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A Simple Method for Shakedown Load Determination of 3-D Structure

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1. Introduction

Limit load analyses have been performed by a number of researchers over the last three or four decades in order to determine the load carrying capacities of structures. Complementary to limit load, however, analyses for shakedown loads of structures have been delayed due to the stress complexity and time consuming cyclic loading conditions. Shakedown analyses are also important to prevent reversed plasticity or ratchetting of structures which are operated under high temperature. In the literature[1-4], several methods can be found including iterative procedure by R5 and Linear Matching Method. Recently Younan M.Y.A. et al.[5] introduced a new simplified technique for shakedown load. In this paper, this new simple method for shakedown load was invoked and shakedown load of two-dimensional Bree cylinder and three-dimensional pipe bend was evaluated.

2. A Simple Method for Shakedown Load

A simple method assumes elastic-perfectly plastic material behavior and involves two analyses. The first is an elastic analysis performed only once and its output is stored. In the present elastic analysis, only the cyclic load type is applied preserving structure stresses within the material elastic range. The second analysis is an elastic-plastic analysis which involves the application of both constant and the cyclic load types. Performing the two analyses and using their outputs, the residual stress is calculated for every element in the structure at every solution increment as follows:

$$\sigma_{r_i} = \sigma_{EP_i} - \sigma_E \frac{P_{EP_i}}{P_E} \qquad (1)$$

σ_{ri} denotes the residual stress at every increment. The subscript '*E*', '*EP*' and '*i*' donates, respectively, elastic analysis, elastic-plastic analysis and increment. *P* is the cyclic load.

In the present work, the post-processor program in ABAQUS[6] is developed to read the outputs and calculate the residual stresses. When the residual stress start to exceed the material yield stress at 'i'th increment, the shakedown limit is determined as the load at 'i-1'th increment.

3. Evaluation for Structures With A Simple Method

3.1 Bree Cylinder

The Bree cylinder is subjected to internal gas pressure and cyclic high linear temperature gradient across thickness. Two-dimensional Bree cylinder model employed in the present work is shown in Fig. 1. Figure 2 depicts the cyclic thermal loading pattern applied Bree cylinder. In the FE analysis, coupled temperature-displacement analysis is performed using ABAQUS. Using Eq. (1), the residual stresses is represented as

$$\sigma_{r_i} = \sigma_{EP_i} - \sigma_E \frac{T_{EP_i}}{T_E} \qquad (2)$$

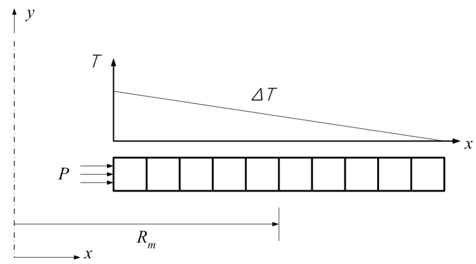

Figure 1. Schematic diagram of the Bree cylinder including FE mesh and temperature gradient across thickness.

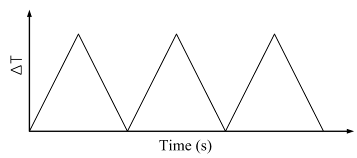

Figure 2. Cyclic thermal loading pattern.

The FE results for three loading cases are shown in Fig. 3. The solid line is the analytically determined Bree diagram of the cylinder[7]. For all cases, the FE results agree well with the analytical shakedown limits.

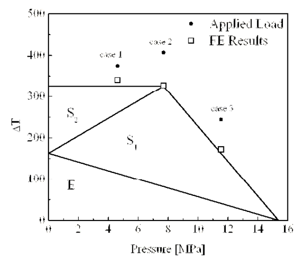

Figure 3. FE results of shakedown limit loads for the Bree cylinder using a simple method.

In order to verify this method, full cyclic simulations are performed. Figure 4(a) shows the traditional shakedown behavior. After the plastic strain occurs at the first cycle, no plastic strain occurs at the other cycles. Figure 4(b) shows the reversed plasticity behavior in the case 1, and Figure 4(c) and (d) show the ratchetting behaviors in the case 2 and 3.

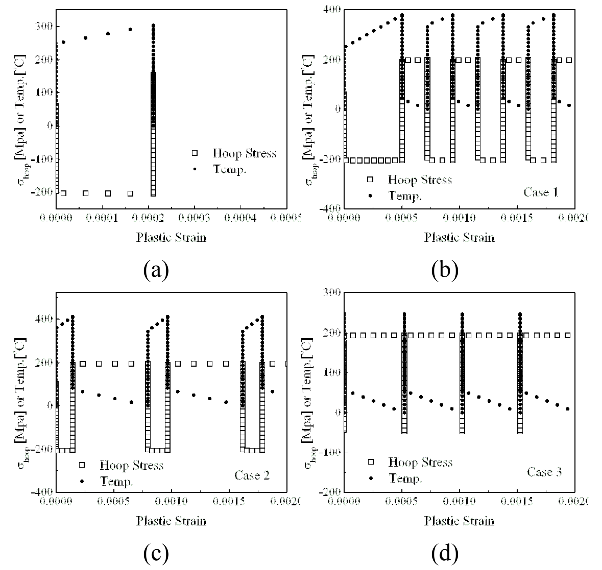

Figure 4. FE results of full cyclic simulations for Bree cylinder: (a) shakedown behavior, (b) reversed plasticity behavior, (c) and (d) ratcheting behavior.

3.2 Pipe Bend

Figure 5 depicts a 90° pipe bend, considered in the present work. The mean radius and thickness of the pipe are denoted by *r* and *t*, respectively, and the bend radius by *R*. The geometric parameters of pipe bend are summarized in table 1. The pipe bend is subjected to both constant internal pressure and cyclic closing bending moments. The cyclic loading pattern is depicted in Fig. 6. Three-dimensional FE analyses are performed using ABAQUS.

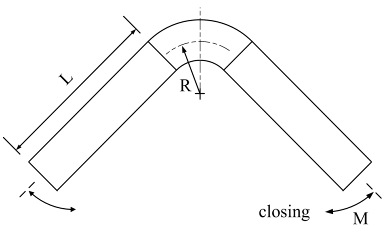

Figure 5. Schematic illustrations of 90° pipe bends, considered in the present work.

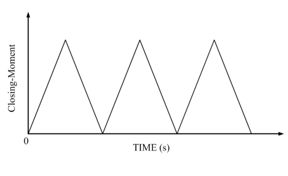

Figure 6. Cyclic closing bending moment pattern applied to the pipe bend.

Table 1. Geometric parameters of the pipe bend.

r (mm)	r/t	R/r	L (mm)
50	10	3	1000

Using Eq. (1), the residual stresses are represented as

$$\sigma_{r_i} = \sigma_{EP_i} - \sigma_E \frac{M_{EP_i}}{M_E} \quad (3)$$

As shown in Fig. 7, the elastic limit and shakedown limit moments are easily determined from the FE results.

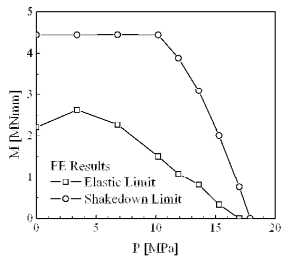

Figure 7. FE Results of the elastic and shakedown limit moments of pipe bend.

4. Conclusion

In this paper, a new simple method for shakedown load was applied to Bree cylinder model, and verified through full cyclic simulations. Based on detailed three-dimensional FE analyses, the elastic and shakedown limit moments of pipe bend are determined.

ACKNOWLEDGMENT

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