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# Organic Space Structure Based on Advanced Technologies

Structure spatiale organique basée sur des technologies avancées

Organische Raumstruktur beruhend auf fortgeschrittenen Technologien

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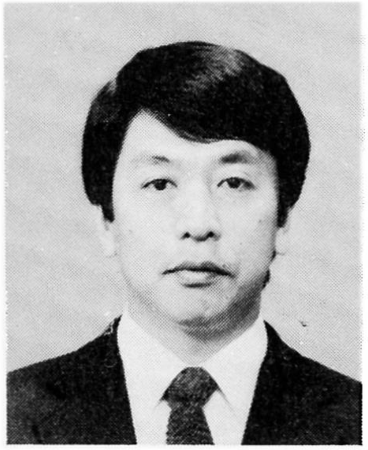

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**SUMMARY**
The refined systematized space truss system referred to as the ''Organic Space Structure'' is an integrated construction system composed of simplified elements which are systematically assembled for the purpose of defining space intended to be used for a specific purpose. This space structure system has an advanced, computer-aided manufacturing and assembly concept.

**RÉSUMÉ**
Le système spatial tridimensionnel, systématisé de façon affinée et désigné sous le nom de ''Structure Spatiale Organique'', est un système de construction intégrale se composnant d'éléments simplifiés lesquels sont assemblés systématiquement, délimitant un espace destiné à être utilisé pour un but spécifique. Ce système de structure spatiale est un concept avancé de fabrication et d'assemblage assistés pas ordinateur.

**ZUSAMMENFASSUNG**
Das verfeinerte systematisierte Raum-Fachwerk-System (Space Truss System), genannt ''organische Raumstruktur'' ist ein integriertes Bausystem bestehend aus vereinfachten Bauelementen, welche systematisch zusammengesetzt sind, um einen Raum, der einem spezifischen Zweck dienen soll, genau abzugrenzen. Dieses Raum-Struktur-System ist eine fortgeschrittene Konzeption der computergesteuerten Herstellungs- und Zusammenbautechnologie.

## PREFACE

The term "organic space structure" is used to mean an integrated structural construction comprising simplified elements that are systematically put together to define a space intended to be used for a certain specific purpose. Accordingly, it may be simply called a space construction system. According to Webster's dictionary, the term "system" as used here is defined as "a complex of elements, often of various kinds, formed to work according to a common plan or serve a common purpose, or a group of bodies, such as the solar system, working in an interrelated manner or under the influence of related gravitational or other forces." Imagining the relationship between the providence and movement of the heavenly bodies in the universe, R. Buckminster Fuller defined their structural construction as "a group of patterns, such as a combination of mechanical phenomena, that is capable of inceptive regeneration." Furthermore, Descartes said, "Any structure, however complex it may look, can be constructed as one likes by putting together carefully designed simple basic elements or members." As may be easily perceived, any intricate structure is made up of members, plates and shells. The space truss is one of the systematized skeleton frameworks supporting large-space architectures. This paper deals with the characteristic features of designing, manufacturing, and assembling significant technologies of the space truss. Particular attention is focused on the technology to make high-precision, high-quality parts and the software technology to enable effective manufacture of multi-item, small-sized production.

## 1. DEFINING OF SPACE BY THE SPACE TRUSS

We consider that the space truss is one of the most effective systems to support large-space architectures. Among other similar structural systems are the shell, suspension and membrane structures. The space truss is a skeleton framework in which joints are used at all hinges. Assuming that all external forces work on the joints, the stresses which occur in its members are of only tensile or compressive force. As such, the space truss is a very effective structural system. A space truss structure is constructed by assembling prefabricated element members at the construction site or constructing such members at the construction site, as with a concrete building, or by combining both. Many attempts have been made to take advantage of the excellent structural feature and simple structural design capability of the space truss, but the need to prepare a large number of so many complicated kinds of component parts and the difficulties encountered in their joints have thwarted such attempts. They have long failed to provide the commercially required cost and quality levels. But it is now possible to build optimum structures using space truss members prepared on a commercially paying basis. The reason for it is one of our themes. This success is undoubtedly due to the recent remarkable progress in information processing and steel making and production technologies. The advancement in special steel quenching and heat treatment technologies has made it possible to make such bolts as can individually transmit such a huge amount of force of 10,000 kN or more. Such innovation has now extremely expanded the feasibility of applying the space truss system to the construction of large space architectures (Fig. 1).

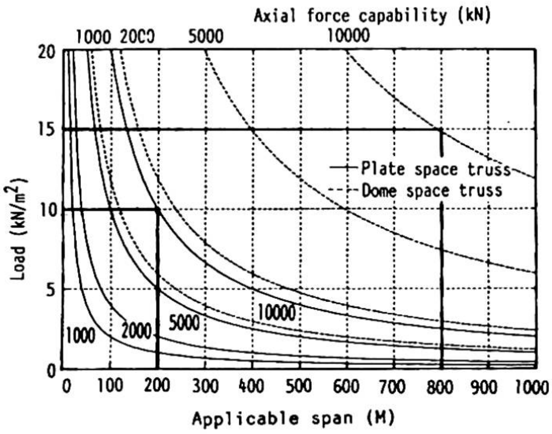


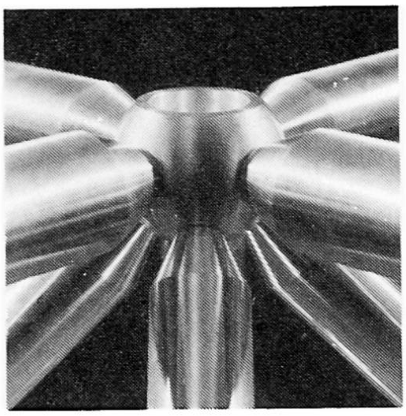

Fig. 1

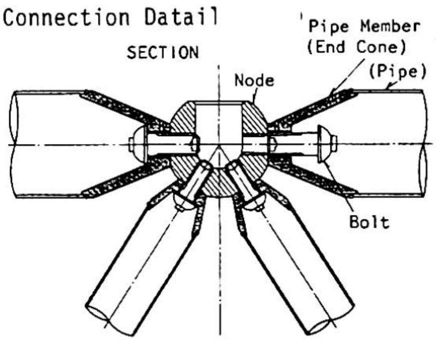
## 2. REQUIRED PERFORMANCE AND ACTUAL EXAMPLE OF SYSTEMATIZED SPACE TRUSS

For the space truss to realize systematized commercial production and obtain wide applicability, it is essential that its component parts have (1) the precise tolerances, (2) the ability to join many members at arbitrary directions, (3) an ability to resist a wide range axial force (of up to 10,000 kN), and (4) are supplied in various lengths. An ideal system unit to meet such requirements consists of a steel pipe, a spherical node, and a bolt joint. The reasons are: (1) Being resistant to buckling and as an axisymmetrical member having no directionality and high torsional strength, pipe is ideal as a member of the three-dimensional space truss. (2) Because the spherical node is point-symmetrical, all pipe members connected to a node never become eccentric to the center so long as they are accurately directed to the center of the spherical node. (3) The single-bolt joint is appropriate because the bolt is an axisymmetrical member like the pipe and the structural mechanical design of the system assumes the mechanism of a hinge. Although several different systems to meet such requirements have been developed and put to practical use in Europe, U.S., and Japan, our actual example based on an advanced technology (hereinafter called the Truss System) will be discussed in this paper (Fig. 2).

The maximum bolt (200 mm in diameter) of this Truss System is capable of transmitting an axial force of 10,000 kN (Fig. 3).
To ensure that the 200 mm diameter bolt meets the desired performance requirement, close quality control should be exercised in the choice of material, heat treatment and machining. To attain a high degree of reliability, all of the produced bolts are subjected to nondestructive inspection. The CZ-COAT applied to the bolt is stable and causes few hydrogen embrittlement problems. This coating consists of the Z and C coats. The Z coat is a layer of zinc applied on the bolt by projecting zinc iron. The C coat is a coating of metal chromate formed by chromate treatment. The combination of the Z and C coats provides a superb corrosion-resistant coating.

| | |
|---|---|
| Material | SNCM630 |
| Tensile strength | 900 - 1,100 N/mm$^2$ |
| Yield point | 750 N/mm2 |
| Elongation | 15% |
| Reduction in area | 43% |
| Hardness | HRc 23 - 32 |






| Component parts | Description |
|---|---|
| Pipe members | Chords and diagonals of the Truss System are made by welding end cones to both ends of pipe. |
| Nodes | Steel joints: thick spherical shells open at the top for bolt insertion. |
| Bolts | Special-high strength bolts for joining nodes and pipe members. |

Fig. 2

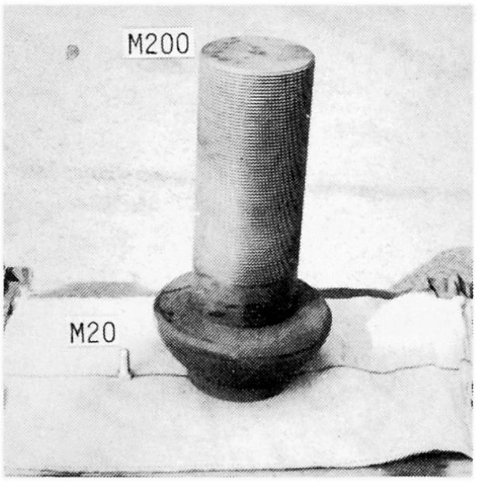



Fig. 3

## 3. DESIGN REQUIREMENTS FOR THE TRUSS SYSTEM

To assemble a satisfactory structure with the prefabricated members of the Truss System, it is considered necessary that (1) the members are capable of permitting angular adjustment at the joints, and (2) the members are capable of length adjustment or made with zero tolerance. But we have recently confirmed that the desired structure can be constructed with such members as are made with only the angular adjusting capability and to such a close length tolerance as plus or minus 1.0 mm, without the length adjusting capability as described below:

The assembling procedure of the Truss System is as follows (Fig. 4):

1) Connect lower chord members
2) Connect diagonal members
3) Connect upper chord members

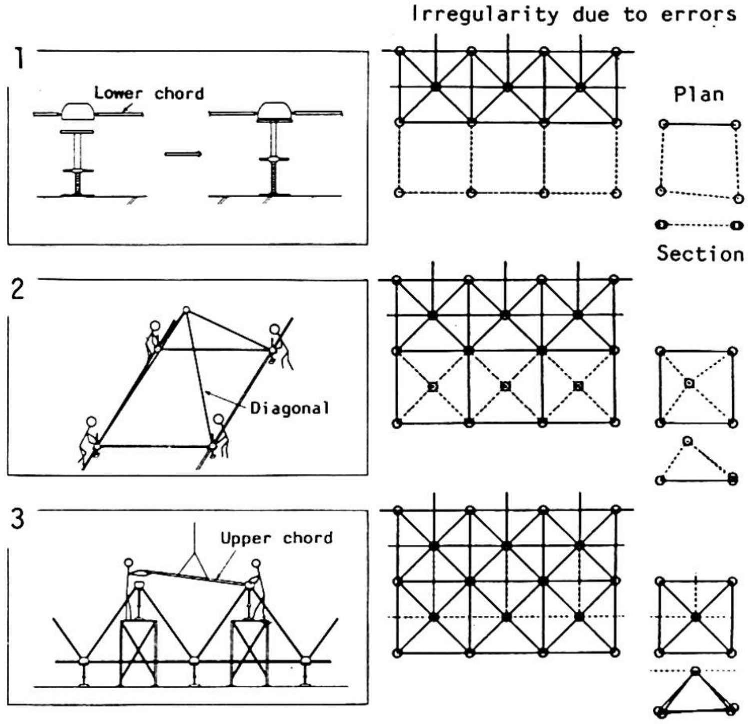


Fig. 4

It is necessary to study if irregularities in the assembled structure due to errors in the dimension of the nodes and the direction of members and the length of the upper- and lower-cord and diagonal members exercise any detrimental influence on the function and safety of the structure. This kind of influence, if any, must be clarified, too. Then, the obtained findings must be used in the establishment of an accuracy control standard. Simulation tests according to the Monte Carlo method were conducted to check how the Truss System will be assembled based on the assumptions that (1) the nodes could be made practically with zero tolerance, (2) the nodes were capable of adjusting the angle of the members fitted thereto (20/1000 radian), and (3) the upper- and lower-chord and diagonal members could be made to a tolerance of plus or minus 1.0 mm.

- Simulation Method

1) The length of all members making up the Truss System was varied within the standard deviation of 0.3 mm which was equivalent to the tolerance of plus or minus 1.0 mm according to the normal distribution.
2) The position of all node joints of the Truss System was calculated using the probabilistic combination of the members involving length errors in the order in which they were assembled.
3) The same calculation was repeated 10,000 times.

The simulation conducted on a plate space truss of 60 meters by 60 meters with 3 meter grid module showed that the accumulated perpendicular downward error at the center node amounted to about 1/220 maximum of the span with respect to the horizontal line.

To permit the construction of the Truss System, as such, it seems necessary and sufficient to keep the accuracy of the its members within the limit of plus or minus 1.0 mm.

## 4. PRODUCTION OF SYSTEMATIZED SPACE TRUSS

### 4.1 Information System for Manufacturing

As mentioned previously, the Truss System consists of nodes, pipe members, and bolts. All of the component parts of the Truss System have different characteristics. They have obviously different shapes and sizes. At the symmetrically opposite points of an axisymmetrical space truss structure, for example, nodes of the same shape and size should be considered to have different characteristics as pipe members are installed in different directions. It may be said that the components of each part have not only their own size and shape but also their own information of the character.
The parts information from a 50 grid by 50 grid double-layer plate space truss, for example, is that it requires 20,000 pipe members, 5,000 nodes and 40,000 bolts. In this case, approximately 200,000 pieces of information are needed for the design, quality control, transportation, and field assembling of the space truss. Smooth construction of the Truss System calls for the accurate processing of a vast amount of information. To carry out a plurality of construction projects simultaneously, it is necessary to work out an information processing system that can integrate not only technical information but also the flow of management and office work. To be more specific, computer-integrated manufacturing (CIM) supported by computer-aided manufacturing (CAM) and computer-aided planning (CAP) will provide an ideal information processing environment for the achievement of a satisfactory operation system (Fig. 5).

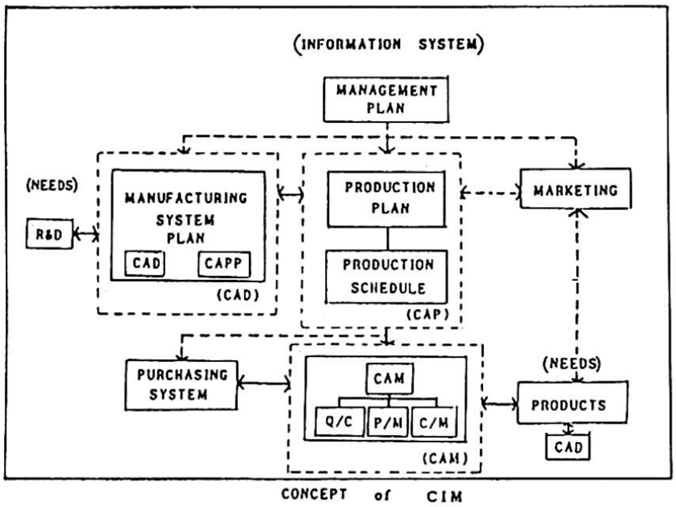



Fig. 5

### 4.2 Manufacturing of the Truss System Component Parts

The following is a brief description of the manufacturing method for the pipe members and nodes. It is based on a computer-aided automatic production system to permit speedy, high-precision and low-cost production of various kinds of parts, each in small quantities.

1) Manufacturing of Nodes
Manufacturing of nodes consists of forging and machining.

a) Forging (Fig. 6): A round bar is cut to a given length (with a tolerance of plus or minus 0.5 mm) having a large enough volume to be made to the ultimate design shape. The work is shaped into a breakdown by upsetting and striking, and then shot-blasted to get ready for subsequent machining.
b) Machining (Fig. 7): First, the external surface is machined by a numerical-controlled milling machine. Then bolt hole tapping and other machining operations are performed in accordance with the preliminarily loaded design information at the machining shop. The bolt hole tapping is controlled by increments of 1/1000 radian.

2) Manufacturing of Pipe Members

Manufacturing of pipe members consists of pipe cutting and the welding of end cones.

a) Pipe Cutting

Pipe is cut to the desired length based on the design information covering pipe diameter, wall thickness, and length.

b) Welding of End Cones

Welding of end cones is preceded by precision cutting (with the tolerance of plus or minus 0.5 mm) and beveling depending on the pipe diameter and wall thickness. To assure even welding and maintain accurate length, automatic welding is performed under the conditions chosen based on a shrinkage allowance estimated on the basis of room temperature, pipe profile, and welding material. The pipe length should be controlled within the limiit of plus or minus 1.0 mm.

## 5. CONCLUSION

It was discovered that the systematized space truss is applicable to the construction of ultra-large span structures and other structures of various shapes. It was also found out that such applications need advanced technologies for materials manufacturing, heat treatment, and design- and production-assisting information processing. The design of a structure composed of a group of component parts made with high reliability and precision needs new concepts and techniques absolutely different from those applied to conventional steel structures. We would like to show a 200 M high television tower with 3-layered observatory in China and a 100 M span x 3 units hangar for housing three jumbo jet planes in Indonesia made by use of the Truss System, which may serve as examples suggesting the expanding applicability of the space truss technology (Figs. 8 and 9).

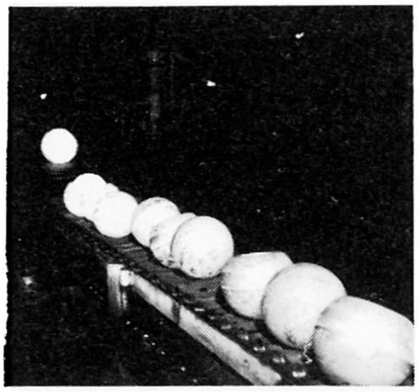


Fig. 6

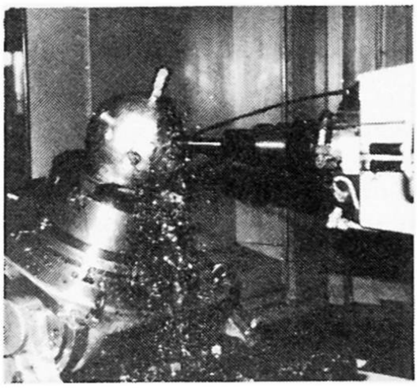


Fig. 7

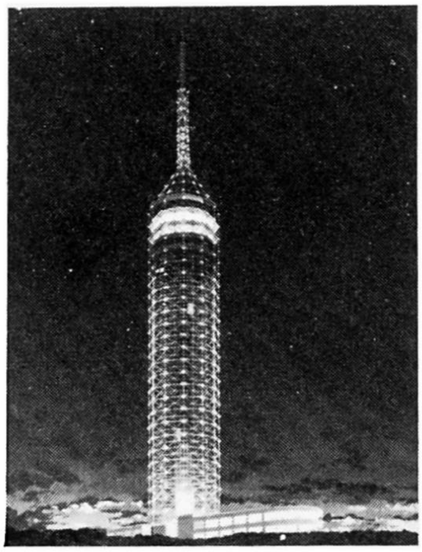


Fig. 8

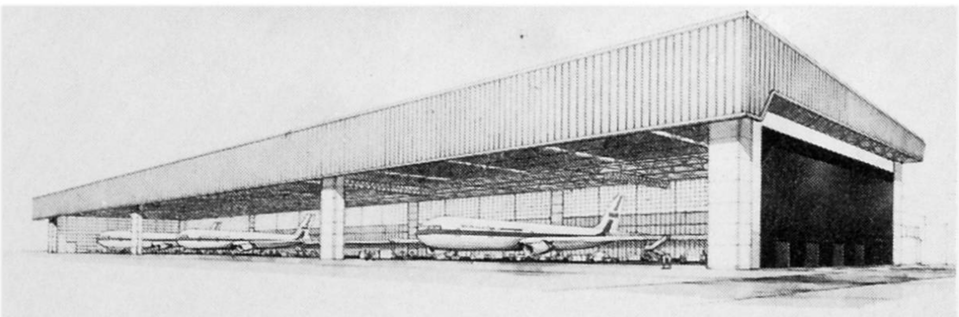


Fig. 9

# Non-welded Structural System

Structures métalliques non soudées

Schweißfreie Stahlkonstruktion

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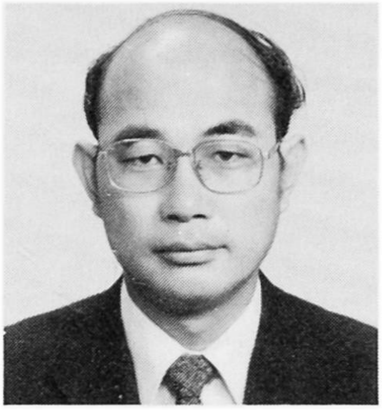

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**SUMMARY**
In Japan, seismic forces and wind pressures are major loads which must be considered in structural design. To cope with these loads, connections of structural members are generally required to be made as rigid connections, which are made only by welding these days. This causes restrictions and problems concerning realization of more fully automatic welding, assurance of weld qualities, reduction of construction time, etc. This paper deals with a non-welded steel structural system which eliminates the above mentioned limitations and problems and thus enables to pursuing total rationality in all such aspects of design, fabrication and construction by fully utilizing CAD and CAM.

**RÉSUMÉ**
Au Japon, les charges dues au vent et aux tremblements de terre sont les deux charges principales qui doivent être prises en compte dans l'étude d'une construction. Ces charges impliquent des assemblages rigides entre les éléments de la structure, qui ne peuvent étre réalisées que par soudure. Il en résulte des problèmes de soudage automatique, d'assurance de la qualité des soudures, de réduction de la durée de construction. Ce rapport aborde certains aspects des structures non soudées qui permettent de se libérer de ces contraintes et de concevoir les éléments aussi rationnellement que possible en faisant appel à tous les moyens offerts par la conception et la fabrication assistées par ordinateur.

**ZUSAMMENFASSUNG**
In Japan müssen bei der Berechnung die Erdbeben- und Windlasten berücksichtigt werden. Dies bedingt feste Schweißverbindungen zwischen den einzelnen Elementen, wodurch jedoch Restriktionen hinsichtlich vollautomatischer Schweißung, der Schweißqualität, der Bauzeit usw. hingenommen werden müssen. Diese Schrift befaßt sich mit nicht geschweißten Stahlkonstruktionen, so daß die erwähnten Restriktionen entfallen und volle Rationalisierung der Konstruktion, der Fertigung und der Errichtung unter Verwendung von CAD und CAM Systemen realisiert werden kann.