# Loss of stability and mechanisms of destruction for spatial structures

**Anita Handruleva, Vladimir Matuski, Konstantin Kazakov**

*Abstract*—**The study of sustainable behavior of structural constructions is inseparable part of their analysis and design. Ensuring their stability and reliability leads to conducting numerous studies and the experiments by scientists all over the world. The main factors influencing sustainable behavior are: morphology of the grid configuration, geometry and material characteristics of structural elements, type of joint connections and the type of supporting. On this basis, four representatives of multilayer structures for structural analysis are selected. An orthogonal structure of the grid on the upper and lower surfaces is accepted. The numerical solution is performed with software based on the Finite Element Method, as are various cases of loading (local, symmetric and asymmetric), consistent with the built influence surfaces. To determine the critical value of the load parameter is used step-load increase with successive approximations to find the boundary equilibrium of the system. The study was conducted in terms of geometric nonlinearity reported with P-Δ effect, i.e. influence of normal forces on the stiffness of the system, assuming that the displacements increased after exclusion of elements of work. Results are presented in graphical and tabular form.**

*Index Terms*—**spatial structures, mechanisms of destruction, loss of stability, geometric nonlinearity (P-Δ effect), Finite Element Method.**

## I. THEORETICAL JUSTIFICATION

The study of sustainable behavior of structural constructions is inseparable part of their analysis and design. Ensuring their stability and reliability leads to conducting numerous studies and the experiments by scientists all over the world. The reason is the large number of cases of damaged structural constructions due to loss of stability of the load considerably less than the critical for the system. The main factors influencing sustainable behavior are: morphology of the grid configuration, geometry and material characteristics of structural elements, type of joint connections and the type of supporting.

In [4] and [5], Malla, Serrete have made a detailed overview of the status and trends for static and dynamic analysis of double layer structural systems. They pay particular attention to factors and phenomena that influence sustainable behavior as an individual element and the whole structure: - in terms of the elements: Non-axial loading, neatness, geometric tolerances, stiffness of the joint connections, the influence of redistribution of efforts by one or more defective rods (lost its bearing capacity), then critical behavior; - in terms of the whole structure: type and density of the grid structure, geometric tolerances and physical nonlinearity, susceptibility supports, local damage or loss of bars and rods, behavior of joint connections, method of supporting, presence of hard floor or cover disk; - in terms of the load: symmetrical or asymmetrical static, dynamic loading of suspended moving loads, fans and other vibrating machinery, earthquake and wind effects, temperature changes.

On the basis of analysis of the state of the problem, can be said that the study of spatial truss is a major challenge for civil engineers, for both practical and for research work. Considerable interest has been shown by scientists and researchers all over the world in this area, as evidenced by the large number of publications and articles in scientific journals: Journal of Space Structures, Proceedings of IASS, Journal of Structural Engineering, and others.

## II. INVESTIGATION OF THE SPATIAL STRUCTURES IN A STATE OF EQUILIBRIUM

To study the behavior of structures in limit state are selected four computational models, see Fig. 1, Fig. 2 and Fig. 3.

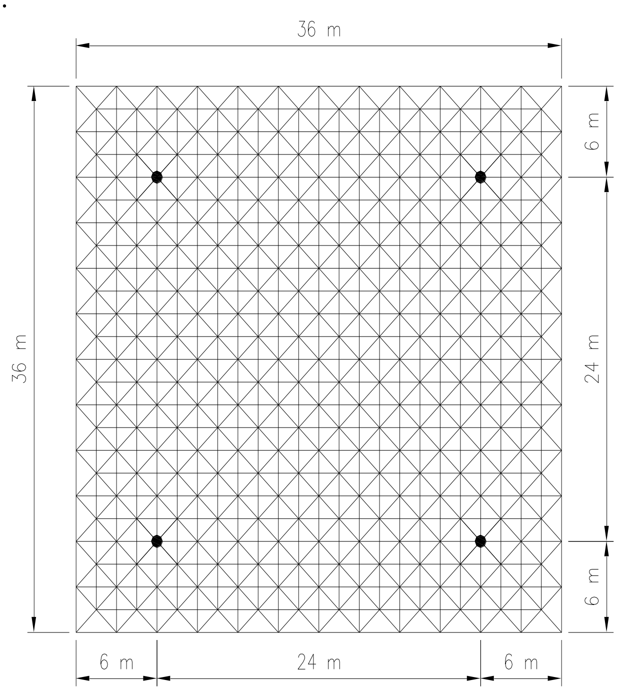


Fig. 1a Structural construction C.1

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**Anita Handruleva**, Department Mechanics and mathematics, University of Structural Engineering & Architecture (VSU) "Lyuben Karavelov", Sofia, Bulgaria, +359 (0)885 922 938.

**Vladimir Matuski**, Department Mechanics and mathematics, University of Structural Engineering & Architecture (VSU) "Lyuben Karavelov", Sofia, Bulgaria, +359 (0)899 022 442.

**Konstantin Kazakov**, Department Mechanics and mathematics, University of Structural Engineering & Architecture (VSU) "Lyuben Karavelov", Sofia, Bulgaria.

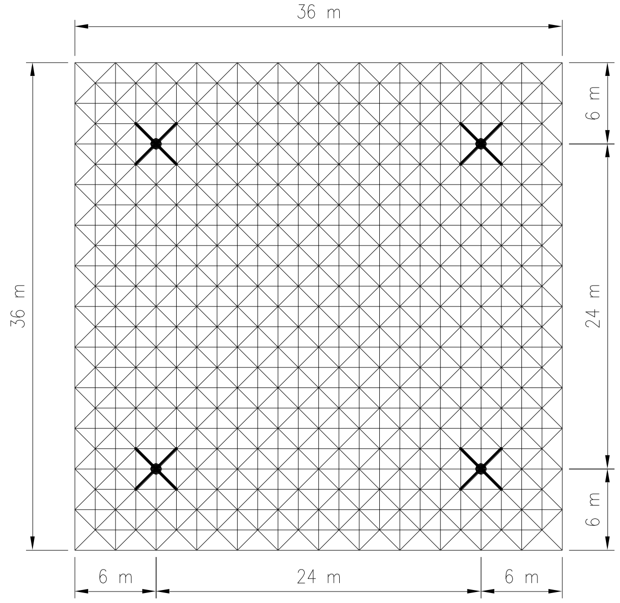


Fig. 1b. Structural construction C.2

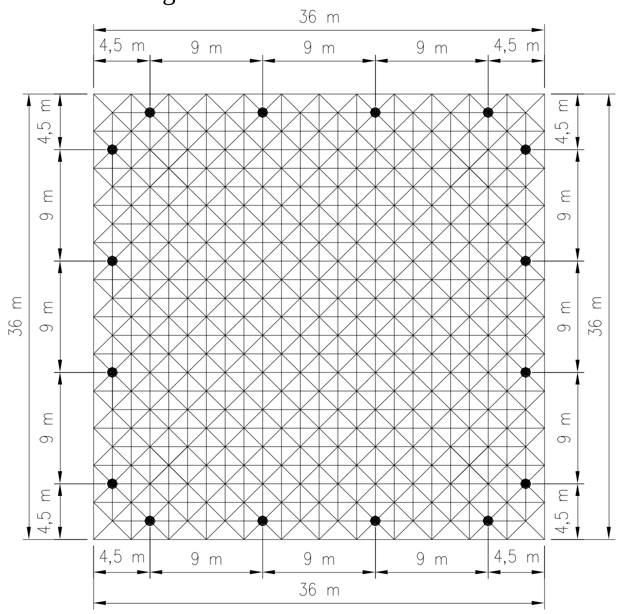


Fig. 1c. Structural construction C.3

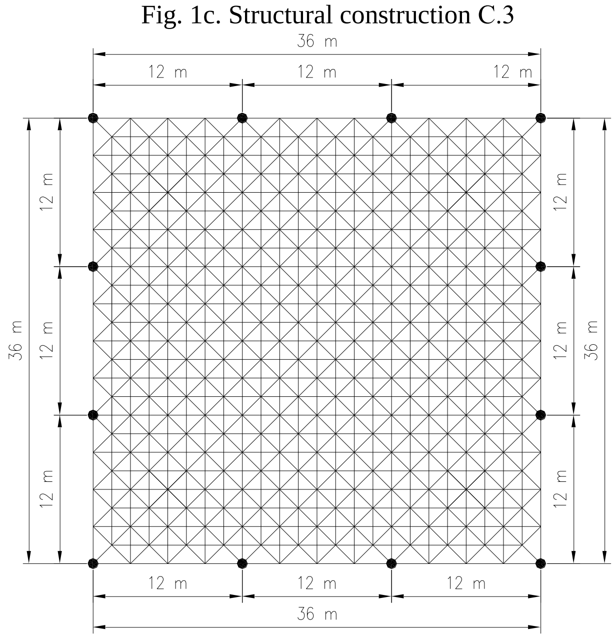


Fig. 1d. Structural construction C.4

1a) C.1 - structural construction, supported on four columns with reinforced zones (spatial trusses), and four console issue; 1b) C.2 - structural construction supported again on four columns with reinforced zones, but in the form of diagonals and four console issue; 1c) C.3 - structural construction supported along the contour of the bottom surface; 1d) C.4 - structural construction supported along the contour of the upper plane.

An orthogonal structure of the grid on the upper and lower surfaces is accepted. The dimensions of the structural modules are *3/3m*. The models differ in the type of supports and are labeled with: C.1 - structural construction, supported on four columns with reinforced zones (spatial trusses), and four console issue; C.2 - structural construction supported again on four columns with reinforced zones, but in the form of diagonals and four console issue; C.3 - structural construction supported along the contour of the bottom surface; C.4 - structural construction supported along the contour of the upper plane.

For the constructive elements are adopted cross-sections of pipe sections, namely: upper and lower surfaces-*∅95x4*; diagonal elements of the grid structure - *∅73x3,5*; reinforced lattice zones (model C.1)-∅114x4,5; reinforced zones C.2–*HEB500*; columns of models C.1 and C.2 - *∅560x10*; columns of models C.3 and C.4 - *∅219x5*. Profiles of steel *S235JRH* according to *EN10219-2* with computational resistance of the steel *235MPa*.

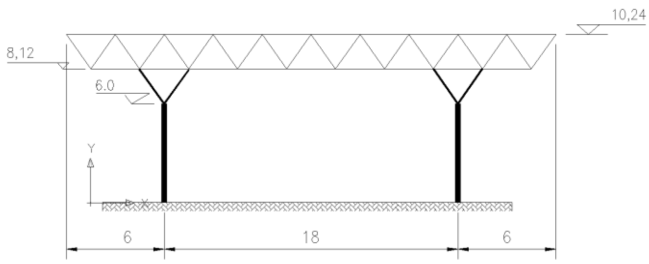


Fig. 2. Geometrical dimensions of the structural construction C.1 in the vertical section

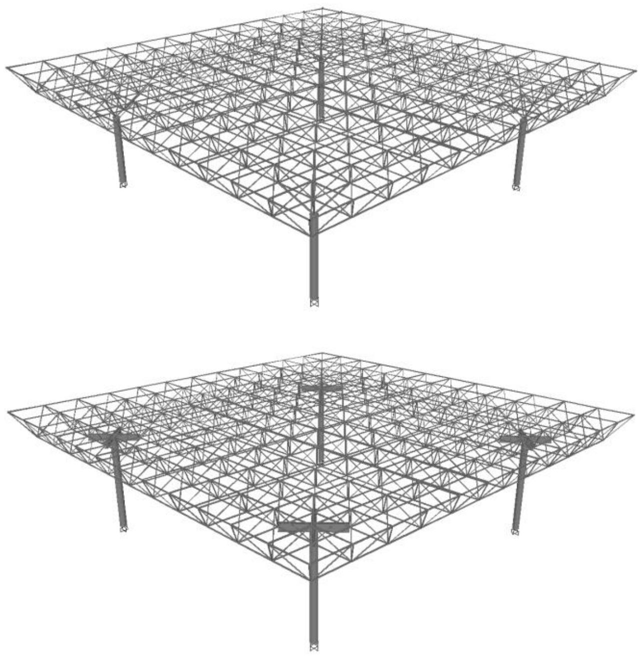

Fig. 3a. Computational models generated with software based on the Finite Element Method: Spatial view of constructions C.1 and C.2

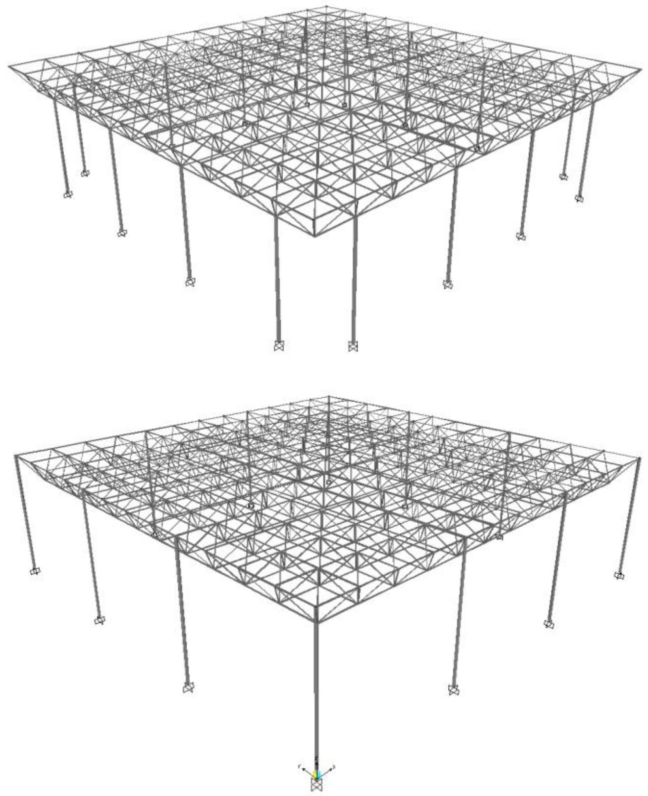

Fig. 3b. Computational models generated with software based on the Finite Element Method: Spatial view of constructions C.3 and C.4

The computational solution is performed with software based on the Finite Element Method, as are various cases of loading (local, symmetric and asymmetric), consistent with the built influence surfaces. To determine the critical value of the load parameter is used step-load increase with successive approximations to find the boundary equilibrium of the system. When an element reaches limit bearing capacity is assumed that he comes from work and in the next stage of computing its contribution is not counted. The study was conducted in terms of geometric nonlinearity reported with P-Δ effect, i.e. influence of normal forces on the stiffness of the system, assuming that the displacements increased after exclusion of elements of work. The conditions of equilibrium are written as is used deformed position of the structure.

## III. Analysis of the Obtained Results

### *A. Structural construction model C.1 - First load case*

In accordance with built influence surfaces is a joint load applied with equal intensity in all nodes, increasing from an initial value of $F_1=1kN$ with similar step.

When the load value is $F_8=8kN$ four rods have lost strength and are excluded in the next calculation stage. With increased load $F_{10}=10kN$ begins progressive exclusion of eight rods and then sequentially exclude another 16 and 100 rods. This process is illustrated in Fig. 4. When the load is $F_{10}=10kN$ are excluded from work 128 rods and then gets destruction. Scheme (Fig. 4) shows the first risk of loss of bearing capacity bars. They should be taken into account at the design stage in order to prevent the destruction of the structure reaching to the limit load. Although essentially due to the destruction of consistently exclusion from work to the maximum buckling working in elastic stage, due consideration of geometric nonlinearity, the overall behavior of the system mimics the work of elasto-plastic material.

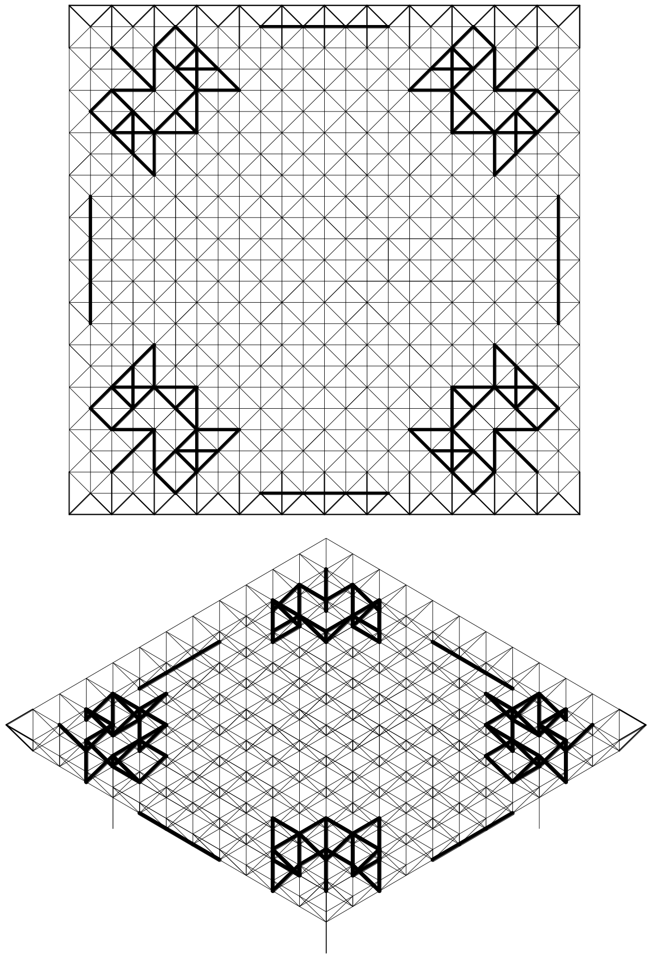

Fig. 4. Scheme of the rods exhausted its bearing capacity in the first load case for structural construction C.1

### *B. Structural construction model C.2 - First load case*

In this case, the load is distributed in all nodes.

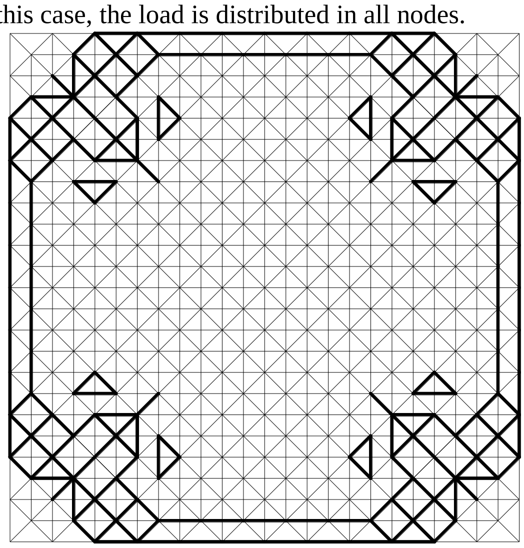

Fig. 5a. Scheme of the rods exhausted its bearing capacity in the first load case for structural construction C.2

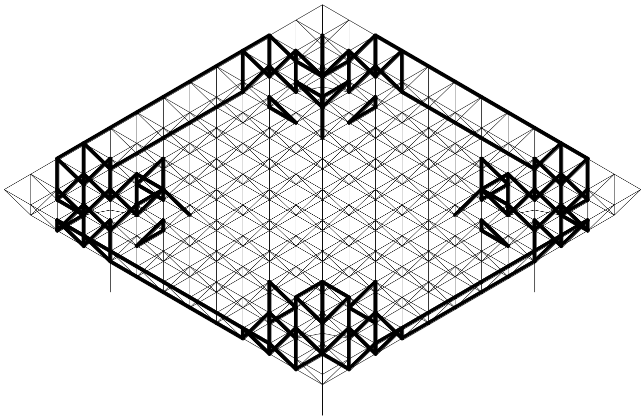

Fig. 5b. Scheme of the rods exhausted its bearing capacity in the first load case for structural construction C.2

Has been conducted step loading. If the value of the load is $F_6$=6kN, loss of stability occurs in 4 bars. With increased load $F_7$=7kN begins progressive exclusion of 8 rods and then sequentially exclude another 20, 36 and 148 rods. When the load is $F_7$=7kN are excluded from work 216 rods and then gets destruction, see Fig. 5.

### *C. Structural construction model C.3 - First load case*

In this case, the load is distributed in all nodes. Has been conducted step loading. If the value of the load is $F_{11}$=11kN, loss of stability occurs in 8 bars and begins progressive exclusion of 16 rods and then sequentially exclude another 72 rods. When the load is $F_{11}$=11kN are excluded from work 96 rods and then gets destruction, see Fig. 6.

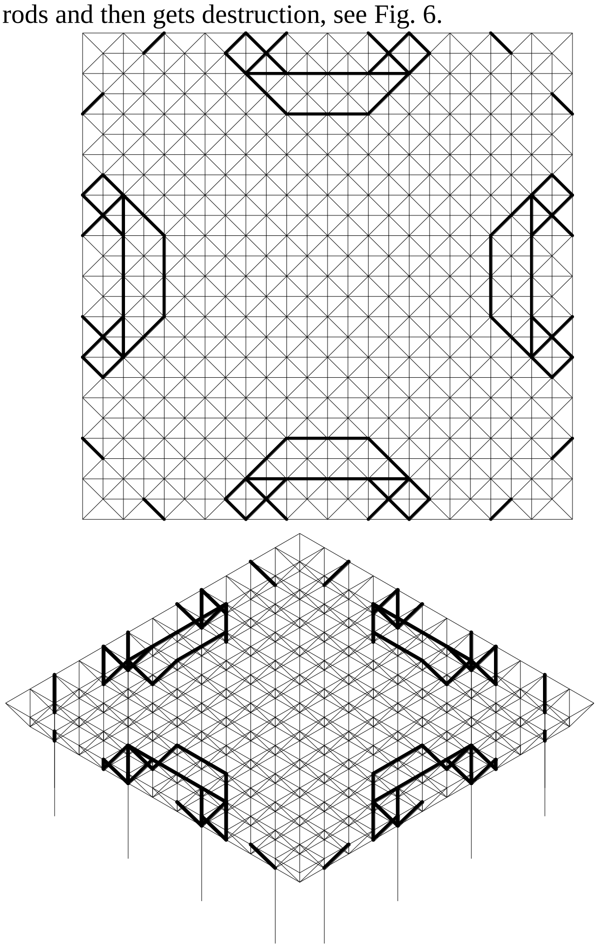

Fig. 6. Scheme of the rods exhausted its bearing capacity in the first load case for structural construction C.3

### *D. Structural construction model C.4 - First load case*

In accordance with built influence surfaces is a joint load applied with equal intensity in all nodes, increasing from an initial value of $F_1$=1kN with similar step.

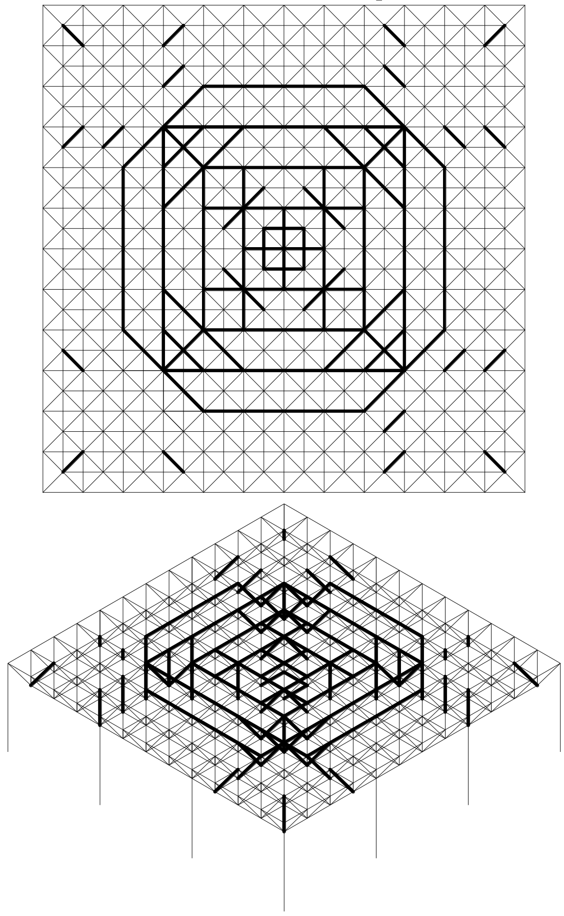

Fig. 7. Scheme of the rods exhausted its bearing capacity in the first load case for structural construction C.4

When the load value is $F_9$=9kN four rods have lost strength and are excluded in the next calculation stage and begins progressive exclusion of 32 rods and then sequentially exclude another 122 rods. This process is illustrated in Fig. 7. When the load is $F_9$=9kN are excluded from work 158 rods and then gets destruction.

## IV. Conclusion

The results of the numerical solutions in the study of limit state for the four models of structural constructions show a general trend of behavior that resembles the work of elasto-plastic body. Although essentially due to the destruction of consistently exclusion from work to the maximum buckling working in elastic stage, due consideration of geometric nonlinearity, the overall behavior of the system mimics the work of elasto-plastic material.

Obviously, the boundary conditions of the structure models C.1 and C.2 increases boundary load. The supports along the contour of the lower grid for model C.3 reduced the limit bearing capacity of the structure. Most sensitive to overload of the structural construction are diagonal rods near the supporting.

The approach of the study by excluding bars work is approximately a specified schedule for the work of the rods, ie a rod bearing working until its capacity is exhausted. This makes it possible after a loss bars to determine the number of rods, which generate additional normal effort. Thus can appreciate constructive endangered bars of overload and take constructive measures necessary to prevent destruction.

From shown schemes of consistently exclusion of rods is seen that first overload rod, located close to the columns. After redistribution of the efforts, there is a progressive depletion of the bearing capacity of more bars. These schemes show the first real threat of loss of bearing capacity bars. They should be taken into account at the design stage in order to prevent the destruction of the structure reaching to the limit load.

## REFERENCES


[1] Kazakov K. S., "Theory of Elasticity, Stability and Dynamics of Structures", Academic Publishing House "Prof. Drinov ", Sofia, 2010.
[2] Kazakov K. S., "Finite Element Method for modeling of building constructions", Academic Publishing House "Prof. Drinov", Sofia, 2010.
[3] Dakov D. V., "Steel constructions of tubes", Building Structures Ltd., Sofia 2008.
[4] Malla R. Serrette R., "Double-Layer Grids: Review of Static and Thermal Analysis Methods", Journal of Structural Engineering, August 1996, p.873-881.
[5] Malla R. Serrette R., "Double-Layer Grids: Review of Dinamic Analysis Methods and Special Topics", Journal of Structural Engineering, August 1996, p.882-892.
[6] Smith E., "Space Truss Nonlinear Analysis, Journal of Structural Engineering", 1984, p.688-705.
[7] Vasek M., "Non-Linear Small Strain-Separate Effects Solution of 3D Beam System", Computational Mechanics, Barcelona, Spain, 1998.
[8] Ikarashi K. Kato S., "Elasto-Plastic Dynamic Buckling Analysis of Reticular Domes Subjected to Earthquake Motion", Int. Journal of Space Structures, Vol.12, No.3&4, 1997, p.205-215.
[9] Brodka J., Czehlowski A., Grudka A., Kowal Z., Lubinski M., "Przekricia Strukturalne", Arkady, Warszawa, 1985.
[10] El-Sheikh A.I., "Sensitivity of Composite and Non-Composite Space Trusses to Member Loss", Int. Journal of Space Structures, Vol.9, No.2, 1994, p.107-119.
[11] Levy R., Hanaor A., Rizzuto N., "Experimental Investigation of Prestresing in Double-Leyer Grids", Int. Journal of Space Structures, Vol.9, No.1, 1994, p.21-25.
[12] El-Sheikh A.I., "Sensitivity of Space Trusses to Uneven Support Settlement", Int. Journal of Space Structures, Vol.11, No.4, 1996, p.393-400.
[13] El-Sheikh A.I., "Sensitivity of Space Trusses to Sudden Member Loss", Int. Journal of Space Structures, Vol.12, No.1, 1997, p.31-41.
[14] El-Sheikh A.I., "Design of Web members in Space Trusses", Int. Journal of Space Structures, Vol.14, No.1, 1999, p.25-33.
[15] See T. McConnel R.:, "Large Displacement Elastic Buckling of Space Structures", Journal of Structural Engineering, Vol.112, No.5, May 1986, pp. 1052-1069.
[16] El-Sheikh, A. I., "Sensitivity of Space Trusses to Member Geometric Imperfections", Int. Journal of Space Structures, Vol.10, No.2, 1995, p.89-98.
[17] Chan, S. L., "Nonlinear Static and Dynamic Analysis of Space Frames with Semi-Rigid Connections", Int. Journal of Space Structures, Vol.8, No.4, 1993, p.261-269.
[18] Dubina, D., "Numerical and Experimental Researches concerning Two New Systems for Double-Layer Grids", Proceedings of the IASS, Vol. III, Copenhagen, 1991, p 213-220.
[19] Lan, T., "A National Code for the design and Construction of space trusses in China", Proceedings of the IASS, Vol.4, Madrid, 1989.
[20] Saka, T., "Approximate Analysis method for Post-Buckling Behavior of Double-Layer Space Grids Construction by a Bolted Jointing System", Proceedings of the IASS, Vol.4, Madrid, 1989.
[21] Schmidt, L., Stevens, L., Morgan, P., "Effects of Imperfections on Space Frame Stiffness", Journal of the Structural Division, Vol.103, No.1, January 1977, pp. 197-210.
[22] Al-Bermani, F., Kitipornchai, S., "Elastoplastic Nonlinear Analysis of Flexibly Jointed Space Frames", Journal of Structural Engineering, Vol.118, No.1, January 1992, pp. 108-127.



**Anita K. Handruleva** was born in Burgas, Bulgaria in 1985. She is assistant professor in the field of Structural mechanics in the department "Mechanics and mathematics", University of Structural Engineering & Architecture (VSU) "Lyuben Karavelov", Sofia, Bulgaria. She is author of three books and more than 55 research papers in the field of FEM computational modelling and the Structural mechanics. Assist. prof. Dr. Handruleva is member of IASS, IABSE and others professional societies.

**Vladimir D. Matuski** was born in Kustendil, Bulgaria in 1975. He is assistant professor in the field of Structural mechanics in the department "Mechanics and mathematics", University of Structural Engineering & Architecture (VSU) "Lyuben Karavelov", Sofia, Bulgaria. He is coauthor of three books and more than 40 research papers in the field of the Structural mechanics. Assist. prof. Matuski is member of IASS and IABSE.

**Konstantin S. Kazakov** was born in Sofia, Bulgaria in 1966. He is professor in the field of Structural mechanics and Numerical methods in engineering in the structural mechanics dept. of University of Structural Engineering & Architecture (VSU) "Lyuben Karavelov", Sofia, Bulgaria. He is author of five books and more than 140 research papers in the field of the Structural mechanics and the FEM computational technology. Prof. D.Sc. Kazakov is member of several professional societies.