Joint modeling techniques using finite element analysis

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1 Introduction

This year, Failures due to joints between parts have become apparent, as high-precision equipment of space structures are demanded. Various contaminants in the air on the ground adhere to the contacting parts of metal surfaces. These contaminants, in turn, act as a lubricant, thereby reducing the coefficient of friction. Therefore, the frictional force on the contact surface is naturally decreased on the ground. Space, however, is a vacuum, and because metal contamination does not occur in space, the friction coefficient between the metals in space increases to about 100 times that on the ground. In space, the friction force causes incomplete movement at joints because of the lack of lubrication.

In this study, to develop the high-precision space structure, we construct a simulation based on contact-friction finite element analysis (FEM) using Advance/FrontSTR [1] [2] [3]. The accuracy of the calculated results using Advance/FrontSTR is verified by comparison with the contact force in [4]. Using the reliable simulation, the non-reversible behavior by contact friction is verified by comparison to the hysteresis of the displacement in the literature.

2 Algorithm of Contact-Friction Analysis

In this study, the Advance/FrontSTR and JAXA supercomputer system (JSS) are applied to solve the contact-friction problem. Advance/FrontSTR was jointly-developed as part of a government project (Ministry of Education, Culture, Sports, Science and Technology) by the University of Tokyo (Prof. Hiroshi Okuda) and Advance Soft Co. Ltd. Presently, Advance Soft Co. Ltd. provides commercial versions of the software and is responsible for upgrades. The software can calculate the geometric non-linearity, the material non-linearity, and the contact non-linearity. The JSS consists of a massively parallel supercomputing system, a storage system, a large-scale shared memory system, and a remote access system. We attempted to realize a large-scale FEM analysis of the high efficient parallel supercomputing system by Advance/FrontSTR and JSS. The increments of displacements are unknown variables at the nodes in the FEM model. The displacement can be obtained by the increments of displacements. The strain can be subsequently calculated by the displacement. Then, the stress can be calculated by the stress-strain relationship. Advance/REVOCAP is applied for the pre-processing and the post-processing. Advance/REVOCAP can easily make FEM meshes, set calculation conditions, and visualize results from Advance/FrontSTR [1] [2].

3 Calculated Results of Contact-Friction Analysis

To verify the distribution of the contact force and the irreversible behavior, the contact problem in 3D FEM analysis is solved using Advance/FrontSTR.

3.1 Computer model for contact force

A computer model consists of a reinforcing ring and circular cylinder that are in contact with each other. The internal diameter and the outer diameter of the reinforcing ring are *99.825 (mm)* and *200.0 (mm)*, respectively. The diameter of the circular cylinder is *100.0 (mm)*. With respect to the radial direction in the initial condition, the distance of interference between the reinforcing ring and the circular cylinder is $\delta = 0.175$ *(mm)*. The number of nodes and the number of elements are *10159* and *8360*, respectively. The element type is applied to the first order hexahedral element. The material properties are set to a Young's modulus of *210.0 (GPa)* and a Poisson ratio of *0.3*. The symmetry condition is set as the boundary conditions.

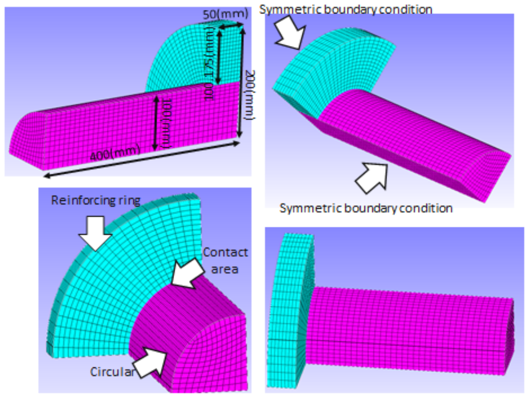

Figure 1 Computer model (by Advance/REVOCAP [1]).

3.2 Contact pressure distribution

The horizontal and vertical axes of Fig. 2 represent the normalized distance and the normalized stress with respect to the z axis, respectively. The distance in Fig. 2 represents the length from the node $N_1(0,0,99.825)$ to the node $N_2(50,0,99.825)$ and is located on the contact surface of the reinforcing ring. The four curves represent the distribution of the contact force with the friction (the coefficient of friction is *0.2*) in [4], the distribution of the contact force without the friction in [4], the distribution of the contact force with the friction (the coefficient of friction is *0.2*) using Advance/FrontSTR, and the distribution of the contact force without the friction using Advance/FrontSTR. Using Advance/FrontSTR, the stress distribution in the frictionless case is almost in agreement with that in the friction case. Compared to the friction case in [4], the normalized stress of the frictionless case in [4] sharply increases around the node $N_2(50,0,99.825)$. It is considered that this difference depends on the friction computational model. Advance/FrontSTR evaluates the occurrence of the friction on the contact surface by the relative displacement between two nodes located on both sides of the contact surface. In classical friction theory (coulomb friction), the friction (= coefficient of friction × surface force) occurs on the contact surface, even if small relative displacement occurs. However, in the numerical algorithm, the steepest friction forces cause numerical error and numerical instability. To obtain a stable solution numerically, the friction force should increase gradually according to the increment of time when a small relative displacement occurs. When a large relative displacement on the contact surface occurs, the maximum frictional force (friction coefficient × surface forces) is better seen on the contact surface. In the literature [4], the coulomb friction is implemented in the computer model. In Advance/FrontSTR, to obtain numerical stabilization, a small force below the friction force occurs with respect to the small relative displacement. It may be impossible for the Advance/FrontSTR to reproduce the difference between the results of the friction and frictionless cases for small relative displacements.

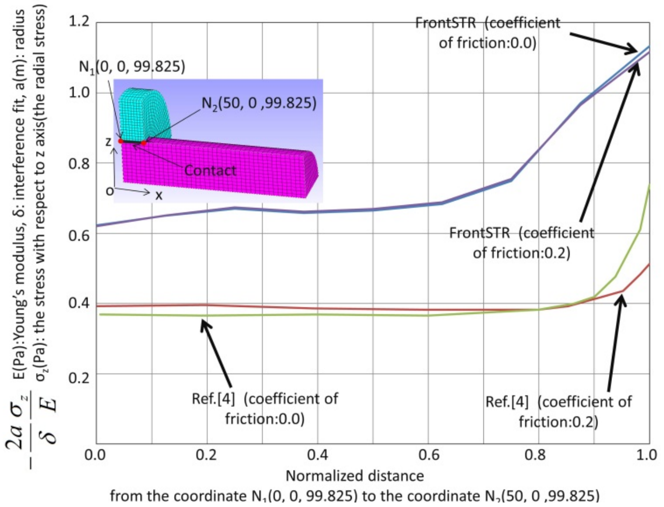

Figure 2 Stress distribution on contact surface.

3.3 Computer model to reproduce irreversible behaviors

We make the one-quarter FEM model. The structures A and B contact each other. The initial interference with respect to the radial direction is δ = 0.0875 (mm). The number of nodes and elements are set to 390 and 156, respectively. The element type is applied to the first order hexahedral element. The material properties are set to a Young's modulus of 210.0 (GPa) and a Poisson ratio of 0.3, respectively.

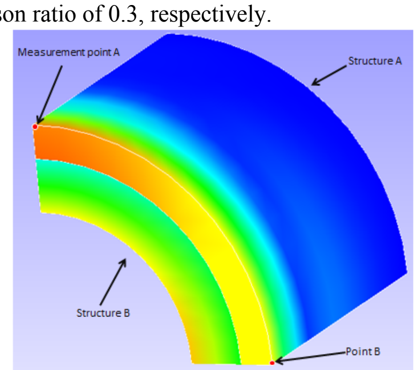

Figure 3 Contour of displacement difference between the initial shape and the deformed shape (coefficient of contact friction is 0.2) (by Advance/REVOCAP [1]).

3.4 Displacement contour map

The displacement contour map under a loading force is shown in Fig. 3. The red area and the blue area represent the large deformation and the small deformation, respectively. The interference between structure A and structure B causes the deformation. Subsequently, the force is loaded at structure A. Then, the force is removed. In the displacement residual (hysteresis), which cannot be recovered to the initial displacement, the displacement at point A is larger than that at point B.

3.5 Hysteresis of displacement

The vertical and horizontal axes in Fig. 4 represent the force and the displacement at point A with respect to the y direction (radial direction), respectively. Using Advance/FrontSTR, the displacements with friction and without friction are calculated. Before loading, the displacement at point A increases by the interference between structure A and structure B. After these deformations of both structure A and structure B, a force (35 kN) is applied at structure A. When the friction coefficient is set to 0.0 (frictionless case), the displacement at point A returns to the initial position before application of the loading force when the force is removed. When the friction coefficient is set to 0.2, the displacement at point A cannot recover to the initial position by the same operation. This phenomenon is known as irreversible behaviors. Compared to the irreversible behaviors in the literature [4], hysteresis displacement by Advance/FrontSTR is almost in agreement. The curves between the force and the displacement by Advance/FrontSTR do not agree with those in the literature [4]. The contact stiffness cannot be sufficiently evaluated because the contact stiffness depends on the contact state identified in various unknown parameters.

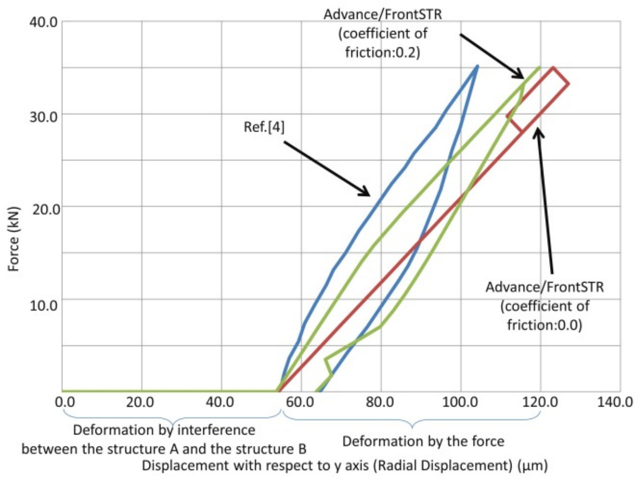

Figure 4 Hysteresis of displacement.

4 Conclusion

To verify the accuracy of the contact-friction analysis for a structure containing interference between two circular rings, the distribution of the contact force by Advance/FrontSTR was compared to that in the literature. In the literature, the radius contact force is minimized at the center of the contact force. The contact force increases sharply as it nears the edge of the contact force. The results by Advance/FrontSTR are qualitatively in agreement with the results in the literature. The irreversible behavior can also be reproduced by Advance/FrontSTR.

References

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