Transactions of the 15th International Conference on
Structural Mechanics in Reactor Technology (SMiRT-15)
Seoul, Korea, August 15-20, 1999 D02/3

Establishment of Simplified Fatigue Evaluation Method by Green's Function

Hideki Fujimoto[1], Yasushi Kanazawa[2] and Yuji Takahashi[3]

1) Babcock-Hitachi K. K., Japan
2) Toshiba Corporation, Japan
3) Tokyo Electric Power Co., Japan

ABSTRACT

Certain fatigue evaluation systems to monitor cumulative fatigue usage factor (CUF) in components of nuclear power plants, have been previously reported. These systems largely calculate stress by Green's Function (GF) within the Simplified Method. However, stress calculations by Green's Function Method (GFM) have not yet been accurately verified. Therefore, in Japan, a Boiling Water Reactor (BWR) utility joint study developed a simplified evaluation method using GF to ascertain the margin of error. This joint study primarily calculated both Finite Element Method (FEM) and GFM stresses using design thermal cycles to verify the accuracy of the simplified method. As a result, stress calculated by GFM proved inaccurate as compared with the FEM, thereby a corrective measures were established. The second paper establishes verification of the Simplified Method by use of plant operating cycles.

1. INTRODUCTION

An integral part of any future nuclear power plant will be the know-how to judge continuous operations, confirmation of plant life margin and the development of technical skills for plant life extension. The Reactor Pressure Vessel (RPV) is designed for detailed stress analysis based on design thermal cycles and fatigue evaluation. However, design thermal cycle's setting for design, both temperature and pressure changing ratios are considered conservative and thereby not reflective on actual plant operations for what they are[1]. Considering plant life extension, it is necessary with fatigue evaluation to use actual plant operating data and not rely on the usage of design thermal cycles.

A scheme of fatigue monitoring system performed stress calculations and fatigue evaluations based on plant operating data is shown in Fig. 1. On-Line Plant Process Data Acquisition System (OPDAS)[2] acquires plant operating data and compresses enormous flows of data for analysis with the purpose of reducing the capacity of recording media, which is stored.
The fatigue evaluation system computes stress using acquired OPDAS data, and calculates CUF from the stress time history.

Calculating stress based on actual plant operating data by FEM requires a large labor resource as well as a long period of time which lowers its practicality in actual circumstances. Given this, a simplified stress calculation method has become prerequisite for fatigue evaluation systems.

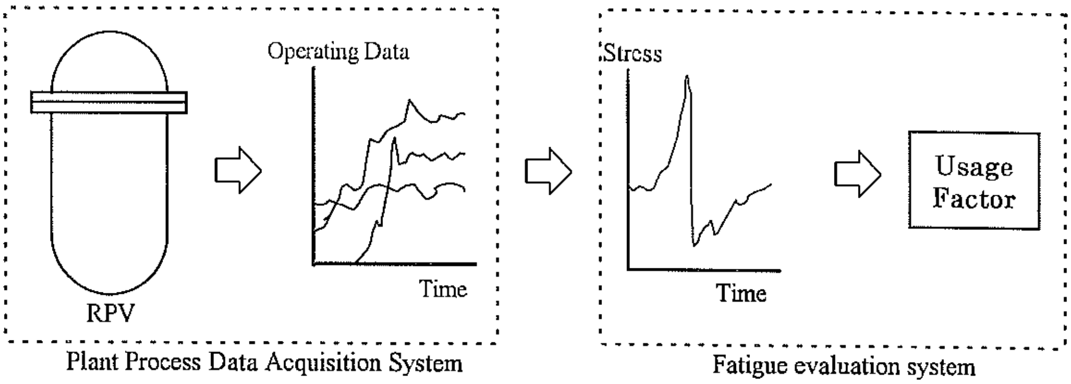


Fig. 1 On-Line Fatigue Monitoring System

2. Outline of this study

The GFM, previously reported, was selected for simplified stress calculation method. The flowchart for the studies is shown in Fig. 2. From the following studies carried out in two steps, the GFM was established.

(1) A primary Study based on design thermal cycles

For stress calculation problems, GF is a noteworthy stress response at a interesting point when a temperature step is subjected to a thermal boundary of the component. GF is obtained for each heat transfer coefficient condition. Furthermore, it is necessary to determine GF for each component and plant, as it is dependent on geometry, dimension and material factors. Stresses are calculated by the integration of GFs. The integration logic was developed, though understanding the characteristics of GF using sample calculations for a simple cylindrical shell.

When GFM applies to actual components, GFM results contain on error as compared with FEM results. The cause of this error is as follows;

ⅰ. Integration logic of GFs
ⅱ. Material properties in setting the Green's Function
ⅲ. Thermal boundary in setting the Green's Function
ⅳ. Thermal stresses in steady-state

plu8s miscellaneous factors.

By the FEM, we carried out a continuous thermal conduction analysis and a thermal stress analysis. The FEM is non-linear in its analysis whereby material properties change in proportion to temperature changes. GFM is a linear analysis showing that material properties are definite values in setting GF, furthermore, on account of the boundary setting for the inner surface of feed water nozzle thermal sleeve, steady-state stress is not calculated due to a lack of influence to the vessel inner surface. This does not fundamentally solve the margin of error in replete with a GF data base.

In the application of GFM to actual plants, fatigue evaluation using calculated stress values are directly predicted without making a conservative evaluation of results. Supplementary treatment is necessary in obtaining well coordinated evaluation results as compared with FEM results. Therefore, applying the GFM, the stress correction factor introduces and multiplies calculated stress by this factor. The stress correction factor α is obtained comparing stress calculation results by GFM and FEM based on design thermal cycles. It is better that α is determined by the analysis based on plant operating cycles, however analysis based on actual plant data is difficult to apply to actual components and plants, as the FEM for the study requires a large labor force. On the other hand, the FEM analysis for design thermal cycles is used to perform for structural design. If a few transients dominating the CUF can be selected, the analysis based on design thermal cycles is applicable to determine α.

Considering fatigue damage under design conditions, one of the most critical components of the RPV were the feed water nozzles in which high stress due to the temperature fluctuation of feed water was found. Feed water nozzles of Tokyo Electric Power Company, Kashiwazaki-Kariwa Nuclear Power Station Units 3 & 4 (1,100-MWe, BWR-5 plants) were selected for this study. In this paper, the investigation of Unit 4 is described in detail.

The study enclosed by the doted lines in Fig. 2 denotes each component and plant.

(2) Verification Study based on actual plant data

To verify the applicability of the α to the feed water nozzle of the actual plant, the stress calculation was performed by both FEM and GFM, employing plant operating cycles. These contents are described in the next paper[3].

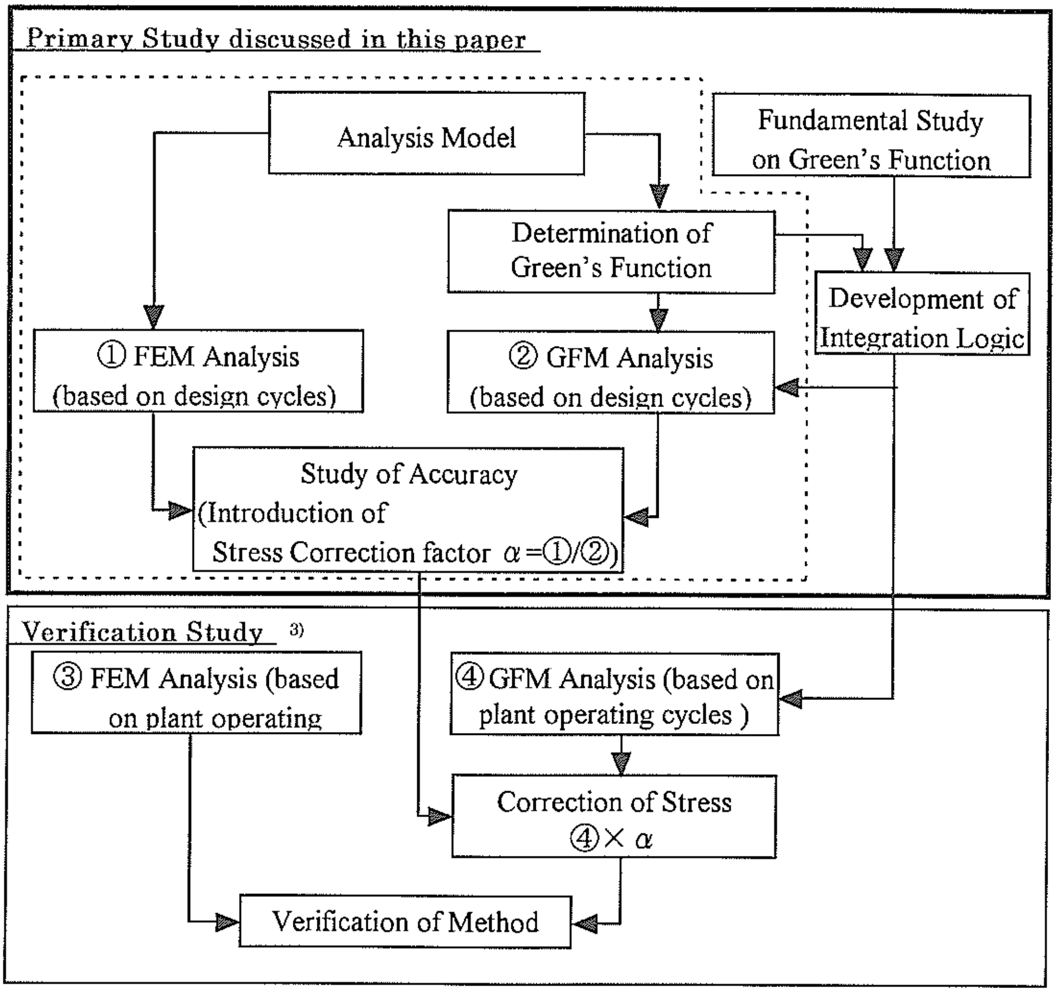


Fig. 2 Establishment of GFM

3. Determination of GF for RPV Feed Water Nozzle

The analysis model of the feed water nozzle is shown in Fig. 3. GF gives temperature step (e.g. 100℃) as thermal condition to the inner surface of the thermal sleeve and calculates stress by FEM. The criteria for determining GFs are shown in Fig. 4.

GF does not set continuous functions, but stress-time tables. Certain cases of stress analysis were performed for various heat transfer coefficients, then GF data base was determined as shown in Fig. 4. Thermal stress was calculated by switching and correcting the GF data base to correlate with heat transfer coefficient changes.

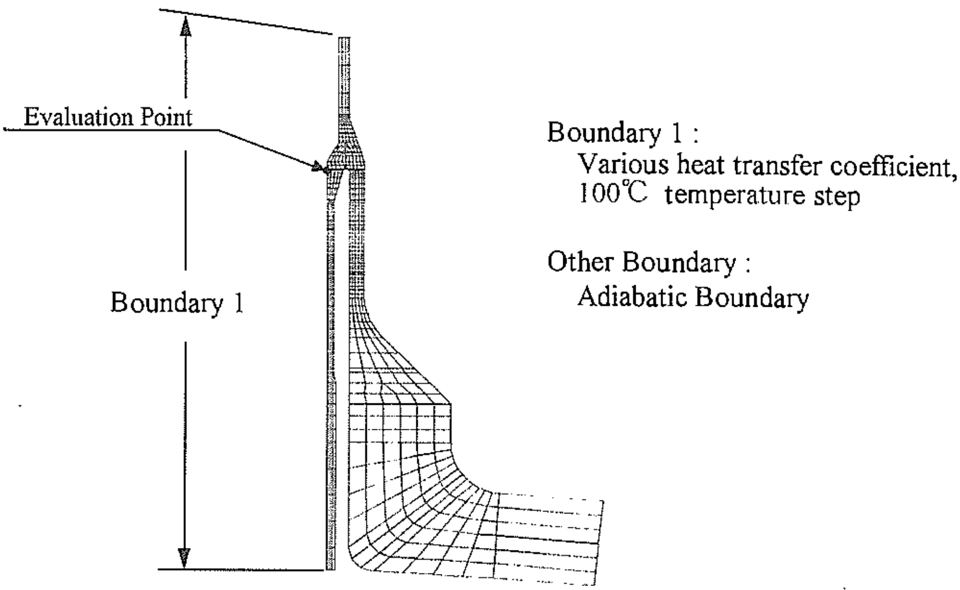


Fig. 3 Analysis model and conditions for FEM

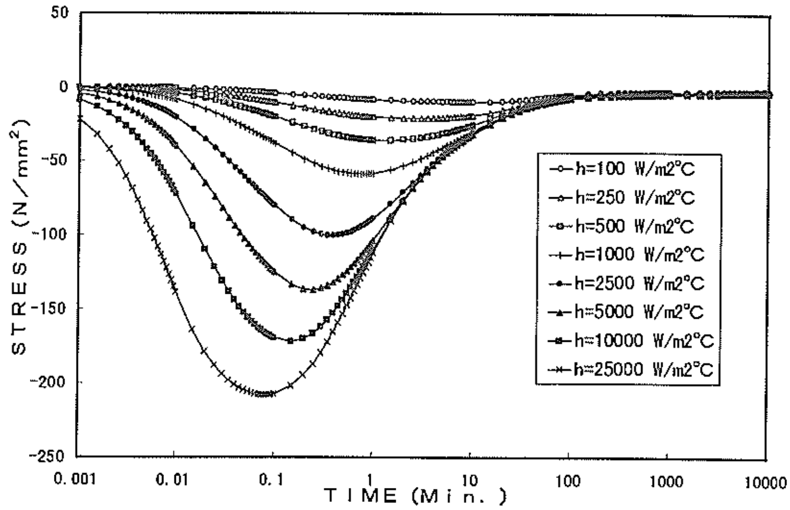
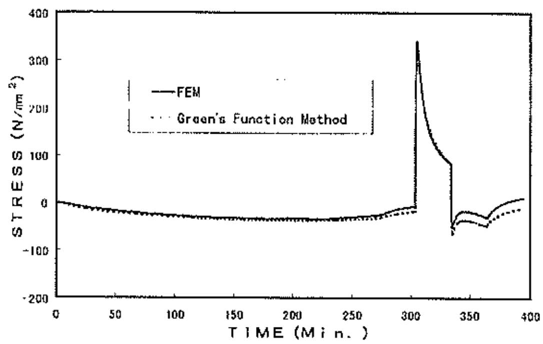


Fig. 4 Green's Function (Stress Intensity)

4. A comparison of the stress calculation results by GFM and those by FEM, using design thermal cycles

There were approximately 20 patterns for design thermal cycles among which Start-up, Turbine Generator Trip and Shutdown were selected for analysis. These were conservatively set for the design and the maximum combination of stress intensity range. Stress analysis by GFM and FEM performance employed these cycles. A comparison of stress analysis results are shown in Fig. 5.

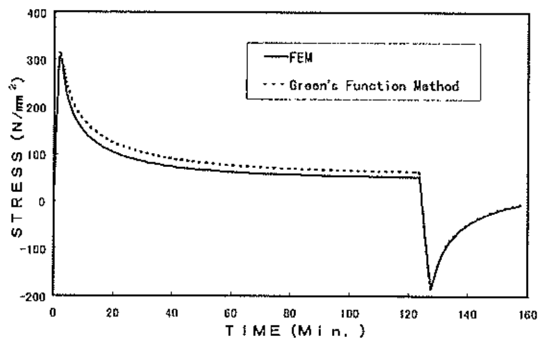
Judging from Fig. 5, the results of GFM correlate well with the results of FEM. For whole transients, the stress ranges of GFM and FEM were 502 and 536 N/mm^2 respectively.



(a) Start-up

Stress Intensity (N/mm^2)

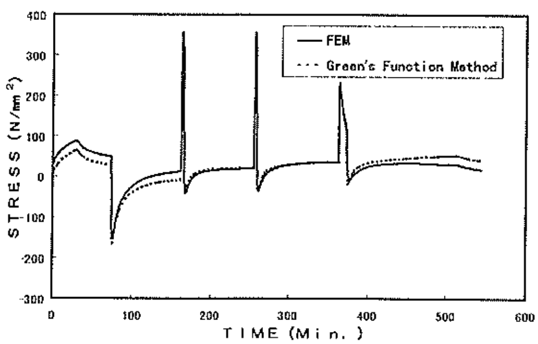
	FEM	GFM.
Max. stress	340	293
Min. stress	-51	-65



(b) Turbine generator trip

Stress Intensity (N/mm^2)

	FEM	GFM
Max. stress	304	313
Min. stress	-181	-187



(c) Shutdown

Stress Intensity (N/mm^2)

	FEM	GFM
Max. stress	355	315
Min. stress	-152	-170

Fig. 5 Stress Intensity comparison between GFM and FEM

5. Investigation of the procedure for the error correction

The stress correction factor α obtained combinations of stress intensity ranges, namely, maximum and minimum. Stress calculation results by GFM and FEM are shown in Fig. 5. From the ratio of stress ranges in both Methods, α was was determined by Eq. 1. And so GFM results was obtained well coordinated results as compared with FEM results.

$$\alpha = \frac{\text{Stress Intensity Range of FEM}}{\text{Stress Intensity Range of GFM}} = \frac{355-(-181)}{315-(-187)} \fallingdotseq 1.07 \qquad \text{Eq. 1}$$

Setting up the α is necessary to examine for each plants and components, as stated above 2. (1). To give an example, the geometry, dimensions and materials of the feed water nozzle in Kashiwazaki-Kariwa Unit 3 are different from these in Unit 4, and so the α for Unit 3 was also investigated in the same way as Unit 4. From the results, in Unit 3, stress correction factor α obtained the value of 1.09.

6. Conclusion and future prospects

A simplified stress calculation method based on design thermal cycles was established by means of what was discussed previously. From the steps taken it was found that a simple fatigue evaluation is possible and accurate. However, this investigation was a primary study for introduction to actual plant usage and for applicability to actual plants, verified based on plant operating cycles.

From now on, employing plant operating cycles, stress calculation and fatigue evaluation shall be performed by both GFM and FEM, as their applicability was verified through procedural steps discussed in this paper. These contents are described in the next paper[3].

7. References

1) O. Maekawa, et al., "*Assessment of Design Margin of Fatigue of RPV Based on Operating Data*", Paper D04/4, SMiRT-12, 1993.

2) Y. Takahashi, et al., "*Trend of Operating Data Monitoring and Fatigue Evaluation Systems for BWR in Japan*", Paper D04/3, SMiRT-12, 1993.

3) Y. Takahashi, et al., "*A study of Fatigue Evaluation Method Based on Operating Data*", SMiRT-15, 1999.