Static Buckling Analysis of the Partial Spacer Grid of the Nuclear Fuel Assembly

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Summary

2D simplified spacer grid model is developed and static buckling behavior is simulated. A buckling strength and primary stress distribution of the fuel rod in the partial spacer gird are determined and post-buckling behavior can be observed using the ANSYS APDL V14.5, ANSYS simulations show a good agreement with the experimental results.

Keywords

Spacer grid, Buckling strength, Non-linear, Post-buckling

1. Introduction

The spacer grid is one of the main structural components of the nuclear fuel assembly. The spacer grids support and align the fuel rod. In addition they maintain the lateral spacing between the rods under operational and the accident loading conditions, such as seismic and LOCA[1-4]. Thus, the spacer grid is required to have a sufficient buckling strength to perform these functions.

In this study, finite element model was proposed to evaluate the buckling characteristics and structural behavior of partial spacer grids. A two-dimensional model was developed to simplify a real spacer gird model and save analysis time. And it was validated for comparison with experimental tests. A non-linear analysis method was introduced to perform realistic simulation. Later, the buckling analysis of the full size grid will be performed based on the analysis results of partial spacer grids.

2. Method and Results

2.1 Test specimen and procedure

The static compression tests were performed for the small size grids having different number of rows and columns (1x1, 3x3 and 5x5). The configuration of test setup and each specimen are shown in Fig. 1. The compression rate was controlled by the displacement of 0.05 in/min. A mechanical test is performed on an INSTRON^{TM} load frame with a maximum force of 50kN. The compressive loads acting on the grids were measured as a function of deflection during the buckling test.

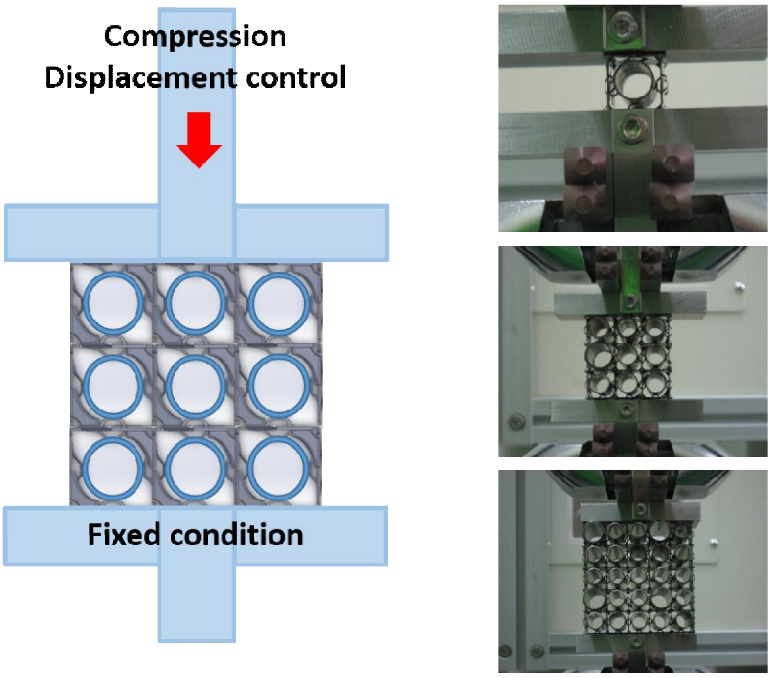

Fig. 1 Configuration of test setup

2.2 Modeling of partial spacer grids

The commercial software, ANSYS 14.5, was used for the finite element analysis[5]. A two-dimensional 1x1 cell was constructed by using BEAM188 element. Additionally, one rod, spring and dimple were modeled by using BEAM188 and CONTAC12 elements. Four CONTAC12 elements were used to produce the correct behavior of dimple and spring. Finally, CONTA171 and TARGE169 elements were used to represent the contact behavior between the rod and strap during large deformation, and the static friction coefficient, μ, was applied between the contact elements. For the boundary conditions, specified displacement was applied on specific location, as can be seen in the scheme in Fig. 2. In other words, the bottom strap was restrained on all degree of freedom and forced displacement was applied by some displacement on the top strap in the compressive direction.

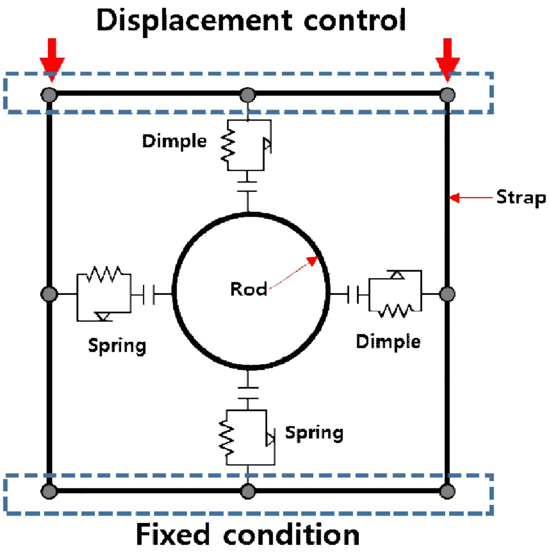

Fig. 2 Spacer grid FE model

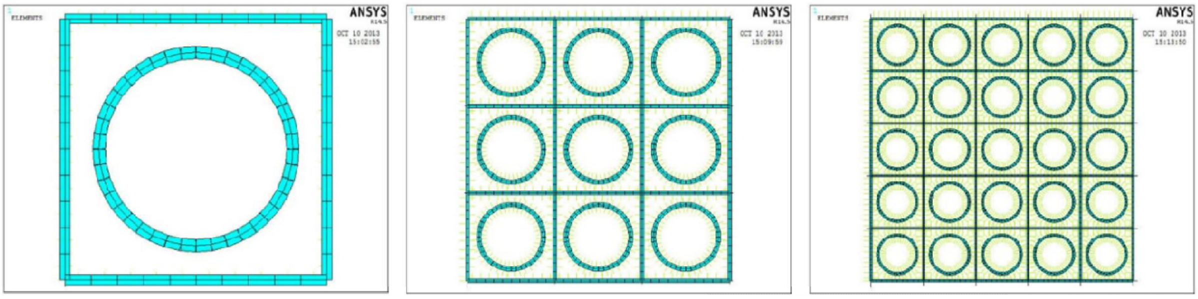

Fig. 3 2D finite element modeling of partial spacer grid

The FE models of partial spacer grid of 1x1, 3x3 and 5x5 are shown in Fig. 3. The same boundary and contact conditions as the 1x1 cell were applied for the other cell. These grids were simulated statically and, as a result, the sum of nodal reaction forces and total deformation were obtained.

2.3 Analysis procedure

The model shows the geometric, material and contact non-linearities during analysis. Especially, it does not converge due to the instability of a geometrical nature(instantaneous buckling) as shown in Fig. 4.

In static problems, equilibrium equations must be satisfied at the end of load increment. However, if the drastic change of the load by buckling occurs like this, the convergence difficulty is caused by inertia force. Thus, in this case, nonlinear stabilization and restart method are used after non-convergence. Nonlinear stabilization method uses atificial mass matrix to offset the inertia force induced by instability.

By adding damping factor in equations (1) and (2), local instability problem can be solved.

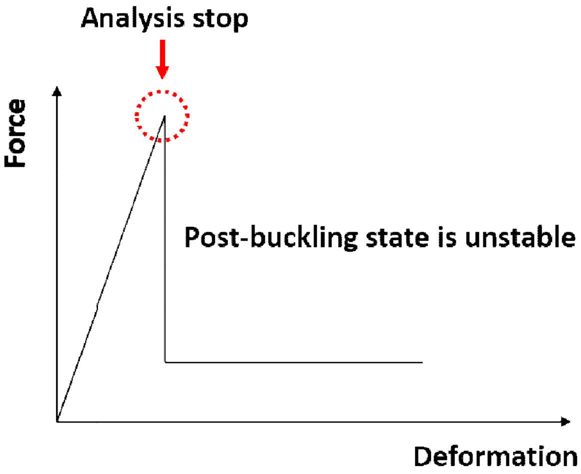

Fig. 4 Grid buckling behavior

$$P - I - Fv = 0, \tag{1}$$

$$F = cM, \tag{2}$$

where p is the external force, I is the internal force, c is the dampinp factor, v is the nodal velocity, and M is the artificial mass matrix defined by unit density.

2.4 Comparison of FE results with test

Fig. 5 is the comparison of the experimental and FEM results for the load-displacement. The curve based on the FE model describes the compressive behavior such as buckling strength and post-buckling behavior. And ANSYS results shows good slopes of the load-deformation after strap-rod contact. However, there are some differences with regard to starting point of initial load increase and degree of load decrease after buckling. These differences can be explained mainly by manufacturing process and geometrical differences. Since the spacer grids are formed by welded strips at their intersections to form grid cells, there exist some deviations. Additionally, the complex geometries such as a spring and dimple will not be implemented in two dimensional space.

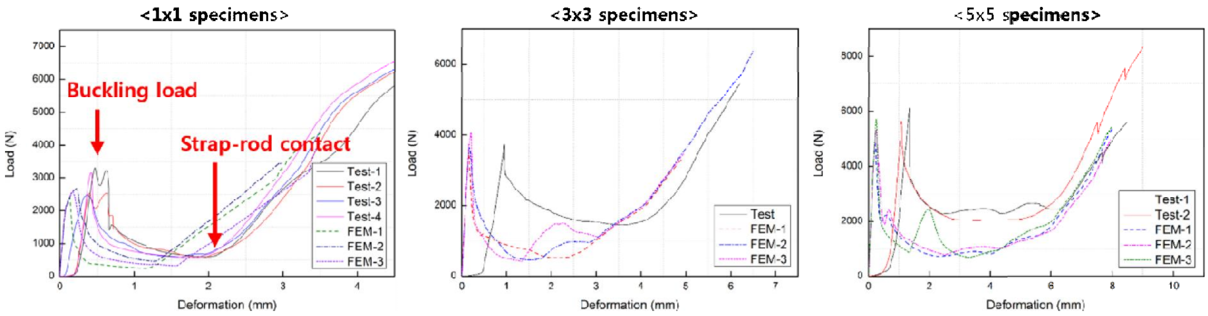

Fig. 5 Load-deformation curves

Fig. 6 shows the deformed shapes of the specimens after the compression test and the geometry obtained by the ANSYS analysis. Based on the load-deflection curves and deformed shape results, it can be said that the FE modeling and analysis are acceptable.

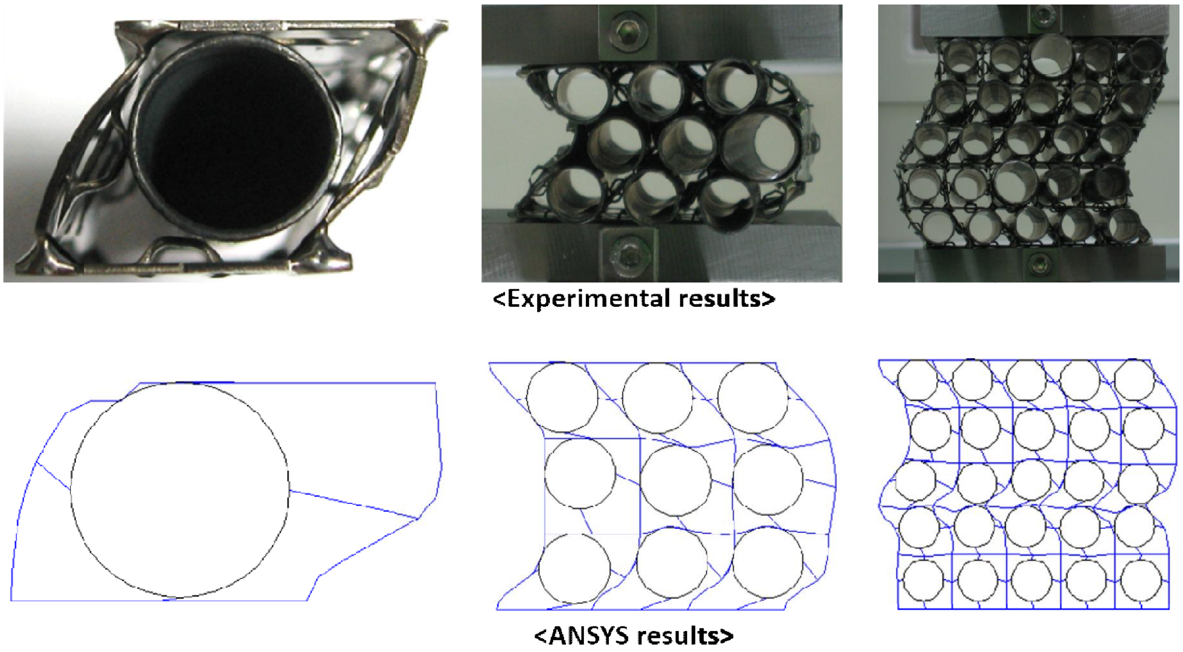

Fig. 6 Deformed shapes after compression

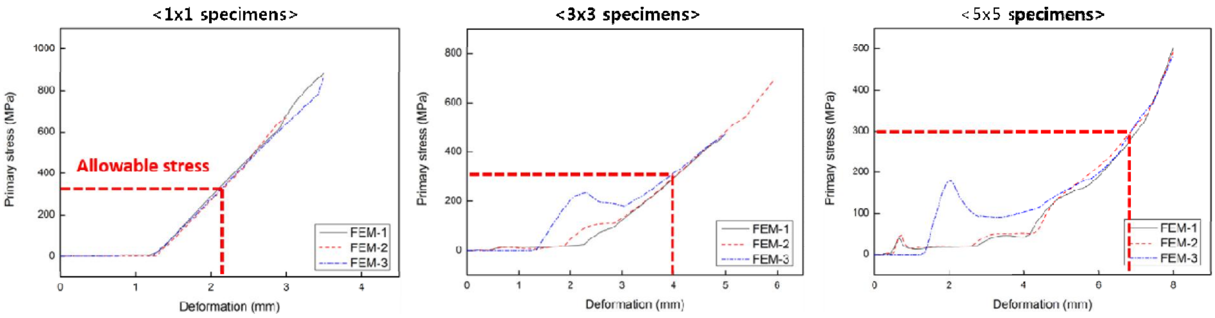

Fig. 7 Maximum stress of fuel rod under compression

Fig.7 shows the maximum primary stress of the fuel rod during compression. Before the strap-rod contact, rod is safe. However, after contct, stress is increased rapidly with regard to the grid deformation.

Rod stress must not exceed allowable stress after strap-rod contact not to affect the integrity of the fuel rod.

3. Conclusions

A research was conducted to develop the simplified model of a spacer grid and provide a prediction of buckling behavior. The ANSYS simulation results are quite similar to the experimental tests.

- The deformed geometry of FE model after compression is consistent and very similar to that of real situation, and the non-linear analysis method used in this model can simulate buckling and post-buckling behavior well.
- The buckling strength obtained by FEM shows a very good agreement with the physical tests.

4. References

[1] Jeon S. Y., Lee Y. S.: "A Study on the Buckling Characteristics of Spacer Grids in Pressurized Water Reactor Fuel Assembly", COSEIK Journal of Computational Structural Engineering, Vol.18, p.405, 2005.

[2] Song K. N., Yoon K. H.: "Nonlinear FE Analysis on the Static Buckling Behavior of the Spacer Grid Structures", Proceedings of the Korean Nuclear Society Autumn Meeting, October, 2000, Taejon, Korea.

[3] Jeon S. Y.: "A Study on the Buckling Characteristics of Spacer Grid in PWR Fuel Assembly", Proceedings of the Korean Nuclear Society Spring Meeting, May, 2001, Korea.,

[4] Schettino F. M., Gouvea J. P., Medeiros N.: "Analyses of spacer grids compression strength and fuel assemblies structural behavior", Nuclear Engineering and Design, Vol.260, pp.93, 2013.

[5] ANSYS APDL User’s Manual