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Research on The Stability Behaviors of Single-Layer Shells Based on The Whole-Course Response Analysis Method

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The static stability analysis as a key problem for design of single-layer reticulated shells has become attractive to many researchers since late 1980s. Instead of traditional analytical method based upon "continuum theory", the procedure of whole-course response analysis based upon non-linear finite element analysis and method for tracing equilibrium path was developed, by which the structural behavior along with the whole loading course of a complicated structure such like reticulated shell can be revealed clearly by the complete load-deflection curve, and the critical load can be accurately obtained. The effects of some practical factors such like the initial geometric imperfection of the structure and the unsymmetrical distribution of load can also be considered in this procedure. Based upon such a procedure, systematical elastic complete load-deflection analyses for different types of reticulated shells with varying geometric and structural parameters have been carried out. By nearly 20 years effort, the elastic stability of reticulated shells has been solved up to now[1-2].

Recently, the problem of elasto-plastic stability of reticulated shells gradually has become more attractive to researchers[3-4]. However, the analysis on elasto-plastic stability is much more complicated than elastic analysis because of distinguished characteristics between elastic stability and elasto-plastic stability. Plastic instability of reticulated shells exhibits obvious nonlinear and non-conservation features, it will be found that some new phenomena and mechanism of instable behaviors not seen before. Taking into consideration of material nonlinearity, the elasto-plastic stability performance of reticulated shells will change greatly, which will be recognized only by plentiful elasto-plastic whole-course response analysis.

Four kinds of single-layer latticed domes constructed widely (Kiewitt 8, Kiewitt 6, Geodesic and Schwedler), are studied systematically with the software ANSYS, in which more than 144 cases of elasto-plastic whole-course analysis were carried out with different initial imperfection, geometric, structural and load parameters.

Firstly, Finite Element software ANSYS and pre-process and post-process programs which written by the authors are used for numerical simulation of typical experimental shell models[5]. The results are compared with experimental data to validate the feasibility of elasto-plastic stability analysis using ANSYS.

Secondly, four kinds of single layer latticed domes (Kiewitt 8, Kiewitt 6, Geodesic and Schwedler) are studied by using the elasto-plastic complete load-deflection response analysis including more than 144 examples with spans in a range from 40m to 70m, rise-span ratios from 1/8 to 1/5, unsymmetrical action ratio of loads from 0 to 1/2, initial geometry imperfections from 0 to L/300 (L is the span). For comparison purpose, elastic large deformation analysis with the same number is carried out. Elastic and elasto-plastic critical loads of latticed domes are obtained for each dome. The displacement, buckling mode and degree of plastic development are recorded. The effects of initial geometry imperfection, unsymmetrical action of loads, different supporting conditions, element sections, spans, and rise-span ratios on critical loads are investigated. The complete load-deflection response analysis of the plastic development for each element is traced and conclusion is drawn that the distribution of plastic development of elements and the degree of plastic development are key factors to determine the critical loads of reticulated domes. This will be helpful to study the failure mechanism of reticulated domes under static loads.

Finally, base upon these results, comparison between elastic and elasto-plastic critical loads has been carried out, and plastic influence coefficients are summarized for each kind of reticulated domes. These coefficients can be used to predict accurately the elasto-plastic stability critical loads of latticed domes in practical project.

Based upon a large-amount parametric study on elasto-plastic stability of reticulated domes with different geometric, structural and load parameters, such the plentiful results obtained from these analyses as mentioned above, a perfect picture about elasto-plastic stability behaviors of reticulated shells was revealed. Practical plasticity influence coefficient - the ratios C_p for predicting critical loads for different types of reticulated domes have been proposed, and some conclusions are drawn as below:

(1) In most cases, the domes have the buckling mode of starting from the snap-through of some joints, but, the concave ring appears in a few of cases, and in such cases, the critical loads are comparatively low. However, this phenomenon can be eliminated by strengthening elements in the second ring from the top.
(2) The stability of reticulated domes is not sensitive to unsymmetrical distribution of load.
(3) The effect on stability on material nonlinearity for these four kinds of reticulated is basically consistent, and the ratio C_p for reticulated domes with L/300 imperfection can be conservatively regard as C_p =0.430.

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