СОВРЕМЕННЫЕ МЕТОДЫ И РАСЧЕТЫ СТРОИТЕЛЬНЫХ КОНСТРУКЦИЙ, ОСНОВАНИЙ И ФУНДАМЕНТОВ

DIFFICULTIES FOR DETECTING THE SINGULAR POINTS WITH COMMERCIAL PROGRAMS IN SPACE STRUCTURE AND A METHOD FOR DETERMINING THE REAL CAPACITY OF THE STRUCTURES

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For design purposes, the stability of any structure being designed is of paramount importance. The fact that it is possible to perform an analysis on a space structure which shows that the stresses in that structure are all below those permissible for the materials used in its construction, is in itself no guarantee that when the structure is loaded it will not collapse. In order to determine this, it is necessary to find out if the structure is stable under the action of the applied loads. The secondary paths, especially in unstable buckling can play the most important role in collapse of the structure [2].

Analytical solutions for space trusses of the desired type which cover both nonlinear deformation and stability are difficult to find in the literature. In order to provide the desired benchmark, the complete theory and the exacl soulution for the nonlinear deformation and the stability of a regular tripod subjected to a load which acts in the direction of its axis of symmetry **is** presented in this work [1].

In this paper the dificulies for analysis the space structure in detecting the singular point and obtaining the real load carying capacity of these structures has been investigated and finaly a method for overcome to this problem has been presented. The numerical predictions in presented method has been verified with analytical soulotion in a space truss and and Laboratory results in a space frame.

Key words: Space Structure, Singular Point, Eigenvalue Buckling Analysis, Post Buckling Analysis.

Introdution. A large number of software packages with nonlinar structural analysis capabilities are available commercially. The list includes products such as ABACUS, ADINA, ALADDIN, ANSYS, COSMOS, DYNA, FRAME3D, GT STRUDL, LIRA, LUSAS, MSC. Marc, NASTRAN, NISA, SOFISTIK, SCAD and SAP2000. Nonlinear. The nonliear analysis functions are frequently embedded in more general packages that also offer linear and dynamic analysis as well as extensive capabilities for the computer-aided specification of structural behaviour.

Commercial software package for nonlinear stuctural analysis contain user manuals that explain the steps of nonlinear analysis, but generaly assume that the user is familiar with the theory on which the analysis is based. Nonlinear structural analysis is far less standardised than linear analysis, where the assumption that the engineer is familiar with the theory on which the analysis is based [1].

Over the last two decades the problem of buckling of shallow lattice domes has grown in importance because of several interrelated developments [3]. The need to cover larger spans without intermediate supports with lightweight structures has made buckling behavior a determining factor in their design.

Two techniques are available in the ANSYS Multiphysics, ANSYS Mechanical, ANSYS Structural, and ANSYS Professional programs, for predicting the buckling load and buckling mode shape of a structure: nonlinear buckling analysis, and eigenvalue (or linear) buckling analysis. Because the two methods can yield dramatically different results, it is necessary for users understand the differences between them [5].

Space Truss Tripod. Tripod is a space regular truss as shown in Fig. 1 and kinds as sallow tripod and steep tripod of this structure analytically has been analyzed with the method thesis submitted by second author.

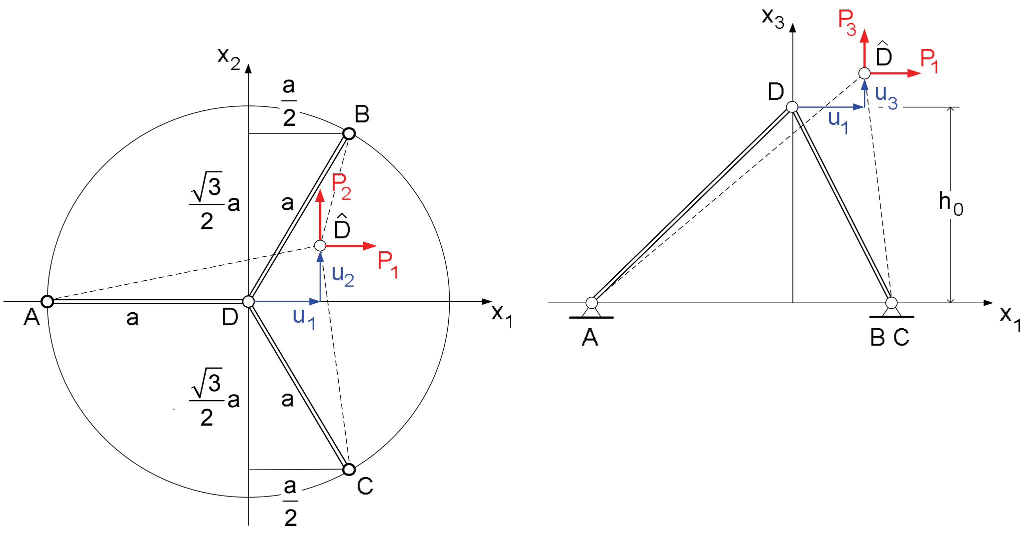

Figure 1. Space truss tripod

The regular tripod is used to illustrate the concepts of the stability analysis for space trusses. The bars of the truss have equal cross-sectional area A, modulus of elasticity E and length L_0 in the reference configuration. The supports A, B and C of the truss are pinned.

The two methods of stability analysis in the software product ANSYS for the sallow tripod and steep tripod structures are carried out and the ability of the ANSYS product is compared with existing analytical solution.

Direct Method, Eigenvalue Buckling Analysis in steep Tripod. Eigenvalue buckling analysis predicts the theoretical buckling strength and the bifurcation point of an ideal linear elastic structure. This method corresponds to the textbook approaches for the elastic buckling analysis. For instance, an eigenvalue buckling analysis of a column will match the classical Euler solution. However, imperfections and nonlinearities prevent most real-world structures from achieving their theoretical elastic buckling strength. Thus, eigenvalue buckling analysis often yields unconservative results, and should generally not be used in actual day-to-day engineering analyses.

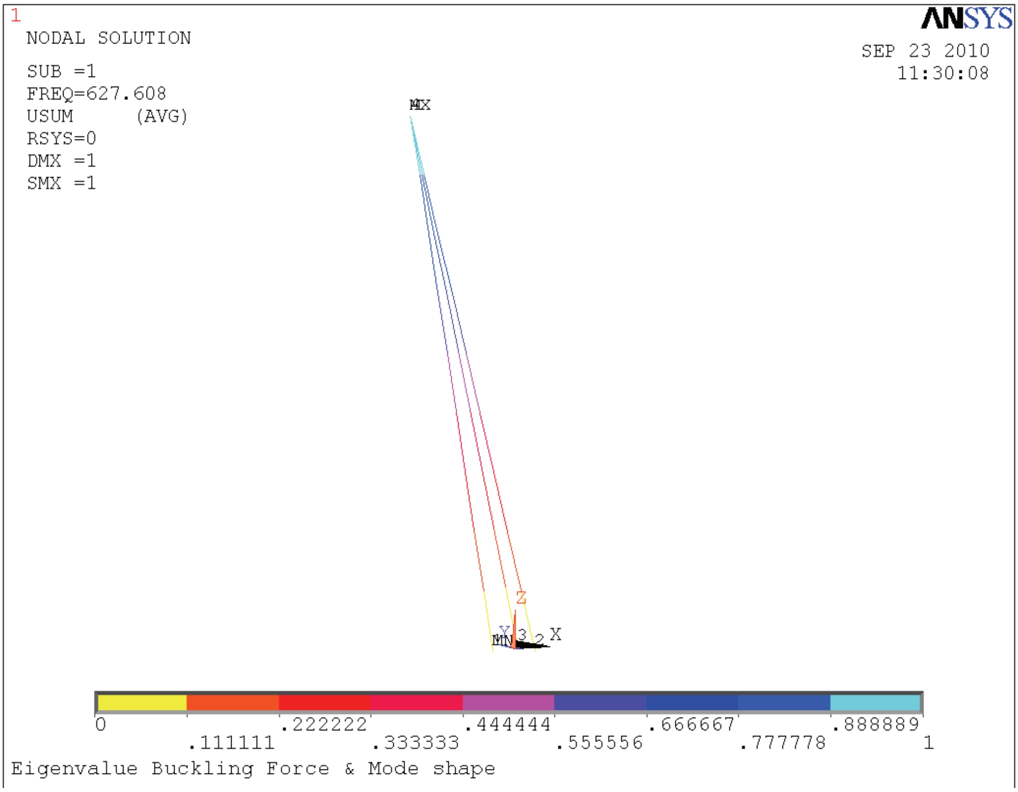

Figure 2. Eigenvalue buckling analysis in steep tripod

In the ANSYS program, according to the result of linear buckling analysis, critical load for steep tripod is 627.608 kN. In comparison with the real behavior of this structure as mentioned before, this method often yields incorrect results.

Post Buckling Behavior. Nonlinear buckling analysis is usually the more accurate approach and is therefore recommended for design or evaluation of actual structures. This technique employs a nonlinear static analysis with gradually increasing loads to seek the load level at which your structure becomes unstable.

Using the nonlinear technique, the model can include features such as initial imperfections, plastic behavior, gaps, and large-deflection response. In addition, using deflection-controlled loading, we can even track the post-buckled performance of structure which can be useful in cases where the structure buckles into a stable configuration, such as "snap-through" buckling of a shallow domes.

In the ANSYS producer, the procedure to obtaining the post buckling of the structure is the non-linear analysis. Three methods that can be used are: arc-length method and displacement control and force control for passing the critical load and seeing the behavior of the structure.

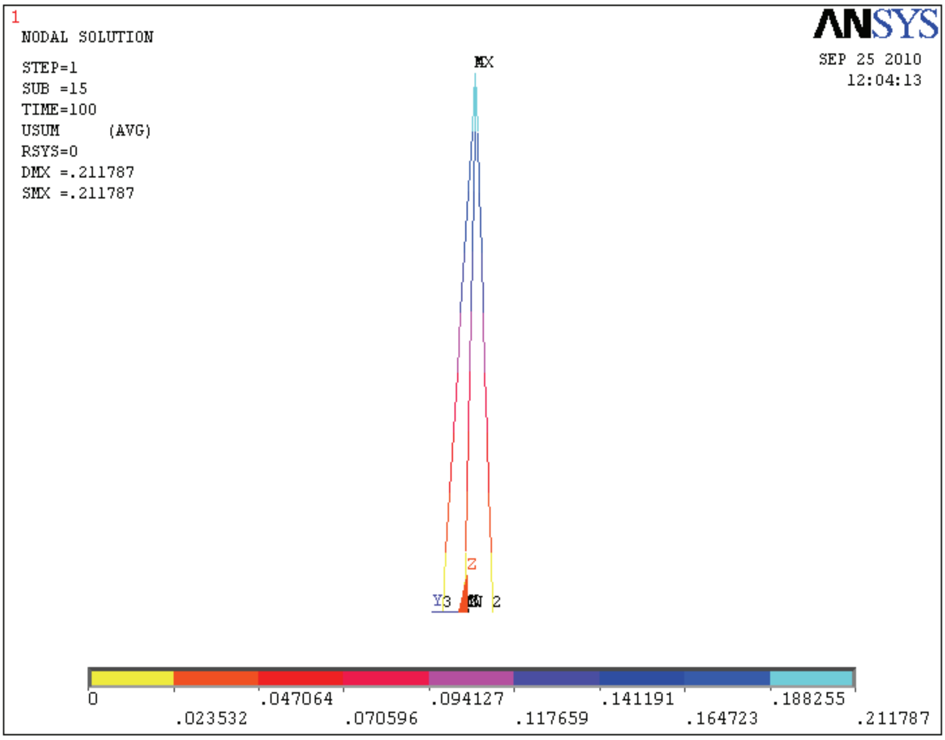

Figure 3. Nonlinear Analysis in Steep Tripod

For thronging the snap-through we can use the procedure arc-length and displacement control, but in large deformation for arc-length method convergence cannot be obtained easily no through of large deformation displacement control can help very good.

For analyzing these space trusses the element link 180 has been used. Link 180 is a spar that can be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. This 3-D spar element is a uniaxial tension-compression element with three degrees of freedom at each node as translations in the nodal x, y, and z directions. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, rotation, large deflection, and large strain capabilities are included.

While applying the critical load or even much more on the top point of structure, the ANSYS cannot obtain bifurcation point and consequently would not be able to lead the structure to bifurcation path. If we increase the load more and more, we will see that the structure is steel stable. For example, on the next model, 62700 kN has been applied as the vertical load on top point, while the structure is stable with only 0.211 vertical displacement.

In another model the structure is subjected to the buckling load in additional a small load to perturbing the structure to the bifurcation path, but this buckling mode is not a real buckling shape for this structure and this form of buckling is not possible in fact.

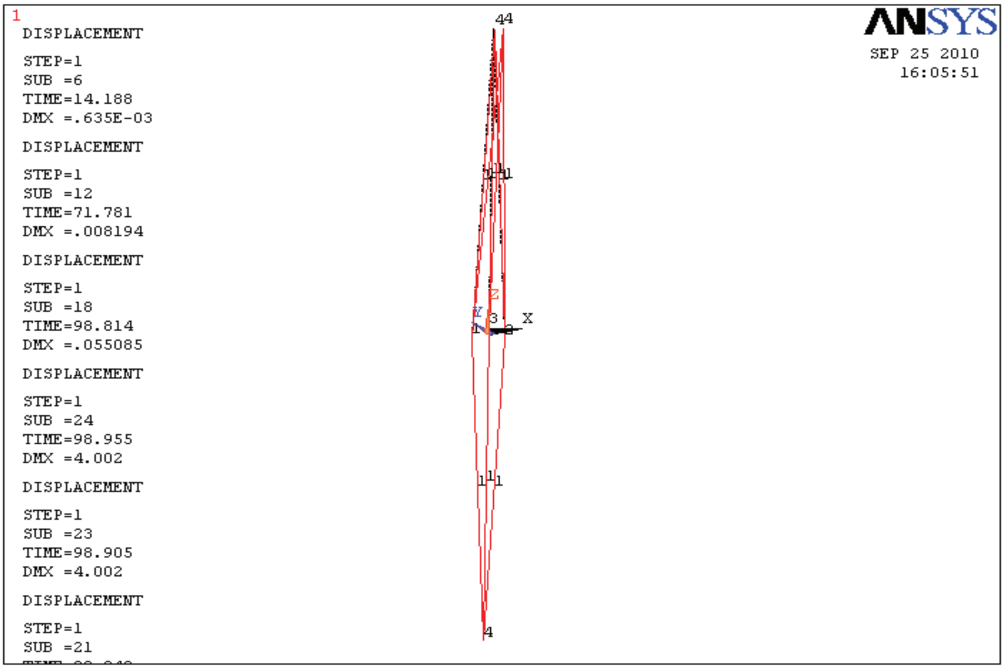

Figure 4. Nonlinear Analysis in Perturbed Steep Tripod

Shallow Tripod. This structure has been modeled and analyzed in ANSYS products. The nonlinear analysis with ANSYS can continue the load path of the shallow tripod beyond the snap-through configuration. The arc-length method and displacement control in ANSYS permits the computation of the full load path of the shallow tripod as follow:

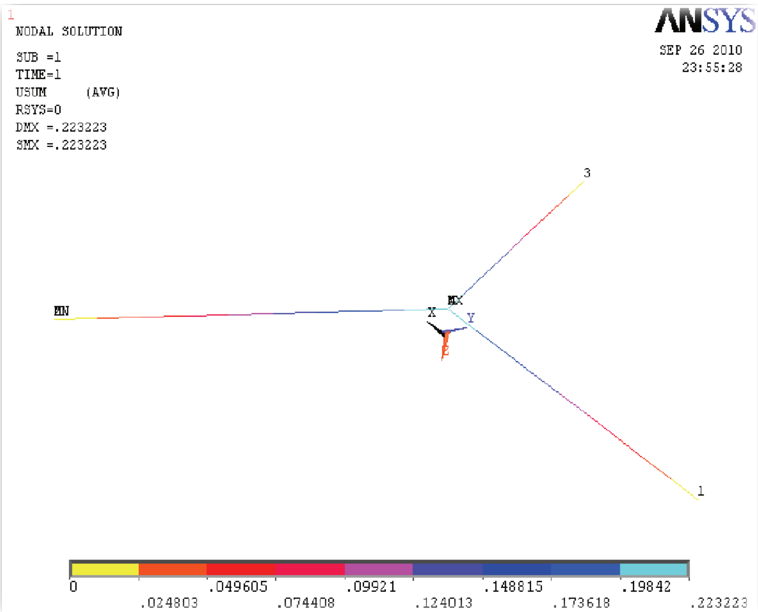

Figure 5. Nonlinear Analysis in Shallow Tripod

The deformation of the structure has been shown in the Fig 5.

The snap-through of the structure obviously has been prescribed in Fig 6. And the poverty of arc-length method in ANSYS to continuation of a load path beyond three critical points has been shown in Fig 7.

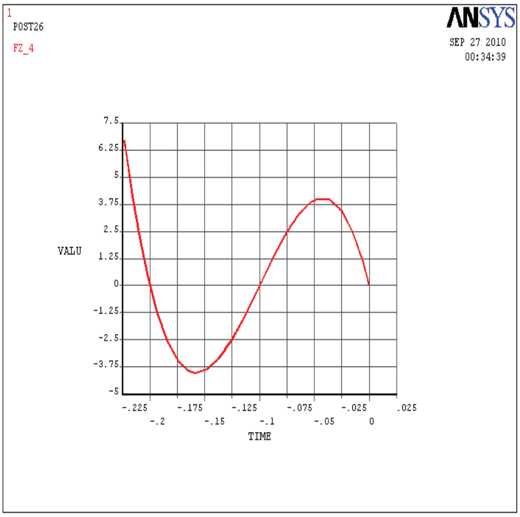

Figure 6. Snap Through in Shallow Tripod

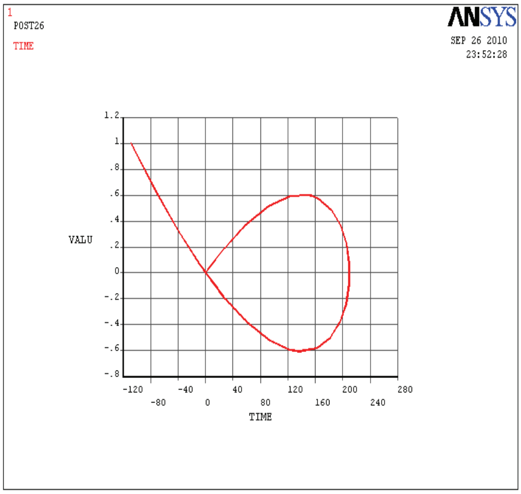

Figure 7. Snap Back in Shallow Tripod

A method for determining the real capacity of the structures [2]. The coefficient matrix of the structure is generally known as the structure tangent stiffness matrix and is denoted by $\underline{\underline{K}}_{\Phi}$. This matrix is not constant throughout the deformation history of the structure. This is due to the effect of the material and geometric nonlinearities included in the formulation of it. Hence the matrix $\underline{\underline{K}}_{\Phi}$ is a function of the equilibrium position at which it is formed and instantaneously relates an increment of loading on the structure to the resulting increment in displacements, as follows:

$$\underline{\underline{K}}_{\Phi} \cdot \Delta\underline{U} = \Delta\underline{C}, \tag{1}$$

Where $\Delta\underline{U}^{\Phi} = \left\{\Delta U_{1}, \ldots, \Delta U_{n}\right\}$; $\Delta\underline{C}^{\Phi} = \left\{\Delta P_{1}, \ldots, \Delta C_{n}\right\}$.

The matrix $\underline{\underline{K}}_{\Phi}$ is a real, n × n symmetric matrix. A method according next four steps has been implemented in a combined materially and geometrically nonlinear finite element analysis computer program based on an incremental/iterative Newton—Raphson solution procedure.

In the first stage analysis, the proportional live load factors at which critical points occur are determined and the primary path is obtained. In the second stage analysis the perfect structure is lead towards the lowest bifurcation path.

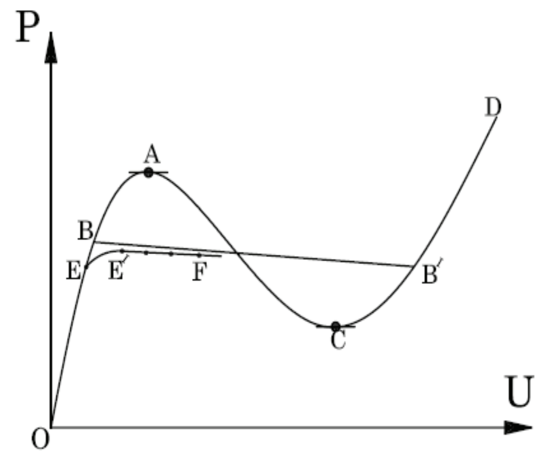

Figure 8. Calculation of Bifurcation Path

(Step 1) An incremental iterative analysis is carried out to obtain the primary path (e.g. OACD in fig. (8)), and determine the existence of any bifurcation point (e.g. point B in Fig. (8)).

(Step 2) In the second analysis, at the nearest equilibrium position just before the first bifurcation point (point E in Fig. (8)), λi and $\underline{\bar{V}}_i$; which are respectively the smallest eigenvalue and corresponding eigenvector of the tangent stiffness matrix $\underline{\underline{K}}_{\Phi}$, are evaluated by a method such as inverse iteration technique.

(Step 3) The increment following point E (Fig. (8)), is a displacement control one. In this increment the live loading vector p of Eq. (1), is replaced by 1% of the eigenvector $\bar{V}_{i(j)}$. The degree of freedom j is then incremented by a very small amount in the same direction of $\underline{\bar{V}}_i$.

(Step 4) The live loading vector p of Eq. (1) is restored to its original form in the fifth increment after point E for the rest of the analysis. Of the new equilibrium path OEE'F (Fig. (8)), the part OE is the same as the primary path, and E'F is very close to the theoretical bifurcation path BB'.

A low-rise circular arch [2]. This structure is shown in Fig. (9). The behavior of the arch under load is depicted in Fig. (10), where the apex load is plotted against the apex vertical deflection and we see the results of analysis via another computer program (ANSYS Registered in P.F.U.R University, Moscow, Russia) in primary path in comparison with our program (CNASS). Four curved 3-noded elements are used in the structures mesh. The program results confirm the existence of a bifurcation point (negative diagonal terms) before the occurrence of the first limit point. The secondary path is obtained by perturbing the perfect structure into its bifurcation path using the technique described above. The deflected shapes of the structure at the end of the primary and secondary paths are shown in Fig. (11) respectively. The bifurcated structure exhibits a tilt at the apex.

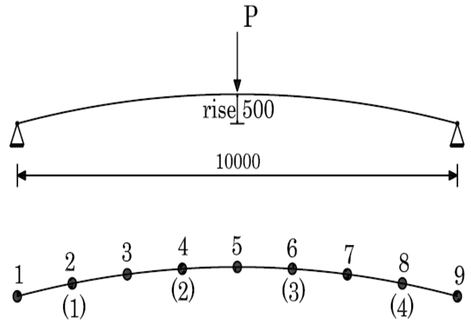

Figure 9. Circular Arc:
E = 200 kN/mm^2, I = 1E8 mm^4, A = 1E5 mm^2

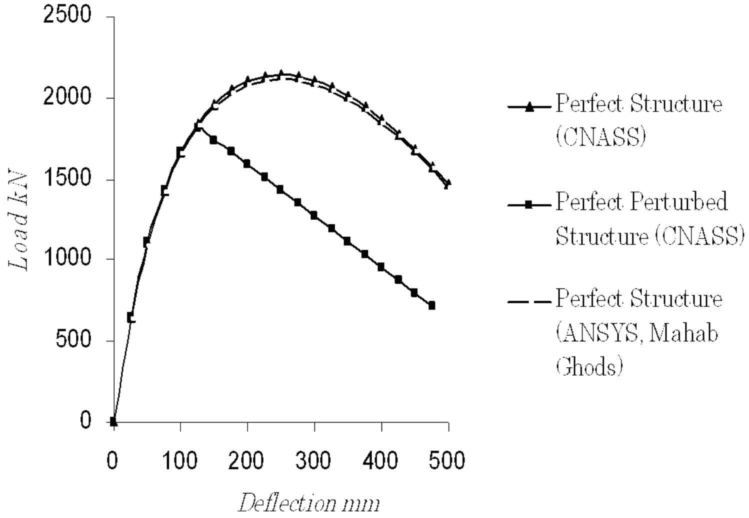

Figure 10. Load-Central Node Deflection Behavior

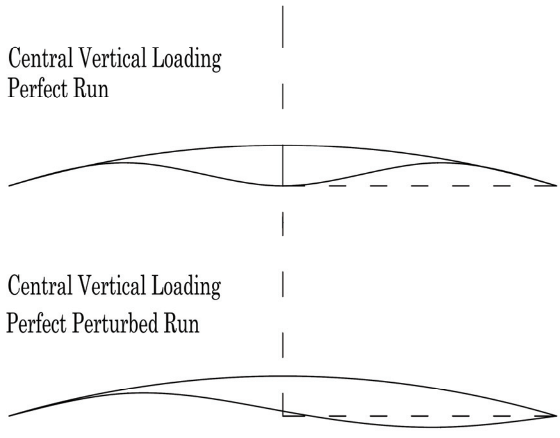

Figure 11. Deformations

Conclusions. For design purposes, the stability of any structure being designed is of paramount importance. The fact that it is possible to perform an analysis on a space structure which shows that the stresses in that structure are all below those permissible for the materials used in its construction, is in itself no guarantee that when the structure is loaded it will not collapse. In order to determine this, it is necessary to find out if the structure is stable under the action of the applied loads.

A technique has been developed in this paper to obtain the lowest bifurcation path and real buckling capacity of reticulated space domes, which worked very well and yielded satisfactory results when applied to the example presented. There is a bifurcation point in the "perfect analysis" of the dome with design geometry that can be a huge difference between the above two limit loads.

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ТРУДНОСТИ В ОПРЕДЕЛЕНИИ ПРЕДЕЛЬНЫХ ТОЧЕК В КОММЕРЧЕСКИХ ПРОГРАММАХ ПО ПРОСТРАНСТВЕННЫМ КОНСТРУКЦИЯМ И ПРЕДЛОЖЕНИЕ МЕТОДА ОПРЕДЕЛЕНИЯ РЕАЛЬНОЙ ПРОЧНОСТИ КОНСТРУКЦИИ

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Обеспечение устойчивости конструкций при действии проектных нагрузок является важнейшей составной частью процесса их проектирования. Особое значение вопросы устойчивости имеют при проектировании легких стержневых пространственных конструкций. Для этого класса конструкций задача устойчивости должна обязательно решаться в нелинейной постановке с учетом развивающихся деформаций. Существует весьма ограниченное количество научных исследований, посвященных данной тематике.

В настоящей статье приведен анализ проблем, возникающих при выявлении критических точек нелинейных траекторий нагружения пространственных стержневых конструкций и определении их действительной несущей способности, предложены методы решения задачи нелинейной устойчивости. Приведено сравнение полученных авторами численных результатов решения тестовых задач с аналитическим решением для трехстержневой пространственной фермы и результатами лабораторных испытаний модели стержневого купола.

Ключевые слова: пространственные конструкции, устойчивость, критическая точка, расчет на собственные значения, закритическое поведение конструкции.