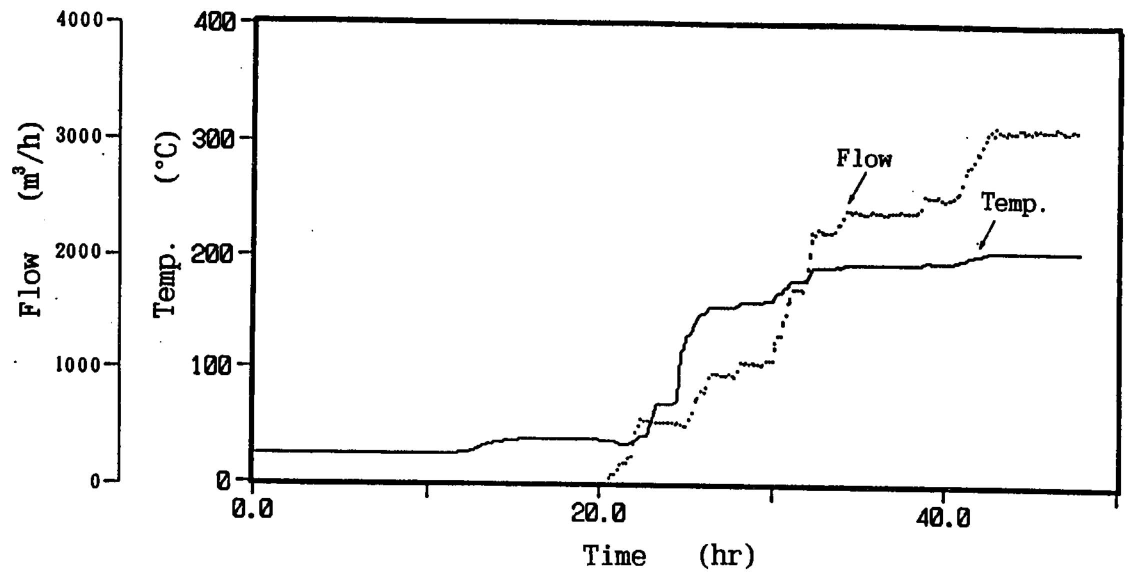


Fig. 1 Evaluation procedure

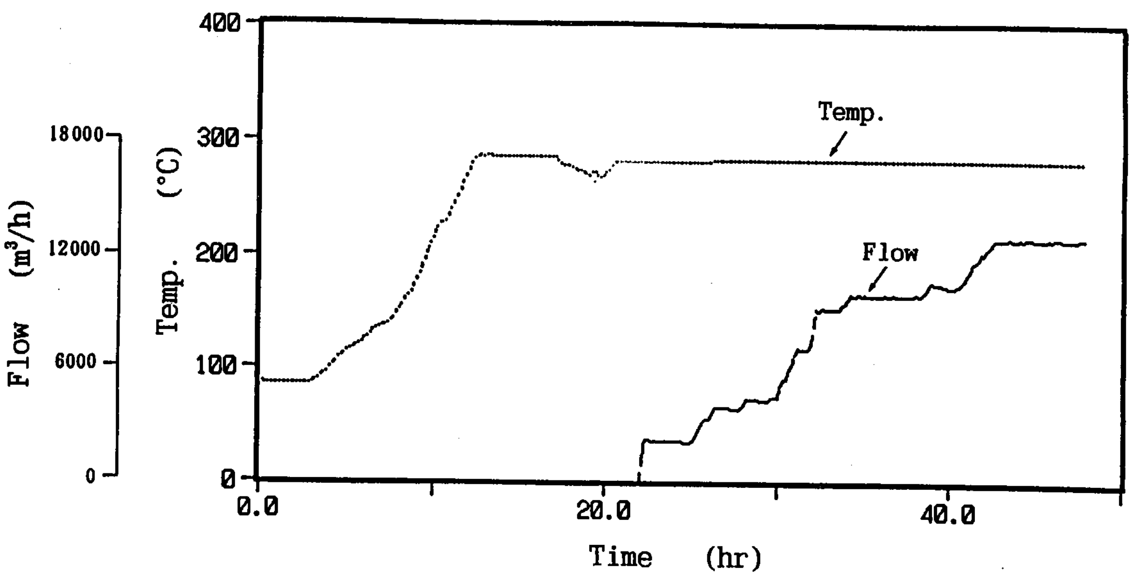
2.1 Optimization of boundary condition of the analysis

In the course of design, boundary conditions of the analysis such as boundary of heat transfer, mode of heat transfer, heat transfer coefficient and so on are set as such that stress resulting from settled boundary condition gives conservative value. For that reason to find the optimum boundary condition of the analysis is necessary to evaluate the exact value of CUF. To increase the accuracy of temperature distribution, for example, such conditions should be determined considering actual process data, i.e., flow rate and coolant temperature measured in plant.

Extensive parametric study has been performed. At first, temperature distribution at specific plant condition is calculated based on design basis boundary condition and the result is compared with the temperature measured in plant. In the next step, boundary condition is re-evaluated based on the comparison study, and re-calculation is performed. These steps are repeated until the result gets the good coincidence against measured temperature. Fig. 2 shows the time dependent temperature and flow rate transient as used for evaluation study. Diagrams shown in Fig. 2 are used as an input data for evaluation.



(a) Inside nozzle



(b) Inside reactor wall

Fig. 2. Time dependent temperature transient measured in operating plant and used for evaluation

Stress analysis model for design basis including thermal boundary condition for feedwater nozzle BWR RPV is shown in Fig. 3. According to the method mentioned above, optimum thermal boundary condition has been found as follows:

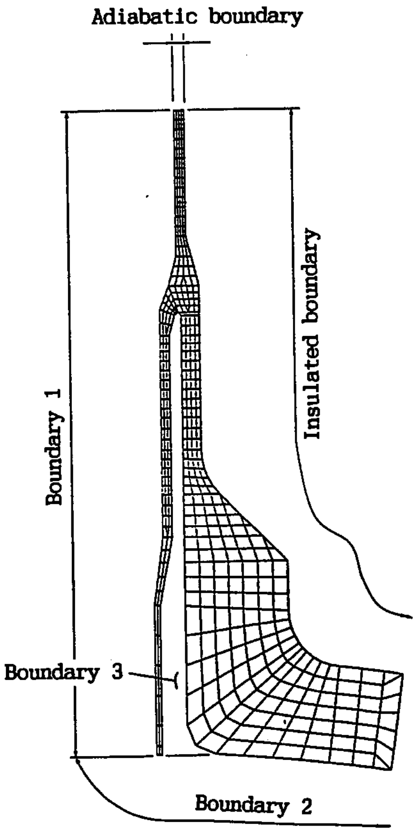
(a) For region 3, fluid temperature of inside the reactor should be applied and free convection heat transfer between two pararrel walls in a packed bed should be applied to calculate heat transfer coefficient.

(b) Thermal insulation boundary can be adopted beyond safeend.

(c) Same heat transfer mode should be applied for both shell portion and nozzle inside reinforcement.

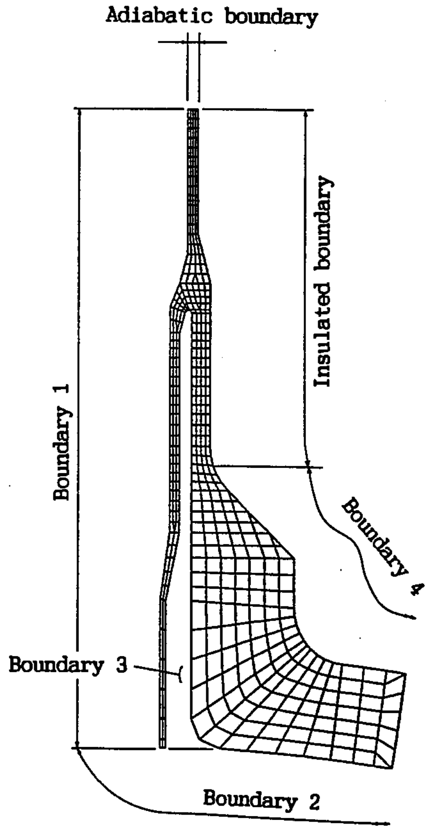
(d) Other conditions adopted in design analysis are effective.

Similar study for support skirt also has been performed and got optimized boundary condition. Fig. 4 shows the optimized thermal boundary conditions.



Boundary 1 : Heat Transfer for Forced Convection (with flow)
Heat Transfer for Free Convection in A Packed Bed (without flow)
Boundary 2 : Heat Transfer for Condensed Film
Boundary 3 : Heat Conduction between two Vertical Walls

Fig. 3. FEA model with design basis boundary condition



Boundary 1 : Heat Transfer for Forced Convection (with flow)
Heat Transfer for Free Convection in A Packed Bed (without flow)
Boundary 2 : Heat Transfer for Condensed Film
Boundary 3 : Heat Transfer for Free Convection btween two Parallel Walls
Boundary 4 : Heat Transfer for Free Convection btween two Parallel Walls

Fig. 4. Modified thermal boundary condition by optimization

2.2 Stress analysis

Following the settlement of the optimized boundary condition for evaluation of actual CUF, stress analysis by 2-dimensional FEA has been carried out using the measured pressure and temperature for the next operating conditions:

(a) Start-up
(b) Shut-down

The results of the analysis are summarized in Table 1. For comparison, design basis analysis results are also shown in the same table. As shown in the Table, calculated CUF based on measured process data in plant shows much margin compared with the one based on design thermal cycles. In addition to the above, the CUF per each event is very low. From both results it can be said that RPV design by current procedure seems to have some design margin in view of fatigue. To comfirm it, further study will be expected.

Table 1. Summary of stress analysis results

(a) Feedwater nozzle

Events: Start-up and shut-down

Input condition	Thermal cycle	Plant data (Fig. 2)	Plant data (Fig. 2)	Thermal cycle
Boundary condition used	Design	Design	Optimized	Optimized
PL+Pb+Q (kg/mm^2)	68.7	20.9	21.2	49.7
PL+Pb+Q+F (kg/mm^2)	65.7	45.4	59.5	56.8
Cumulative usage Factor Factor (CUF/event)	0.003	0.0001	0.0003	0.0005

(b) Support skirt

Events: Start-up and shut-down

Input condition	Thermal cycle	Plant data	Plant data	Thermal cycle
Boundary condition used	Design	Design	Optimized	Optimized
PL+Pb+Q (kg/mm^2)	65.4	58.8	59.5	43.7
PL+Pb+Q+F (kg/mm^2)	82.1	83.4	61.9	74.0
Cumulative usage Factor (CUF/event)	0.0019	0.0011	0.000195	0.00066

3. Simplified evaluation procedure

As discussed in the previous chapter, there is much margin in current design method and design conditions. In view of PLEX, however, simplified evaluation procedure by which exact value or a slightly conservative value can be got is needed to be developed.

As a result of preliminary study, the Green's function method is found to be applicable as one of the tools for above object. Fig. 5 shows the results of stress obtained by both Green's function and FEA. As shown in Fig. 5, the stress obtained by Green's function is coincident with the one obtained by 2D FEA.
In the next stage, we will improve the method by modifying boundary conditions.

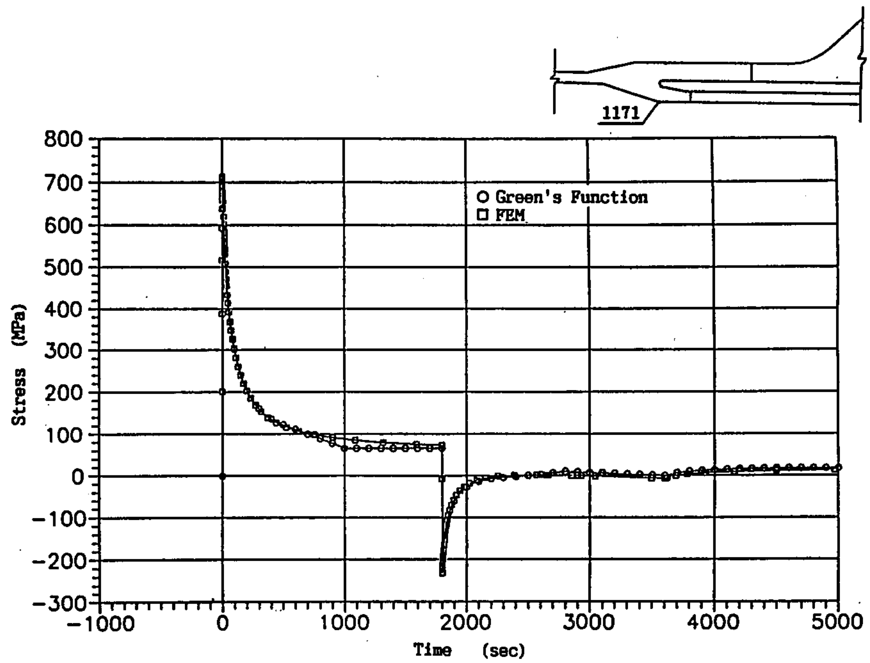


Fig. 5. Comparison of Green's function to FEA

4. Conclusion

Through the comparison study between CUF based on actual plant process data and the one based on design basis thermal cycles, following knowledge could be obtained.

(a) Both temperature and pressure transient in design thermal cycles seems to be severe compared with those measured in operating plant. That means thermal cycles themselves have margin in RPV design.

(b) Stress and subsequent cumulative usage factor calculated in accordance with design basis thermal cycles in the course of design of BWR RPV are in some cases very conservative compared with those calculated based on measured ones. That means current stress evaluation procedure has margin in RPV design.