DEVELOPMENT OF THE STEEL SPATIAL STRUCTURES IN BULGARIA

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1. ABSTRACT

In this paper the authors examine the recent state and development of steel space structures in Bulgaria. Possibilities for the construction of buildings, using space structures by means of the updated construction system "PPK' 84- MArchI" are analysed. The paper reviews the application of the system by the construction of several buildings in Bulgaria, which are interesting with their architecture. Attention is drawn to the possibilities for using the system in regions with high earthquake activity.

2. INTRODUCTION

The requirements for greater expressiveness of the modern forms of architecture based on frequently repeated members brought forth framework structures of new type called spatial structures.

They are with considerable advantages, which make possible to raise the economic efficiency of construction work as compared to the results with the traditional methods obtained so far.

In this sense the advantages involve:

- Spatial behaviour of the structures, which is the reason for the increased reliability in respect of unexpected collapse of single joint members or bars;
- Less overall height of the roof construction;
- Spanning of greater support distances;
- Planning and design of: overhead transport, suspended ceilings;
- Screens with various decorative effects;

- Lighting units and other fixtures as arrange in interior would contribute to the artistic set ups and apprehension of the roof construction and of the space as a whole;
- Flexible solutions in case of complicated layouts and vertical compositions;
- Prefabrication of the steel structures;
- Lower transport expenditures and easier transportation to place difficult for asses;
- Assembling and erection of the construction on ground level and lifting up large size block elements, etc.

In geometrical composition the spatial structures are formed of individual unitized modules, which are called structural crystals, fitted in space so as their peaks would from two even surfaces- upper and lower- in such a way that the system nodes formed by the upper surfaces are in positions as to the lower surfaces arranged specific modules (fig.1).

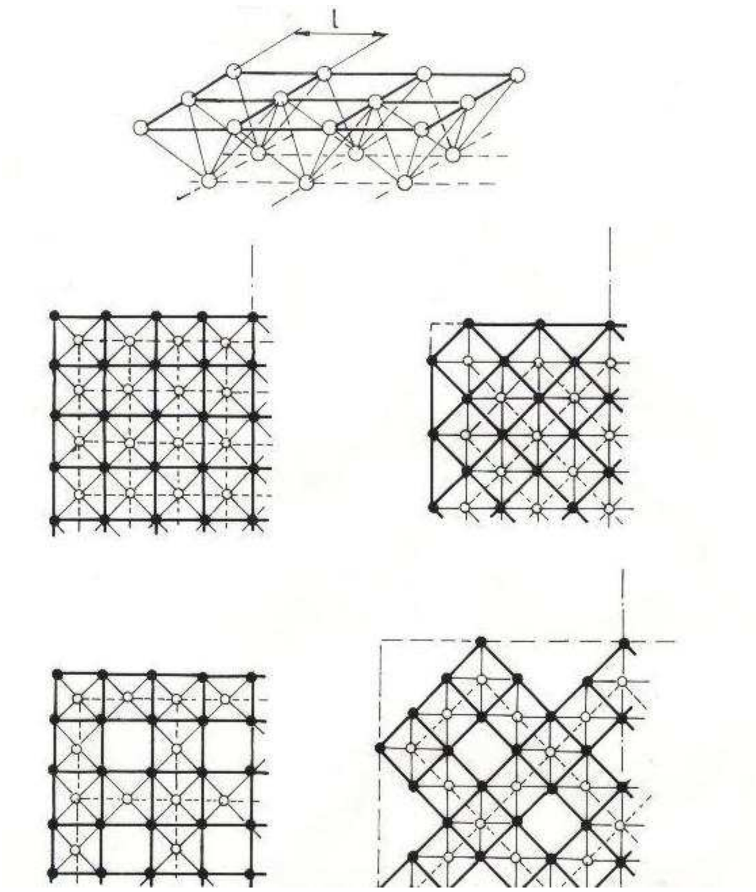

Fig.1 Double-Layer Grids Systems

In general the structural crystal are 3D members, which can be with different geometrical forms- inclined prisms with triangular, square, rectangular or another cross-section; wedge on rectangular or square base, ect.

The choice of the form of the structural crystal depends upon the type and size of the load as well as the nodal connections.

The first spatial structures appeared by the end of the forties of the XX century. Within the next 20 years a great number of space structures were introduced all over the world in USA, Germany, Czech Republic [1], Spain [2], Japan, Macedonia and other countries.

Of particular importance among all spatial structures is the structures developed at the Moscow Architectural Institute in Russia and KNIPIAT "Glavproject"- "SLS' 85-MArchI". It is manufactured at factory "Montex" at the town of Montana, Bulgaria since 1975.

3. MAIN COMPONENTS OF THE CONSTRUCTION SYSTEM

Basically the geometrical composition of the spatial frame type MArchI consists repeatedly used pyramids with square or rectangular contours, which made up of rods and nodal members (fig.2).

The rods are made of steel pipes of different diameters. At the ends of the rods are welded inserts fitted with axial bolts and moving hexagon special sleeves. The rods are with coordinating lengths of 1,5 m, 2,0 m, 3,0 m, 4,5 m, (figs.2 and 3).

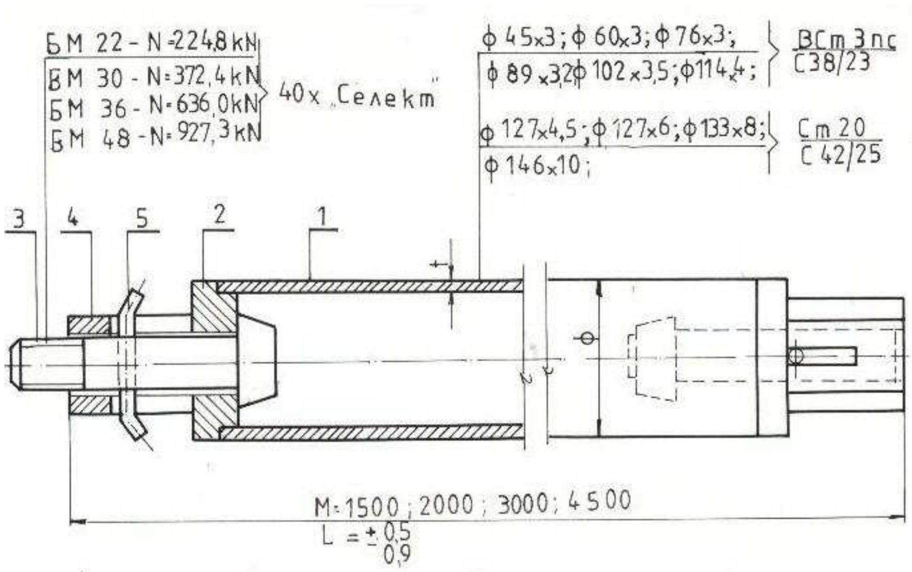

Fig.2 Structural rod

Fig. 3 Main structural element

The nodal members represent polyhedrons inscribed in spherical surfaces. On the flat side of the polyhedrons are drilled holes, which are threaded on the inside. Parts of the nodal members are used to connect horizontal rods at an angle of 90° and diagonal rods at 45° (figs.4 and 5). Predominantly they are used for buildings with spatial structures composed pyramids with square basis.

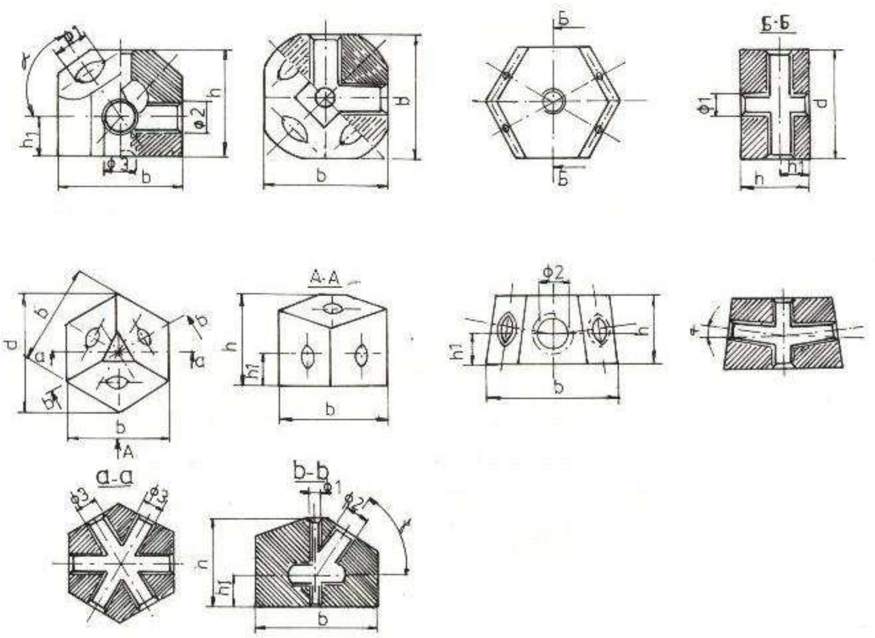

Fig.4 Nodal members

Fig.5 Nodal members before anticorrosion protection

When rods are connected by means of nodal members with holes drilled at 90°, then upper and lower rectangular and even lattices are formed with the size of the orthogonal cells 1,5×1,5 m; 2,0×2,0 m; 3,0×3,0 m or 4,5×4,5 m depending on the coordinating rod lengths. The rods of the upper lattices are shifted in respect of the lower ones by half a cell module. In the space nodes of the upper and lower lattices are connected by diagonal rods, which are arranged at angles of 45° in relation to the horizon. Their coordinating lengths are equal to the lengths of the chord rods. By connecting the members in the space (rods and nodal members) it is ensured that the horizontal and vertical loads acting upon the roof construction are transferred to the column heads.

The rods and nodal members are connected with the aid of high-strength bolts, which are built at the tubular members. The bolts are driven into the nodal members by the rotary-translation movement when rotating the special fixed to the bolts with retention pins. Driving of the special sleeves continue until their lower surfaces would get in touch with the retention surfaces of the nodal members.

The tightness of the connections is ensured through the initial tensions formed in the bolts while the tensioning forces depend upon the pin bearing capacities.

For the construction system there are nodal members in which holes are drilled for chord rods at 60° and for diagonal rods at 54°. With these elements it is possible to form pyramids with rectangular bases and then construct space frames either triangular or hexagonal in planning. Also, nodal members are developed which are making possible to construct cylindrical space frames (fig.4).

In terms of geometrical composition building system “MArchI” represents a “non-limited” system (term, used in typification of structures determining universally and serviceability of building systems), since it enable design of various in configuration and dimensions (in plan and elevation) different spatial skeletons with considerable large borders of architectural performance.

From the point of view of flexibility, the system satisfies in practice arbitrary kind of buildings or structures accounting an appreciable range of design loadings and a seismic impact. An important advantage of that system is its manufacture in every plant or workshop equipped according to standard. Likewise a basic prerequisite for its application is the possibility of permanent perfection, reaching high technical and economical indices. In comparison to traditional solutions structures manufactured after the “MArchI” system consume 20-25% less of metals. The reduction of labour of 20% is due to the adopted flow-line production and assembling of large size blocks. In practice it shortens building terms up to three times.

It is obvious from the foresaid that the efficiency of spatial structures at the present day of their development is not confined by the only criterion for example materials or labour expenditure but a range of criteria as reliability, durability, universality, unification possibility, architectural expressiveness etc. Structures after “MArchI” response in the highest degree to that combination of criteria therefore they are in great prospects in our building practice, i.e. sports centers (gymnasium, athletics halls, swimming pools, covered skating rings etc.), for trade objects (supermarkets, covered bazaars), for multifunctional buildings (youth clubs, educational buildings), exhibition halls, industrial and agricultural buildings.

The unified used by now assortment of rod and nodal members envelops the most advantageous economical solutions of the great majority available so far. Cross-sections of rods have been selected according to the definite gradation of stresses, where the min. dimension satisfies the ultimate value of the corresponding compressed rod, the max. dimension corresponds to the max. stress undertaken by the heat-treated bolt.

System columns are worked out in two versions:

- Pipes, providing an elevation from 4.8 m to 8.4 m to the bottom chord;
- Rolled rectangular or square steel angles, providing an elevation of 10.8 m to the bottom edge of the spatial structure.

At the lower end columns are equipped with supporting traverses and there are special supporting heads at the top, where the spatial construction treads. Steel columns are fixed to the foundations by means of anchor bolts.

The elements included in the building system permit erection of the main construction of one-storey blocks with dimensions in plan from 12×12 m to 90×120 m without intermediate supports.

Maximum vertical loading, for which spatial structures are studied and performed with the help of the system elements is 3,70 kN/m^2 and minimum loading- 2,0 kN/m^2 (including snow load- 0,7 kN/m^2, suspended transportation load- 32 kN, seismic load- level 9, according to MSK.

With building structures manufactured in our country after the system "MArchI" various projects of one million square meters and more have been built of very good economic and social effect.

4. APPLICATION OF DOUBLE-LAYER CONSTRUCTION SYSTEM "MARCHI" FOR BUILDINGS

4.1. Tennis playground hall in Plovdiv

The basic dimensions of the hall is 36×54 m, with clearance height of 10 m, measured from level 0,00 to the lower chord of the structure (fig.6). Two-layer framework is used composed of cells with dimensions 4,5×4,5 m and 3,18 m in height. In longitudinal direction the spatial structure is supported by 16 tubular columns of ∅ 402×9 mm. Transversely the spatial structure is supported along the left edge by the steel stand and in opposite direction continues as a sloped space wall. In order to maintain maximum load capacity in sense of tensile strength at bolt M30, which is 370 kN, the space frame is prestressed at the respective locations. The total amount of steel used for the roof structure is 38,7 tons. The building is constructed in 1983 (fig.7).

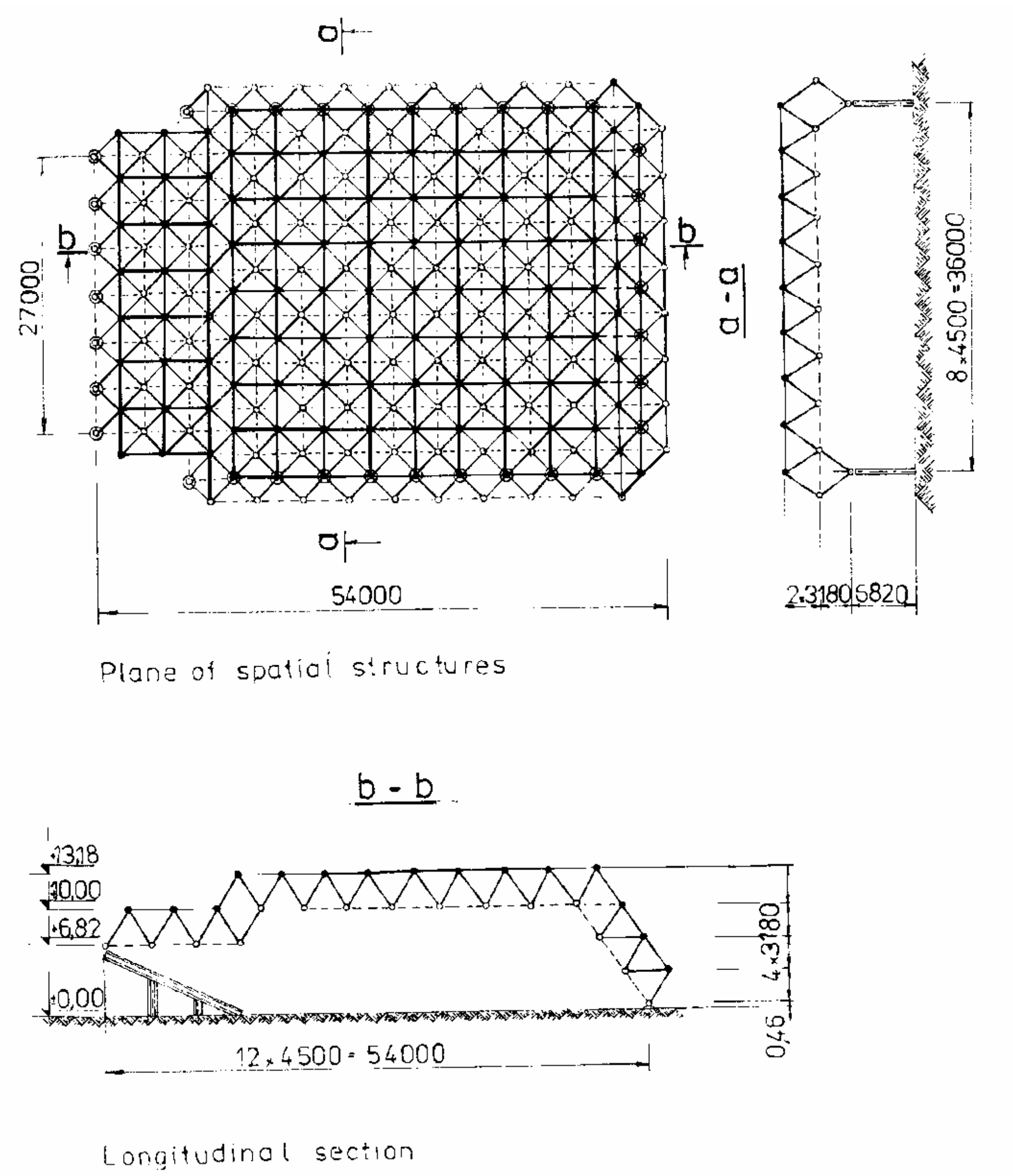

Fig.6 Tennis playground hall

Fig.7 Outside view

4.2. General store in Pravetz

The building consists of two main structures. The dimensions of these structures are 30×30 m and 27×27 m, respectively (fig.8). The roof framework is made of rods with lengths 3,0 m in each direction. The height of the space frame is 2,121 m. Each of the both structures is supported by four tubular columns, spaced 18×18 m. In order to meet the architectural design the space structure is made in three levels. The total amount of steel, used for both structures is 43,04 tons (21,54+21,50 tons). The roof cover and wall encloser are made of sandwich type panels "Alucobond". The building is constructed in 1985 (figs.9 and 10).

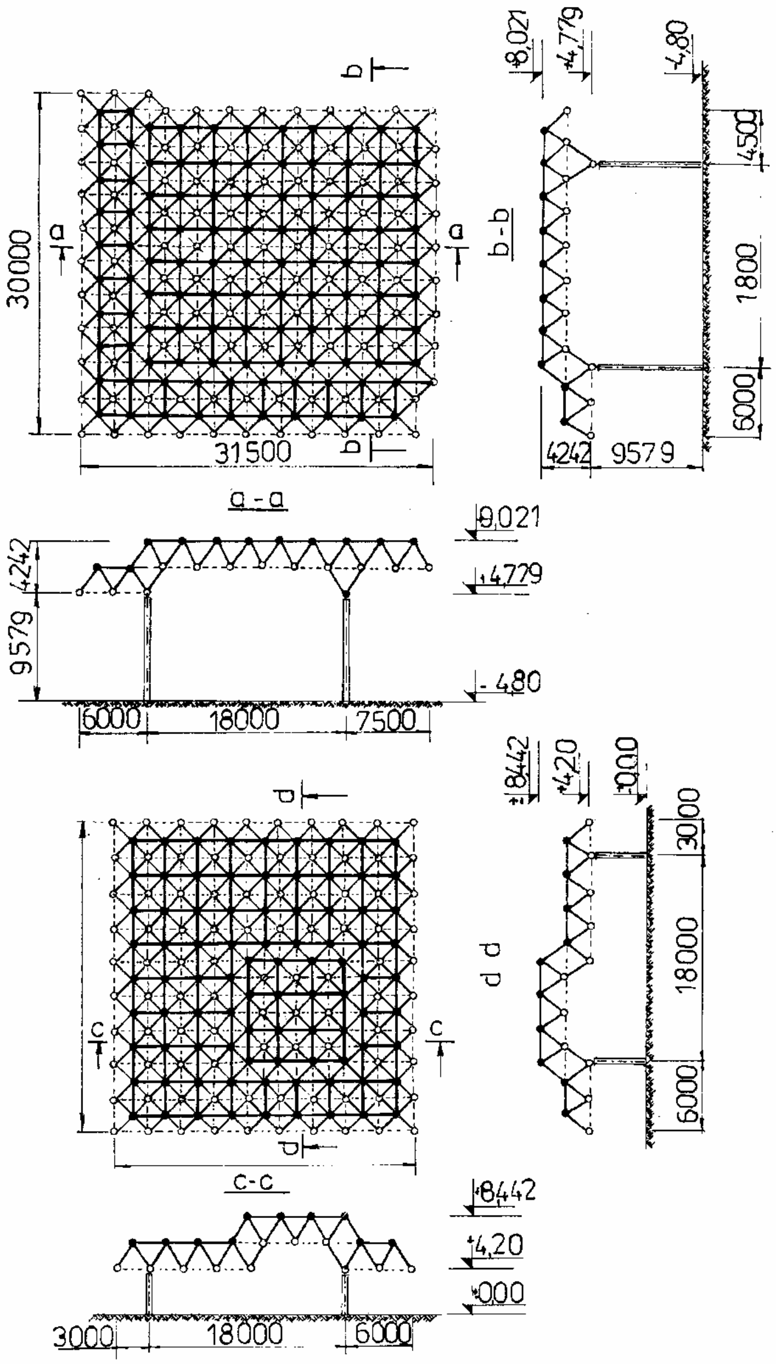

Fig.8 General store

Fig.9 General store under construction

Fig.10 Outside view

4.3. Training hall for ice-hockey in Sofia

The training hall is designed for ice-hockey but can be used for other sports as well (basket ball, volley ball, hand ball, tennis etc. The spatial structures with dimensions 51×30 m and 2,121 m height handed up on ten inclined columns, which are situated on the contours of the building (fig.11). The inclination of the ten columns is really effective by reason of lessening the bulk and the span of the building. It is also gives a possibility to assemble the construction on ice-level and to lift it to the defined level unobstructed with elevating gears, situated on the top of the assembling steel columns without using an assembly means. The inclined columns are working as real consoles (in a static aspect) only in situation when lifting the covering construction to it's defined level, carrying its own weight. After the lifting the ten horizontal joint connections are to be realized between the upper band "MArchI" and columns. They begin to work after laying the rest vertical loadings. They work only against pressure and insure the connection between covering construction and columns. They also lead the horizontal wind (and earthquake) forces to the bases of the columns. Besides, they unload the diminishing considerably the degree of the bending moments of the vertical loading. The inclined steel columns are with box-like section, with dimensions 1,0×0,5 m. Here are used steel plates (16 and 20 mm). Their steps on the sub-columns are made traditionally with travers and anchoring bolts. The spatial structure "MArchI"-type is to be hanged on the inclined columns by four suspenders ∅ 32 mm, on steps and X-like (cross-like) bearings with I section (fig.12). By the suspenders, the suspending of the covering construction is at the joints on the lower band, so it steps on them naturally. The covering of the building is made of panels "Monopanel"-type, laid on bearings of cold-formed bars. The static determination for all horizontal and vertical loadings and their combination are made by computers program "STRUDL". The spatial bar construction "MArchI" was assembled on the ice-level for 30 days. The lifting to the defined level (about 13,0 m height) took only 3 days. The expense of steel for spatial construction is 15 kg/m^2. The building is constructed in 1988 (fig.13).

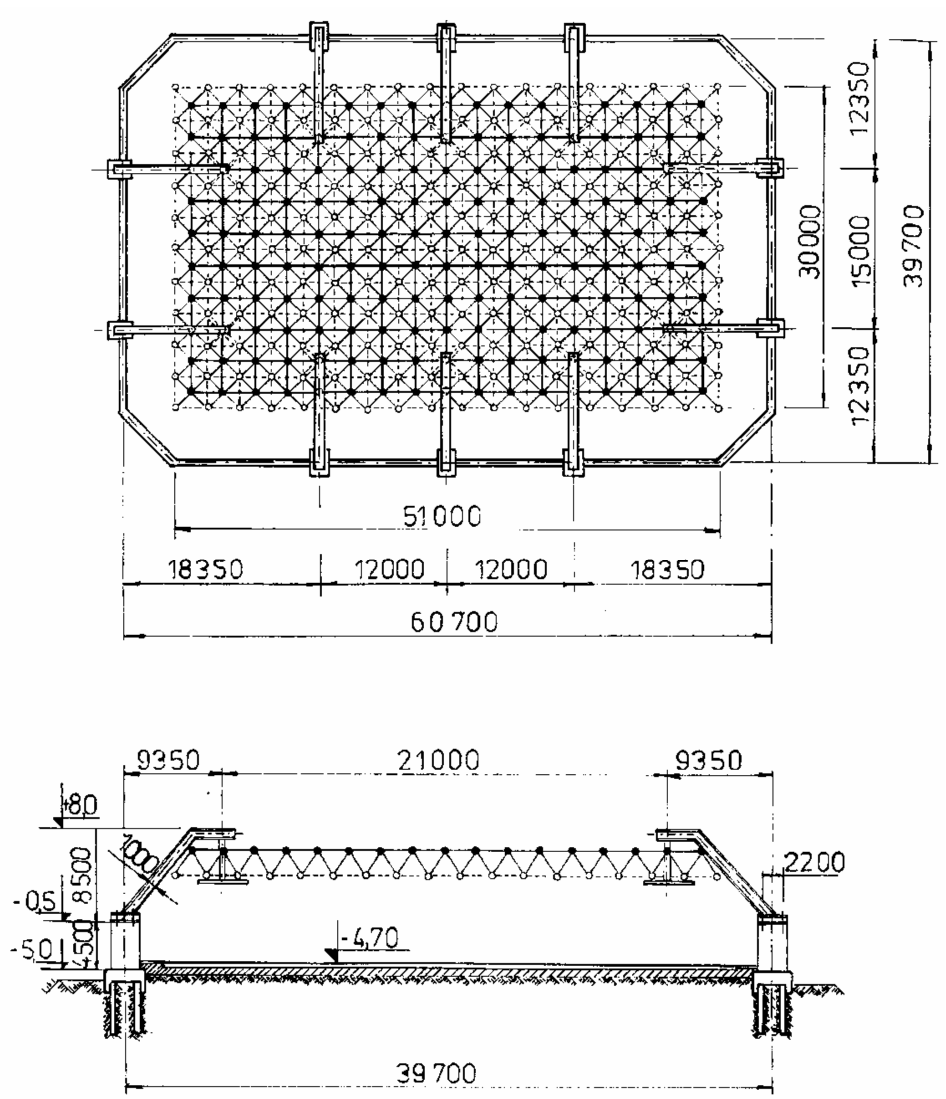

Fig.11 Ice-hockey Hall

Fig.12 X-like support

Fig.13 Outside view

4.4. Exhibition hall of the Association "Building Industry" for the International fair in Plovdiv

The exhibition hall is intended for display of the latest achievements of our and foreign building industry. The project is developed in the studio of architect H.Stainov in partnership with the authors of this article (fig.14). The exhibition hall is rectangular in plan with basic dimensions 30-33-21×54 m. The cell of the lattice work is dimensioned 3,0×3,0 m, and the height of the structure is 2,121 m. In longitudinal direction the roof construction is varying in height from the finished floor level to the lower belt of the structure as follows- 5,1 m, 7,221 m, 9,342 m. the maximum tension force developed and took up by bolt M30 is 370 kN. The structure is supported along four sides with 34 columns. The columns are welded solid I section with dimensions 200×340 mm. The roof construction is continuous slab of two spans supported 3-6-6-6-6-6 m at 42 m of the main entrance. In front of the main entrance is erected an independent spatial structure in order to demonstrate the system "MArchI". The roof construction is assembled synchronously at the level 0,00 and +3,60 m for 7 days by 4 workers and erected in place with the aid of three cranes "Liebherr", "Grove", "Faun". The space stability of the building is ensured by concrete diaphragms. On particular interest are the members used for the space stability of the office building adjoining the exhibition hall. For the purpose some of the belt rods run through apertures left in the concrete diaphragms. The total weight of the tubular frame only is 42 tons. The design and construction began on 01.01.1987 and was finished on 15.09.1988 (figs.15 and 16).

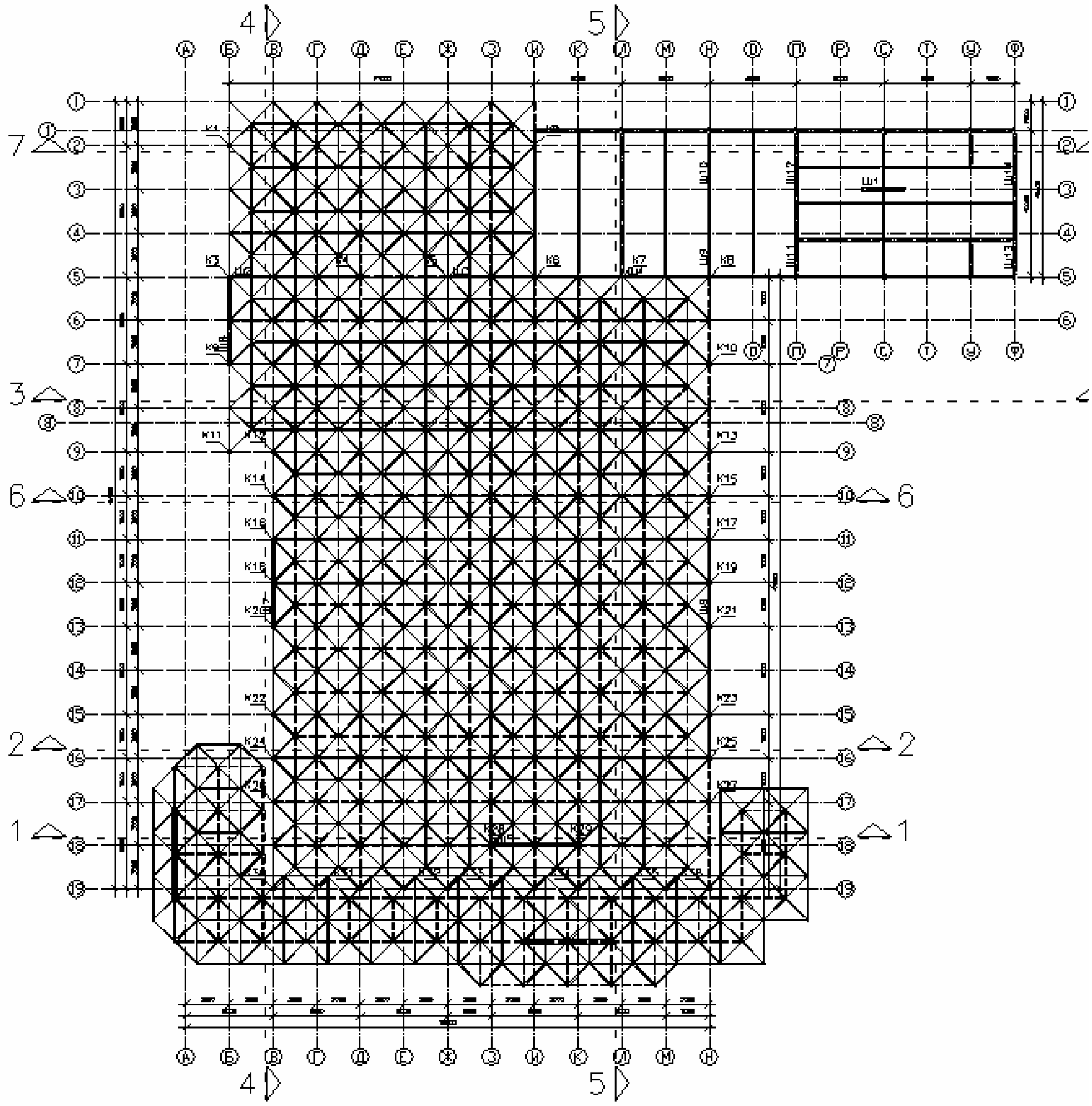

Fig.14 Exhibition Hall

Fig.15 Exhibition Hall under construction

Fig.16 Outside view

4.5. Experimental plant of the Technical University in Sofia

The building consists of six main structures. The basic dimensions of the plant are 30 by 252m with height of 9,06m, measured to the lower chord of the structures (fig.17). Two – layer framework is used composed of cells with dimensions 3,0 by 3,0m and 2,121m in height. Each of these structures is 30 by 42m and supported by 12 tubular columns spaced 27 by 3-3-24-3-3m. The roof cover is made of sandwich panels "Fenolpanel". The building is constructed in 1990 (figs.18 and 19).

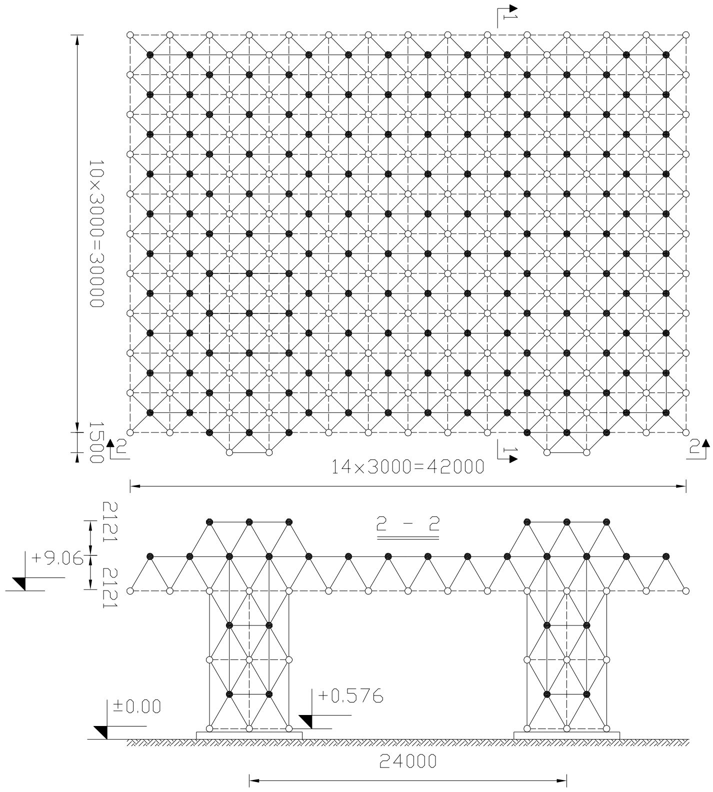

Fig.17 Experimental plant

Fig.18 Experimental plant under construction

Fig.19 Outside view

4.6. Spatial roof for Hyundai show-room

The building consists of three main structures. The area of the roof is 770 m^2. The central part of the structure has dimensions 21 by 21 m. The structure is supported on four columns (fig.20). Two – layer framework is used composed of cells with dimensions 1,5 by 1,5 m and 1,0605 m in height. The roof cover is made of plastic panels. The building is constructed in 1997 (fig.21).

Fig.20 Outside view

Fig. 21 Tubular X-like support

5. REFERENCES

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[2] Martinez A. - “Main Roof Structures for the “Palau d’Esports Sant Jordi”- Barcelona- as an application of the New Technologies in Steel Construction”- *Proc. 1989. IASS Symposium* Vol. 4 “Space frames”;