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The application of bifurcation buckling analysis in computer-assisted shell structures design

Master thesis abstract, cooperation with the Lab of Structural Mechanics, Tohoku University.

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Introductions

The term "shell structure" is defined as a shell with a thickness, which is rather small compared to its span. Because of the efficiency of the load capacity, this structure is wildly used in large-span construction, such as train stations and airports. To avoid the unexpected failure of the shell structure, the physics of shell buckling must be researched.

In this paper, the buckling behavior of shells will be simulated and analyzed using Dynamic relaxation method.

The objectives of the analysis

- The general purpose of buckling analysis is to determine the limit and bifurcation loads of the shell structure.
- To classify the critical points into bifurcation points and limit points, the post-buckling of the structure has to be computed.
- To determine the imperfection sensitivities of the shell structures, an initial imperfection has to incorporate into the system.

Theory and programming

Dynamic relaxation (DR)

Based on the equation of motion, the method of dynamic relaxation used an explicit solution method for the analysis. The equilibrium and compatibility relations in DR are separated, and no overall stiffness matrix is assembled, which means, for each iteration, only the internal forces of the elements need to be updated. Therefore, it is better suited for systems with a more significant number of components and more comfortable for handling structures with large deformations, e.g., shell structure.

Grasshopper and Kangaroo solver

Grasshopper is a graphical algorithm editor, which is integrated with CAD program Rhinoceros 3d developed by Robert McNeel & Associates. As a plug-in for the Grasshopper, Kangaroo solver is a physic engine which simulates physical behaviors of the structure using DR. In the newest version, Kangaroo 2, a position based DR is introduced. The users are also allowed to script their physic solver through an API.

In this project, a plug-in “KUMA” for Grasshopper, using C# and Visual Studio, will be scripted to analyze and simulate the buckling effect based on Kangaroo 2 Solver.

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http://mechanics.civil.tohoku.ac.jp/c-indexe.html
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The KUMA solver

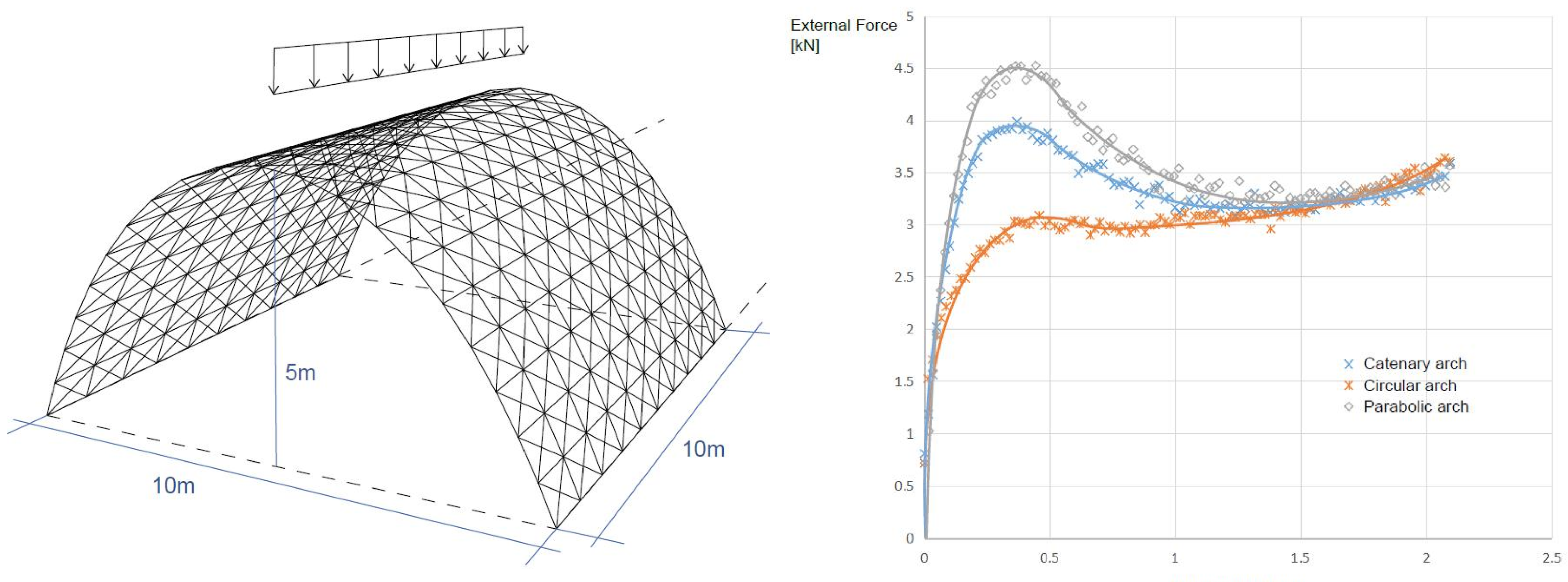
Usually, the buckling load is calculated through the buckling eigenvalue equation. Since DR do not generate global stiffness matrix, it is going backward for the solver to use this equation. A new method based on monitoring the stored-up energy is tested. Shell structure can absorb a great deal of membrane strain energy. If this stored-up membrane energy converted into other forms of energy, the buckling happened.

Post-buckling behavior

Notice that the solver is similar to the Newton–Raphson method by using Load control, it can not track the post-buckling behavior. Therefore a new approach by adding spring to calculate the equilibrium path is proposed. By adding a constant stiffness K at the stress points, the load-displacement curve can be tracked without a load decrease, and then the post-buckling curve can be calculated. With this method, the solver can follow the path similarly to displacement control.

Imperfection sensitivity

An initial geometrical imperfection is implemented. Through the comparison between the results of the perfect and the imperfect shape, an imperfection sensitivity can be determined.



Parameter study of a grid shell with different cross-sections using the KUMA solver

Conclusion

In this stage, the KUMA solver is functional in simple shell structure designs. Although it has limitations on efficiency and accuracy regarding practical examples, the KUMA solver indeed reveal the potential of DR in respect of buckling analysis.

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