

AN IMPROVED CONNECTOR FOR SPACE FRAMES

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1. ABSTRACT

On July 7, 2010 the European Patent Bulletin 2010/29 mentioned the publication of the extended European search report for a European patent application (EP 1 997 972) concerning an improved connector for space frames. According to the European search opinion, which is included in the above-mentioned search report, this improved connector meets the requirements regarding novelty and inventive step. Patent No. GR 1 005 940 concerning the same connector was granted in 2008.

It is an object of the present paper to communicate the technical effects which have been achieved as a result of this patent. Another object is to summarize the current version of Skytech® SYSTEM 2000—a space frame system comprising spherical nodes, tubular structural members and connectors.

Keywords: *Space structures; space frame systems; connectors; structural reliability; high tensile strength; sustainable construction; lightweight; wide-span; internally tensioned space structures.*

2. INTRODUCTION

Space frame systems comprising spherical nodes, tubular structural members and connectors have been well known for over sixty years. The first commercially available system of this type was developed by Dr.-Ing. Max Mengerlinghausen and a small team of close collaborators in Berlin. In this system the connector disclosed in Patent Nos DE 874 657 (date of filing: March 12, 1943) [1] and DE 901 955 (date of filing: July 23, 1950) [1]—both Patents issued to Dr.-Ing. Max Mengerlinghausen in 1953—is used. Figure 1 shows the Patent drawings of this connector.

Connectors of this type gained in popularity after the Second World War—particularly after the expiry of the above mentioned patents in the late 1960s—and were originally used for temporary exhibition buildings. However, during the 1970s they were used in large-span permanent buildings.

In connectors of this type, a relatively large opening is made on the pipe portion of the tubular structural member for the insertion of the bolts, which reduces both the ultimate tension and the ultimate compression resistance of the pipe. In the case of compression, it is possible to have

failure of the pipe due to asymmetrical local elastic-plastic buckling of the walls of the pipe (“asymmetrical” because of the fact that only one opening is provided, although claim 2 of document DE 901 955 recommends symmetrical—with respect to the longitudinal axis of the tubular framework member—openings).

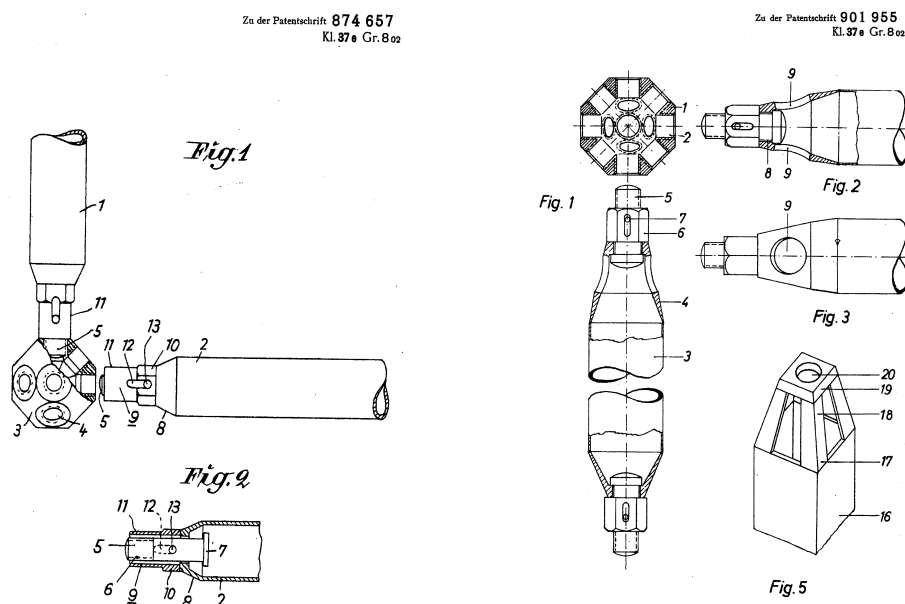


Fig. 1: Patents DE 874 657 and DE 901 955 issued to Dr.-Ing. Max Mengerinhausen, Würzburg

Figure 2 shows the modes of failure of the tubular structural members of a steel space frame canopy covering the excavations of a 3,700-year-old archeological site on Santorini, one of the Cycladic Islands. The canopy partially collapsed in September 2005. The canopy was designed to carry a 150 mm layer of earth to make it blend in with the surrounding environment.



Fig. 2: Partial collapse of a steel space frame canopy, Santorini, 2005

Furthermore, the longitudinal slotted holes through the walls of the sleeve, as in Figures 1 and 2 of document DE 901 955, reduce the ultimate compression resistance of the sleeve. In this case, it is possible to have premature failure of the sleeve due to plastic buckling.

In addition the above mentioned strength problem of the sleeve, the longitudinal slotted holes through the walls of the sleeve expose the most highly stressed portion of the bolt to the environment; thus it is possible for dust and water to collect between the bolt and the walls of the sleeve. In this case, the presence of specific chemical compounds in the environment, e.g. aqueous electrolytes, particularly when containing H_2S , may induce cracking of the bolt. This cracking (stress-corrosion cracking) may take the form of a relatively slow, stable crack extension or, as is often the case, an unpredictable catastrophic fracture. It is thus necessary to effectively protect the bolt with the pin against corrosion.

For many years, it has been the usual practice to protect the bolt with the pin against corrosion with electroplated coatings. Since, however, bolts are now made of high-strength steels, e.g. of property class 10.9, electroplating—including pickling for scale and rust removal—increases the probability for a hydrogen-induced fracture of the bolt (hydrogen embrittlement). Hydrogen embrittlement can cause dangerous and sometimes catastrophic failures, if it occurs in critical tubular structural members, particularly in wide-span roof structures. The probability of encountering hydrogen embrittlement can be reduced by using lower-strength steels, by limiting immersion times in acid or plating baths, and by in-process (intermediate) baking. According to International Standard ISO 4042:1999(E) “Fasteners—Electroplated coatings”, page 3: “In cases of parts with high tensile strength or hardness or which have been surface hardened, which have absorbed hydrogen and are under tensile stress there is the risk of failure due to hydrogen embrittlement.”; and, page 4: “**Complete elimination of hydrogen embrittlement cannot be assured. If a reduced probability of encountering hydrogen embrittlement is desired, alternative procedures should be evaluated.**” [2].

Patent No. GR 1 004 166 discloses a connector in which there are no openings through the walls of the structural components of the framework members, e.g. no relatively large openings on the pipe portion [3] and no longitudinal slotted holes through the walls of the sleeves of the structural members. Figure 3 shows the connector disclosed in document GR 1 004 166 [1].

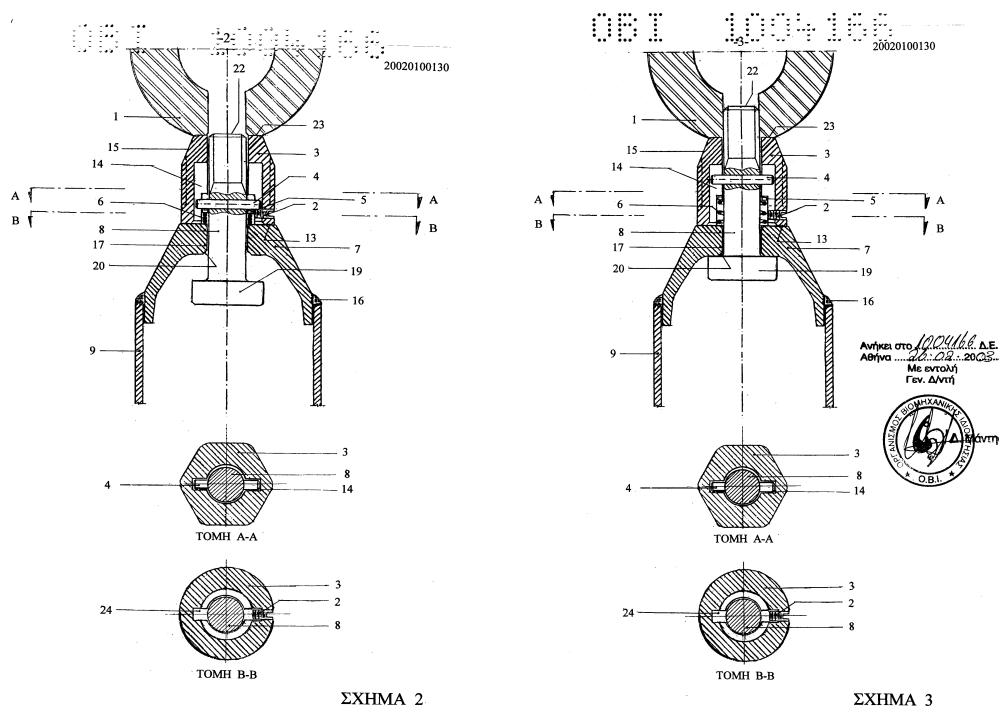


Fig. 3: Patent No. GR 1 004 166 issued to Gamanis, George A., Thessaloniki

Notwithstanding the advantages of connectors of this type, the problem of the confirmation—that the bolt is completely screwed into the threaded hole of the node—still needed to be solved.

Incomplete (i.e. less than the required) length of engagement in the threaded assembly is likely to happen under the following possible conditions: when the length of the internal thread of the node has been manufactured to a length shorter than the required length of engagement, when there is a manufacturing error, or damage, in the internal thread of the spherical node or in the external thread of the bolt, or when the erection worker has not fully screwed the bolt into the threaded hole of the spherical node. If this occurs in the assembled space frame, the corresponding connector cannot carry tension; and, when the space frame is loaded, the redistribution of internal forces may overload neighboring tubular structural members.

If failure of the threaded assembly should occur, it is preferable for the bolt with the pin to break rather than to have either the external or internal thread stripped; and the length of engagement of mating threads should be sufficient to carry the full load necessary to break the bolt without the threads stripping. This length determines the required length of engagement to prevent stripping of either the external or internal thread in connectors of this type.

3. BRIEF DESCRIPTION OF THE IMPROVED CONNECTOR

Patent No. GR 1 005 940 [1] discloses an improved connector for space frames. Figure 4 shows the Patent drawings of this improved connector. It was an object of this invention to provide a solution to the problem of the confirmation that the bolt with the pin is completely screwed into the threaded hole of the node; and, as a consequence, that the corresponding connector in the assembled space frame can carry tension as well as compression. Another object was to provide an improved connector which solves the connection problem of the pipe in a simple, economical and aesthetic manner; and this with a minimum number of different components. Still another object was to provide an improved connector with increased structural reliability by eliminating the above mentioned disadvantages of prior art connectors (see 1. Introduction). By rotating the sleeve (3) (see figure 4), a torque is transmitted to the bolt (8) through the pin (4), thus screwing the bolt (8) into the spherical node (1). When the bolt (8) is fully screwed in, the sleeve (3) is in contact with both the spherical node (1) and the conical end (7). By applying an appropriate torque to the sleeve (3), the bolt (8) with the pin (4) tightens the spherical node (1) and the conical end (7) on the sleeve (3), the bolt head (19) being in contact with the rear bearing surface (29) of the conical end (7). Next, the socket set screw (2) is fully screwed in. If the rear end (24) of the socket set screw (2) is at least flush with the outermost peripheral surface (25) of the sleeve (3), this confirms that the bolt (8) with the pin (4) is completely screwed into the threaded hole (10) of the node connector (1). In the assembled three-dimensional structure, tension from the pipe (9) to the spherical node (1), and conversely from the spherical node (1) to the pipe (9), is transmitted through the bolt (8); compression is transmitted through the sleeve (3). In this way a closed system—with no openings through the walls of the structural components—was achieved in which the engagement of the bolt into the node is confirmed by visual inspection and/or by touch. Furthermore the bolt can be fully retractable.

The improved connector of Figure 4 is useful for the construction of space frames of any structural form, e.g. flat, cylindrical, spherical or free-form.

As will be illustrated herein below, the connector of Figure 4 can also be used for the realization of lightweight wide-span *internally tensioned space structures*.

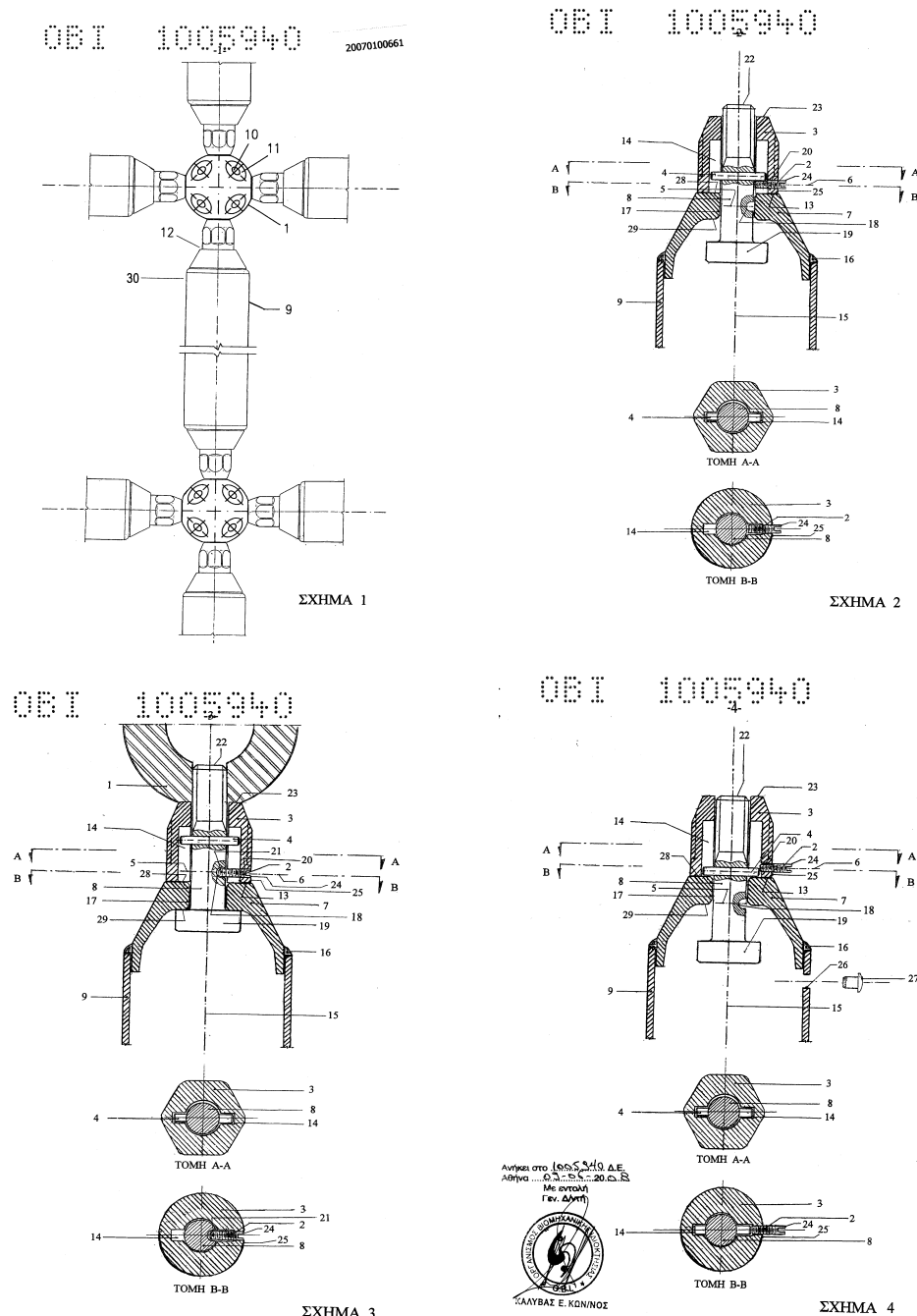


Fig. 4: Patent No. GR 1 005 940 issued to Gamanis, George A., Thessaloniki

4. SKYTECH® SYSTEM 2000

Skytech® SYSTEM 2000 is a space frame system comprising spherical nodes, tubular structural members and connectors. The improved connector of Patent No. GR 1 005 940 (granted in 2008) is used in this space frame system. The first version of Skytech® SYSTEM 2000 was presented at the 5th Space Structures Conference in 2002 [4].

Skytech® SYSTEM 2000 was revised in 2009 in order to comply with the new Product Standards on Fasteners and Screw Threads and with EC3 (EN 1993 Parts 1-1, 1-2, 1-8, and 1-10). In this major revision the number of different parts was further reduced, the maximum bolt size was increased to M100, and the reliability of the system was further improved.

The structural modeling, design and analysis of the components of Skytech® SYSTEM 2000 is carried out in accordance with Clause 13 (FEM-calculations) in prEN 1993-1-5 (see Figure 5). FEM-calculations are verified by mechanical testing.

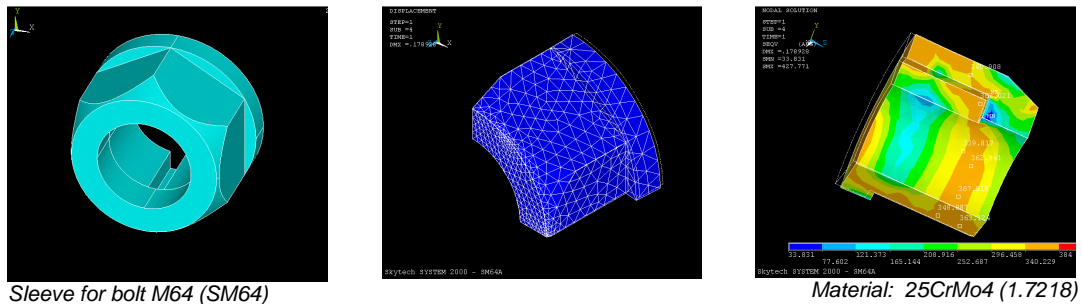


Fig. 5: FEM-calculations of the components of Skytech® SYSTEM 2000

Skytech® SYSTEM 2000 is appropriate for use in the design / development and construction of steel space frames subject to static loads, snow loads and wind or seismic actions. This system is especially adaptable to buildings requiring special aesthetic forms in wide-span roof construction, e.g. sports arenas, exhibition halls, shopping centers, etc. (see Figure 6).



Fig. 6: Applications of Skytech® SYSTEM 2000

5. REALIZATION OF INTERNALLY TENSIONED SPACE STRUCTURES

The improved connector can also be used for the realization of lightweight *internally tensioned space frame structures* and *shell-like reticulated space enclosures*, having tension components, compression components, pre-stressing components, and nodes.

The tension components form nets of tension components, the compression components form non-connected sets of interconnected compression components, and both the tension and compression components are preloaded by the pre-stressing components, the pre-stressing components being independent of the tension components and interconnected only with the compression components.

In these structural systems the tension components can be slender tubular structural members, or “cables”, the compression components can be tubular structural members having a low slenderness ratio, or “struts”, the pre-stressing components can be high-strength steel rods (e.g. 42CrMo4), the nodes can be spherical, and both the tension components and the compression components are inter-connected, through the spherical nodes, using the improved connector.

Furthermore, due to the low slenderness ratio of the compression components, together with the inherent favourable distribution of material in circular hollow sections, the exploitation of the material approaches its maximum. In this way, sustainable lightweight wide-span internally tensioned space structures can be realized, with the maximum degree of industrialization of their construction and with a minimum number of different structural components, so that the industrial manufacturing of both the tubular structural members and the improved connectors is carried out at minimum cost.

6. MODULAR SPACE STRUCTURES: A SUSTAINABLE WAY OF CONSTRUCTION

In his paper on “The Industrialization of Modular Space Structures” [5], S. Du Chateau illustrates the advantages of what he calls “*open-ended type of industrialization*”, which “offers the economic advantage of an industrial mass production technique combined with a high degree of flexibility...”. Also, the small amount of material per square meter required to bridge a large span, together with the greatly reduced erection time, on site labour costs, and waste and dust on site, make these structural systems quiet competitive.

Furthermore, the efficient selection of structural materials and the use of appropriate manufacturing processes [4], combined with good design, assist in reducing energy consumption, waste, and pollution, thus achieving a sustainable way of construction. To this end the *shell molding process* [Patent Nos DE 832 937 and US 2 706 163] plays an important role in the mass production of high-strength cast steel structural components for connectors. In this process, scrap of certified steel plate is recycled.

7. CONCLUSIONS

An improved connector for space frames, and a space frame system in which this improved connector is used, were presented. Some advantages of this novel connector are:

- The connection problem of the tubular member is solved in a simple, aesthetic, and sustainable manner, and this with a minimum number of different components.
- A closed system was achieved in which the engagement of the bolt into the node is confirmed by visual inspection and/or by touch. Furthermore, the bolt can be fully retractable.
- Due to the increased structural reliability of the connection, it is possible to realize lightweight wide-span space structures and space enclosures of any structural form.

8. REFERENCES

- [1] <http://worldwide.espacenet.com/advancedSearch>
- [2] ISO 4042:1999(E), *Fasteners—Electroplated coatings*, pp. 3–4.
- [3] DUTTA D., WARDENIER J., YEOMANS N., SAKAE K., BUCAK Ö., and PACKER J. A., *Design Guide for Fabrication, Assembly and Erection of Hollow Section Structures*, TÜV-Verlag, Köln, 1998, pp. 142–143.
- [4] GAMANIS G., “Skytech® SYSTEM 2000”, *Space Structures 5*, Thomas Telford, London, 2002.
- [5] DU CHATEAU S., “The Industrialization of Modular Space Structures”, *Analysis, Design and Construction of Double-Layer Grids*, MAKOWSKI Z. S., Ed., pp. 381–383, 403, and 406–407, Applied Science Publishers, London, 1981.

ΒΕΛΤΙΩΜΕΝΟΣ ΣΥΝΔΕΣΜΟΣ ΓΙΑ ΧΩΡΟΔΙΚΤΥΩΤΟΥΣ ΦΟΡΕΙΣ

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ΠΕΡΙΛΗΨΗ

Στις 7 Ιουλίου 2010 το Ευρωπαϊκό Δελτίο Διπλωμάτων Ευρεσιτεχνίας 2010/29 ανέφερε την δημοσίευση της εκτεταμένης Ευρωπαϊκής έκθεσης έρευνας σχετικά με μια αίτηση Ευρωπαϊκού Διπλώματος (EP 1 997 972) για ένα βελτιωμένο σύνδεσμο για χωροδικτυωτούς φορείς. Σύμφωνα με την Ευρωπαϊκή άποψη έρευνας, η οποία συμπεριλαμβάνεται στην προαναφερθείσα έκθεση έρευνας, ο βελτιωμένος σύνδεσμος είναι *νέος* και *εμπεριέχει εφευρετική δραστηριότητα*. Το Δίπλωμα Ευρεσιτεχνίας GR 1 005 940 για τον ίδιο βελτιωμένο σύνδεσμο χορηγήθηκε το 2008.

Σκοπός της παρούσας εργασίας είναι να προβάλλει τα τεχνικά οφέλη που επιτυγχάνονται σαν αποτέλεσμα της εκμετάλλευσης του προαναφερθέντος Διπλώματος Ευρεσιτεχνίας. Ένας άλλος σκοπός είναι να συνοψίσει την τρέχουσα έκδοση του Skytech® SYSTEM 2000— ενός συστήματος δομικών χωροδικτυωμάτων που αποτελείται από σφαιρικούς κόμβους, σωληνωτές ράβδους, και βελτιωμένους συνδέσμους.

Μερικά πλεονεκτήματα του βελτιωμένου συνδέσμου είναι:

- Λύνει το πρόβλημα σύνδεσης της σωληνωτής ράβδου με ένα απλό, καλαίσθητο και βιώσιμο τρόπο, και μάλιστα με ένα ελάχιστο αριθμό διαφορετικών εξαρτημάτων.
- Αποτελεί *κλειστό* σύστημα χωρίς ανοίγματα στις σωληνωτές ράβδους ή τους συνδέσμους, όπου το πλήρες βίδωμα του κοχλία στον κόμβο επιβεβαιώνεται με έλεγχο οπτικό ή/και αφής. Επιπλέον, ο κοχλίας, σε οπίσθια θέση πριν την έναρξη του βιδώματος, μπορεί να βρίσκεται ολόκληρος εντός του συνδέσμου.
- Λόγω της αυξημένης δομικής αξιοπιστίας της σύνδεσης, καθίσταται δυνατή η υλοποίηση ελαφρών χωροδικτυωτών φορέων για κάλυψη μεγάλων ελεύθερων χώρων.