TWO STRUCTURAL SYSTEMS APPLIED
IN MASS PRODUCED SHELTER ROOFS

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SUMMARY
This paper presents two industrialized shelter roof building systems applied until now on more than 50 self service gas stations in Denmark. The author describes the principle features of the space frame system and the space grid system adopted for this application. It is shown, how new forms of bolted joints in connection with a rational partition into shop fabricated straight members have met the basic requirements to adaptability and fast erection.

ZUSAMMENFASSUNG
Diese Schrift präsentiert zwei industrialisierte Bausysteme für Wetterdächer die bis jetzt auf mehr als 50 Selbsbedienungstankstellen in Dänemark montiert sind. Der Verfasser beschreibt die charakteristischen Eigenschaften der zwei Systeme - ein Trägerrostsystem und ein Fachwerkrostsystem - die hier verwendet werden. Es wird gezeigt wie neue Konzeptionen in Schraubenverbindungen zusammen mit einer zweckmässigen Teilung in Werkstatthergestellten gerade Elemente die grundsätzlichen Forderungen zur Verwendung und schneller Montage erfüllen haben.

SUMARIO
Este artículo presenta dos sistemas constructivos industrializados de techos cobertizos aplicados hasta ahora a más de 50 estaciones de servicio de gasolina en Dinamarca. El autor describe las características de principio del sistema espacial de vigas y del sistema espacial de celosía adoptados para esta aplicación. Es asímismo demostrado como nuevos tipos de conexiones atornilladas, juntamente con una división racional de la estructura en elementos rectos prefabricados en taller, han satisfecho los requerimientos básicos de adaptabilidad y montaje rápido.

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1. INTRODUCTION

This paper presents two industrialized shelter roof building systems developed by the author. Both systems have now been in production a couple of years and about 70 have been mounted as shelter roofs over the petrol pump aprons on self service gas stations in Denmark.

The introduction of new forms of bolted joints in connection with a rational partition into easy transportable shop fabricated straight members has satisfied basic requirements to fast erection and adoptability of the shelter roofs on existing gas stations.

A selection of few standardized elements and connections has made the systems suitable for online mass fabrication even allowing for application to a wide range of roof shapes and sizes.

Figure 1, 2 and 3 show examples of such roofs with various column configurations and rectangular, square and prismatic shape of the roof plan.

Most of the roofs are built with a clear height of 3.60 m. In order to achieve an attractive appearance the roof cover is arranged on the underside of the structure. Together with the contour fascia, with a height of 450 mm and 600 mm respectively in the two systems, this means that the structure proper will be invisible from the ground.

Both the contour fascia and the roof cover of corrugated trapezoid shaped steel sheets are integrated elements of the systems. Thus the roof cover act as horizontal diaphragm between the steel members and thereby assuring the spatial stability of the system. Whereas most systems also apply a top cover or only a top cover the present systems only apply the bottom cover. This is made possible by provision of a special tightening procedure to ensure the "water basin" to be drained fully through the columns made from rectangular hollow sections.

The exposed steel structure call for a special corrosion protection to reduce maintenance costs: Innovating hot galvanizing of the members of the space frame system, made possible because of the throughout bolted joints, a weather resistant long life protection is achieved for less costs than an equivalent protection based on painting.

The introduction of rigid end plate connections with prestressed high tensile hot galvanized bolts in most of the joints have facilitated the site assembly and met the requirements to only a few hours shot down on the service stations.

2. SPACE GRID SYSTEM

2.1 General Arrangement

The structural system is based on a square space grid system with a planning module of 3.0 m. The system is built up of plane lattice girders with a node spacing of 1.0 m., which gives great freedom of choice in regard to the placing of the columns supporting the roof structure. This is of dominating importance because of restrictions to consider on existing gas stations. Exploded view of the grid system occur from figure 4.

By adopting a relatively open, square space grid instead of a true doublelayer two-way space system, a considerable reduction in both the number of members and the number of nodes is achieved, together with a significant simplification of the node design (1), (3). Even though the load distribution is more favourable
Figure 1. Shelter roof supported on a single row of columns. Rectangular shape.

Figure 2. Square shaped roof supported on two rows of columns.
Figure 3. Prismatic shaped roof supported on three rows of columns.

Figure 4. Isometric perspective of a roof grid showing its components.
Figure 5. Cross section in grid systems with two rows and one row of columns respectively.

Figure 6. Lattice girder elements of space grid system.
Figure 7. Typical plan of space grid system.

Figure 8. Welded node located at the intersection between two lattice girders of the central core.
in true space systems, especially for concentrated loads, this is of no practi-
cal importance in roof structures with the relatively small spans -9 to 18 m-
in question here.

2.2 Space Grid Elements

The space grid system is built up of orthogonally placed, plane lattice girders
with a height of 800 mm over the central part and 350 mm over a length of 2.5 m
measures from the edges of the roof. The edge girder has a corresponding height
of 350 mm.

The system can be extended longitudinally and transversely in module lengths of
3 m, by a corresponding lengthening of the lattice girder sections. The system
geometry of the cross section is shown in figure 5.

The space lattice grid is built up of only the four types of units shown in fi-
gure 6. The edge girders are manufactured in standard lengths of 6 and 9 m, the
cantilevered parts in lengths of 2.5 m and the intermediate units that connect
the continuous lattice girders, in lengths of 3.0 m.

Figure 7 shows an example with a base area of 15 x 15 with the columns placed
at the intersections of the lattice girders, whereas figure 4 shows an example
with the columns placed outside these intersections.

The dimensions in the system are fixed to allow the columns to be freely placed
in the intersections of the lattice girders or in the third-points between the-
se, under a vertical member in the girder.

The lattice girders with a height of 800 mm are welded without gusset plates,
with flanges and lattice in square hollow sections, □ 80 x 80 x 5 and □
40 x 40 x 4, respectively. In the sections with a height of 350 mm, the flanges
and V-shaped lattice are made of square hollow sections, both □ 40 x 40 x 4.
In the edge girders, the lattice consists of a zigzag bent, plain round bar, dia. 18, while, here too, the flanges are made of square hollow sections □
40 x 40 x 4. The columns as well are made of square hollow sections.

The roof cladding forms an integral part of the statical system, partly trans-
mittting vertical loads to the planes of the lattice girders and partly forming
a horizontal diaphragm via which the horizontal wind load is transmitted to the
columns (2). The diaphragm at the same time ensures restraint of all intersec-
tions in the space grid and provides further restraint against buckling for the
bottom flanges, in which the biggest compression forces occur. The roof struc-
ture is simply supported on the columns, and the overall stability of the struc-
ture is achieved by the above mentioned diaphragm-action, in connection with
restraint of the columns in the foundations.

2.3 Nodes and Erection Joints

The basic idea in the present system was to avoid the complicated and costly
node designs that characterize most standardized true space lattice systems,
which are built up of single members with bolted nodes. Both welded and bolted
erection joints are used for assembly of the shop-built units in order to achie-
ve an optimum solution with regard to manufacturing process and erection.
The flexurally rigid joints in figure 8 are thus best welded at the site. The
welded connection between the intersecting lattice girders has been simplified
by the introduction of a slight eccentricity in the diagonal connection (see
figure 8), such that only the flanges are joined together with full penetration
butt welds.
The tensile strength of the cross joints between orthogonal flanges is considerably lower than the yield load of the section because the vertical faces of the jointed hollow section are not fully effective. However, the tensile strength of the connection corresponds very closely to the compression strength of the flanges at the top flange level, which have a buckling length of 3.0 m.

The cantilevered beams, on the other hand, are bolted to the central space grid core and the edge girder is bolted to the cantilevered beams. All joints are of the end plate type with prestressed grade 8.8 bolts.

Figure 9 shows such a standard connection for the 2.5 m long cantilevered beam sections.

3. SPACE FRAME SYSTEM

3.1 General arrangement

The structural system is arranged as an orthogonal two-way plane frame with module of 3.0. The system is built up of rolled IPE-sections moment rigid joined at the intersections.

The perimeter frame is a cold bent channel shaped section, 600 m high, with rigid connections in the corners, but simple supported on the frame core. The system provides great flexibility for adapting to various column positions and apron configurations as seen on figure 1, 2 and 3. An exploded view of a typical rectangular configuration is shown on figure 10.

3.2 Space Frame Elements

The space frame system is built up of merely straight members thus enabling easy transportation of the whole system on a single lorry. The main girders passing over the columns vary depending of the column distance, between IPE 400-500. The secondary girders vary accordingly between IPE 200-220. The fascia beams distribute load on the cantilevered part to the main girders. Because all joints in the system are bolted, it has been possible to apply hot galvanizing of all structural elements in the core, both a more resistant and cheaper solution than painting. Only the fascia beams are sandblasted and painted, because release of residual stresses from rolling and cold bending here will cause unacceptable distortions when hot galvanized. Typical plan layout and cross sections of the system is shown in figure 11 and 12.

3.3 Nodes and Erection Joints

All the joints between sections in the space frame core and joints in the fascia beams are designed as rigid prestressed end plate connections proportioned to resist the yield moment of the adjacent section (5). This joint method has proved very efficient in respect of erection and mass fabrication, because all drilling can be executed separate in layers of end plates before mounting into the beams. Figure 13 and 14 show continuity joints for secondary beams, continuity joints between secondary beams and a main girder and a butt joint in a main girder where transport length is limited to about 16 m. The simplicity of the system now applied in 55 roofs occur from figure 15 which clearly shows the structural components of the standard shelter roof structure.

4. CLADDING DETAILS

Unlike the shelter roof types with roof cladding at top and bottom flange, the through design described here, with bottom cladding only, calls for special care in the detailed design in order to achieve an absolutely tight roof surface.
Figure 9. Bolted end plate connection between lattice girders at a transition.

Figure 10. Isometric perspective of a space frame showing its components.
Figure 11. Cross section in frame systems with two rows.

Figure 12. Typical plan of space frame system.

Figure 13. Continuity end plate joints in secondary girders.
Figure 14. End plate joints in main girder and in secondary girders.

Figure 15. Space frame mounted on columns.
Figure 16. Watertight arrangement of the roof's edges. From left to right: (a) On one of the sides perpendicular to the gutter; (b) on the side opposite the gutter; (c) On the gutter side. (1) Corrugated steel sheet. (2) Neoprene closure coating. (3) Foam nylon. (4) Edge girder. (5) Front panelplane steel sheet.

Figure 17. Watertight arrangement above a column. (1) Corrugated steel sheet. (2) Neoprene closure coating. (3) Foam nylon. (4) Lattice girder's bottom chord. (5) Box shaped column with square cross section.
Figure 18. Watertight arrangement for the space frame cladding at the roof's edges.

Figure 19. Watertight arrangement for the space frame cladding above a column.
Figure 20. Space grid during lifting operation.

Figure 21. Space frame during lifting operation.
All longitudinal plate points are therefore tightened with adhesive jointing material along the overlaps. The trapezoidal edges are tightened with blocks of foam nylon and sealed with a neoprene sprayed on membrane.

The three types of connection to the fascia edge for the space grid system are shown on figure 16. A similar tightening system is used where the columns are led through the roof cladding and fixed to the steel structure, as shown in figure 17. The corresponding solutions for the space frame system are shown on figure 18 and 19.

All mutual joints between sheet cladding are executed with stainless steel rivets, sufficient in number to satisfy the requirements to strength and diaphragm action. All edge connections are executed with stainless steel 6 mm self-cutting screws with neoprene washers in each corrugation.

5. TRANSPORT AND ERECTION

The steel structure is partitioned into plane units with lengths varying from 3 to 14 m. This means that all units for a roof of both types, can be transported by one lorry, since the weight of steel in one 15 x 15 m roof, including columns, is about 5.5 tons. The space grid or the space frame proper takes about 1 working day to assemble and this work is usually carried out next to the apron area. The space grid is then hoisted up onto the columns by means of a mobile crane. Service operations are thus only interrupted while the grid is being hoisted in place. In the case of bigger roofs, the bolted edge structure is mounted after erection of the central core, while small roofs are completely assembled on the ground before being hoisted into position, as shown in figure 19 and 20 for the space grid and the space frame respectively. The sheet cladding is mounted from rolling scaffolding with special adapted lift tools. The mounting of the sheet cladding normally takes a total of two working days. The sealing of joints and electrical work is carried out from the completed shelter roof.

6. CONCLUSION

The inherent flexibility of the modular space systems presented here requires a slightly greater amount of steel than a corresponding individually tailored system. However this is more than compensated by the standardization and suitability for mass production. The systems has until now been applied to about 70 shelter roofs of size between 200 m² and 650 m² and proved extremely competitive in relation to other types of shelter roofs, mounted in Denmark.

BIBLIOGRAPHY