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EXTENDED ABSTRACT

Investigation into the Stability Behavior of Single-Layer Triple Domes Free-Form Reticulated Space Structure (Triangular Novation)

Mozhgan Valinezhad, Karim Abedi*

Faculty of Civil Engineering, Sahand University of Technology, Tabriz, Iran

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1. Introduction

Free form surfaces are referred to as a combination of double-curved surfaces, which are not necessarily a combination of common geometric shapes such as cubic, spherical and elliptic shapes or a combination of them (Tian, 2004). Two types of instability occur in space structures: limit point instability and bifurcation point instability. The structures that exhibit bifurcation point instability, have more sensitivity to geometric imperfection (in particular the type of node deviation) than limit point instability. Therefore, it is necessary to investigate the sensitivity to imperfection in these structures, particularly single layer dome structures. So far, no research has been conducted on triple domes free form space structures. Therefore, in the present paper, the numerical finite element method is used to analyze and study the instability behavior of triple domes free form single-layer space structure. In this research, the approximate-perturbed method and the method of generalized conformable imperfection mode were used to implement imperfection.

2. Methodology

2.1. Configuration and loading of models

Novational function of FORMIAN software is used for configuration processing of triple domes free form single layer space structure. Novational displacement is a particular type of geometric translation that modifies a form and generates various forms by means of one or more parts on the base form. Novatioal function equation is written as follows (Nooshin and Moghim, 2007):

$$G = NOV\ (m, c, L1, L2)|E$$

The initial form in this research is three-way flat configurations with square plan. The configuration (Fig. 1-c) of triple domes free form space structure models is obtained by using notational function on the noted base form in the specified areas of plan with black dots and the implementation of two-way middle-rise as dash line, as shown in Fig. 1-a.

In this research, the models with three-way configuration, triangular novation and fixed supports are considered and the effects of height to span ratios of 1/4, 1/5 and 1/7 and middle rise to span ratios of 1/8 and 1/10 and symmetrical and asymmetrical loading in two directions were studied. In the design of the models, dead load, a live load of snow, seismic load, and thermal load were considered. In the research, dead load was applied in the models as a nodal load with the value of 0.5 Kn/m^2. The snow load was assumed as P_g=1.5 Kn/m^2.

* Corresponding Author
E-mail addresses: mozhgan.valinezhad@gmail.com (Mozhgan Valinezhad), k_abedi@sut.ac.ir (Karim Abedi).

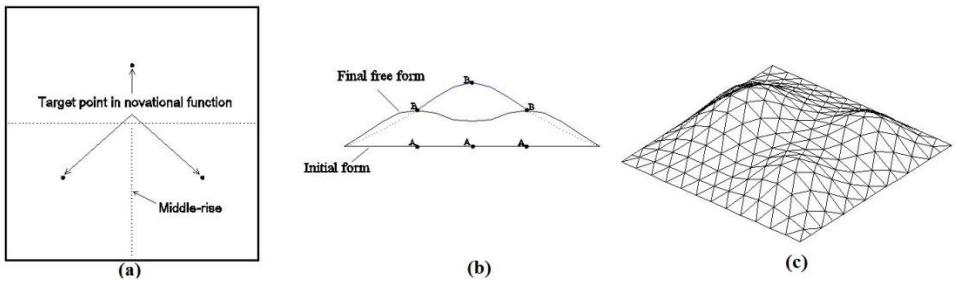

Fig. 1. a)The position of points in generating triple domes free-form in plan, b)The front view, c)Configuration of triple domes free form space structure models

According to the equations of code due to the different slopes of the lattices, the snow load for each lattice was calculated and applied separately. According to the space structure code regarding the seismic load, it is necessary to conduct Time History dynamic analysis with at least 3 accelerographs. In the research, according to the assumed criteria, three accelerographs of Parkfield, Imperial Valley and Chalfant Valley were extracted and applied after Scaling. The load combinations were applied by considering dead, snow, seismic and thermal loads. In the design of the models, four types of tubular sections are selected with external diameter and thickness of 8.5mm and 120mm, 10mm and 160mm, 20mm and 190mm, 30mm and 270mm.

In order to study the instability behavior of triple domes free-form space structures, nonlinear finite element analysis should be carried out. In the present study, all analyses were carried out using ABAQUS, which is a general-purpose finite element program designed specifically for advanced structural analysis. In the meshing and modeling of triple domes free-form members, a three-dimensional first-order beam (B31) element is used. The yield criterion in the modeling is the Von-Mises criterion and the models have been analyzed using Abaqus/standard Solver. To determine the equilibrium paths through limit points into the post-critical range, the 'Arc-Length-Type Method' was used which is the most efficient method for his purpose and it was now predominantly used in structural nonlinear analysis programs.

2.2. Stability analysis of the models

In this research, the application of imperfection is conducted by the approximate perturbed method as well as generalized conformable imperfection mode method. After modeling, the application of loading and boundary conditions, nonlinear analysis is conducted on the models and the presence of a bifurcation point before the limit point is investigated for determining the type of instability. In the research, the stability behavior of 6 models with triangular novation, height to span ratios of 1/4, 1/5 and 1/7 and middle rise to span ratios of 1/8 and 1/10 were studied.

Due to the occurrence of bifurcation point instability in the models with the rise to the span ratio of 1/10 and the height to the span ratios of 1/4 and 1/5, at first, the approximate-perturbed method is used to apply imperfection. In order to conduct an imperfection analysis of the approximate-perturbed method, a linearized buckling analysis is carried out and buckling modes are extracted. Then, these buckling modes are applied to the model as a primary geometric imperfection and the model is subjected to static nonlinear analysis. In the research, 80 primary buckling modes are applied in the model as imperfection with a value of S/500 (S is the length of dome span). It was observed that lower modes of buckling have a slight effect on the reduction of limit load and are considered insensitive modes. Among the applied modes, the 11^{th} mode is the most sensitive mode due to the greatest reduction in the limit load. Considering this mode as primary imperfection, the limit load can be reduced to 8.69 by an imperfection value of S/150 and the correct path of the balance can be obtained.

The second method for imperfection application is the generalized conformable imperfection mode method that was proposed in 2015 by Mousavi (Mousavi et al., 2015). In this method, geometric deformations of the structure are calculated in each of the three directions near the critical loads, before and after the buckling of the structure, and their difference is applied to the structure as a form of buckling mode for primary imperfection with a given value. Then, the structure is subjected to nonlinear static analysis. The correct required value for primary geometric imperfection is S/220 in this model. Therefore, the required imperfection value in this method is less than that of the approximate-perturbed method.

3. Results and discussion

In this study, it was observed that the generalized conformable imperfection mode method is a more appropriate method to obtain the correct equilibrium path in triple domes free form space structure.

The load-displacement responses of the models with the middle rise to span ratio of 1/8 and 1/10 in the

central node for global loading are shown in Fig. 2. As it is seen, the overall collapse occurs in all models, and the increase of the height to the span ratio with the same rise to span ratio increases the value of load factor of the models.

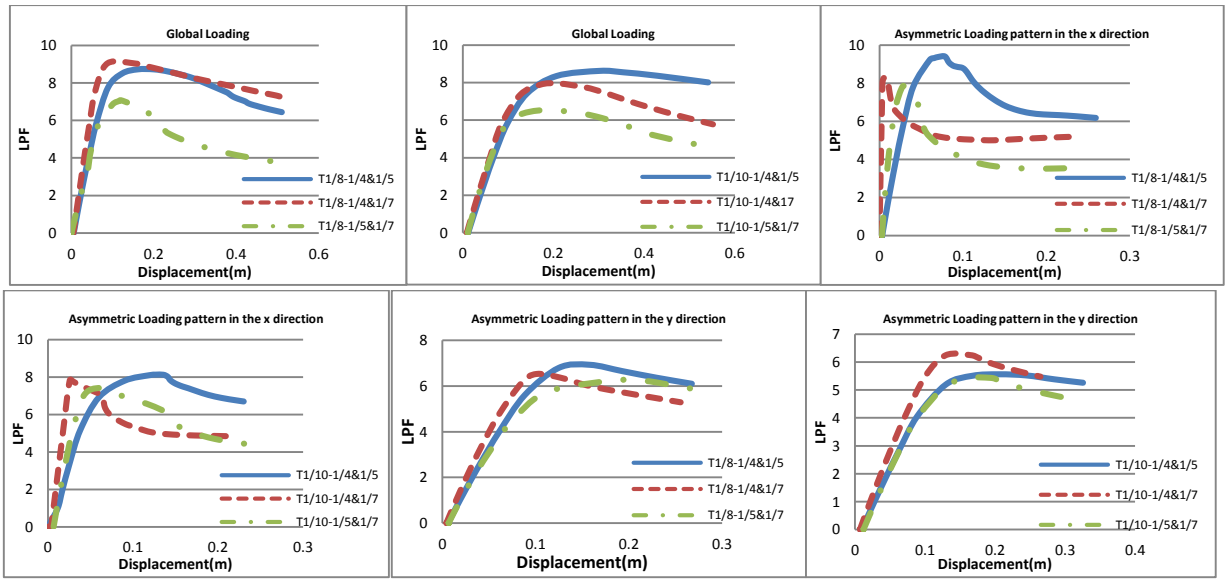

Fig. 2. Load-displacement responses of models in the different Loading patterns

4. Conclusions

- Lower modes of the buckling do not have a significant effect on the reduction of limit load, and sensitive modes of these structures are upper modes.
- The comparison of the approximate-perturbed method and the generalized conformable imperfection mode method shows that the generalized conformable imperfection mode method is a more appropriate method to apply imperfection in triple domes free form single layer space structures.
- In both symmetrical and asymmetrical loading modes, overall collapse occurs in all models.
- In most of the models, the increase of the height to span ratio increases the value of the load factor.
- The increase of middle rise to span ratio increases the value of the load factor of models.
- The asymmetric loading pattern in the y direction is the most critical loading pattern in the triple domes free form.

5. References

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