Proceeding of Shanghai International Conference on Technology of Architecture and Structure (ICTAS 2009)

(II)

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◎ China Civil Engineering Society
◎ Division of Civil, Hydraulic and Architecture Engineering, Chinese Academy of Engineering
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同济大学出版社
TONGJI UNIVERSITY PRESS

图书在版编目(CIP)数据

2009 中国上海国际建筑科技大会论文集 = Proceeding of Shanghai International Conference on Technology of Architecture and Structure(ICTAS 2009). 2:英文/中国土木工程学会等主编. —上海:同济大学出版社,2009.9

ISBN 978-7-5608-4168-7

Ⅰ. 2… Ⅱ. 中… Ⅲ. 建筑学 - 国际学术会议 - 文集 - 英文 Ⅳ. TU - 53

中国版本图书馆 CIP 数据核字(2009)第 176694 号

Proceeding of Shanghai International Conference on Technology of Architecture and Structure(ICTAS 2009) (Ⅱ)

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责任编辑 高晓辉 宋 磊 **责任校对** 荆 华 **封面设计** 陈益平

出版发行 同济大学出版社 www.tongjipress.com.cn

(地址:上海市四平路 1239 号 邮编:200092 电话:021 - 65985622)

经 销 全国各地新华书店

印 刷 江苏句容排印厂

开 本 889mm × 1194mm 1/16

印 张 41

印 数 1—530

字 数 1 312 000

版 次 2009 年 9 月第 1 版 2009 年 9 月第 1 次印刷

书 号 ISBN 978-7-5608-4168-7

总 定 价 360.00 元

2009 Shanghai International Conference on Technology of Architecture and Structure

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Preface

The 2009 Shanghai International Conference on Technology of Architecture and Structure (ICTAS 2009) is held in Shanghai, China, October 15 ~ 17, 2009, hosted by Division of Civil Hydraulic and Architecture Engineering of Chinese Academy of Engineering, China Civil Engineering Society (CCES), Tongji University, Chinese State Construction Engineering Corporation.

As World EXPO 2010 will be held in Shanghai, many new types of structures are expected to be constructed for the EXPO, the theme of this conference is "Theory and Practice of Large-scale Public Building and Infrastructure". It supplies a platform for experts, professors, scholars, engineers and technicians to exchange the knowledge and experience for large-scale public buildings and infrastructure planning, design, construction and management, reveal the technology achievements in construction of large-scale public buildings and infrastructure, improve the city construction level and push forward the process of city sustainable development with keynote lectures, technical sessions and technical tours.

This conference proceedings volume contains 172 papers from over 150 contributors, including the invided keynote papers by some very prominent experts in their respective fields. It provides an opportunity to all contributors to share your latest research works and findings. The major areas covered at the conference and presented in this volume include:

- Planning, design and construction technology of large-scale public building and infrastructure;
- Construction management and informatization construction technology of large-scale public building and infrastructure;
- Strengthening and retrofit of large-scale public building and infrastructure;
- Application of green building technology;
- Application of new structure style, technology and material;
- Large-scale public buildings, infrastructure construction and the city sustainable development

It is our pleasure to present to you the proceedings of ICTAS 2009. Furthermore, we would like to thank all the keynote speakers who make splendid presentations, authors who present papers, participants who take part in the conference, whose support and encouragement is essential in facilitating this conference ICTAS 2009. Finally, we wish all delegates an enjoyable and unforgettable conference, a pleasant fellowship and conviviality gathering amongst friends and colleagues.

Conference Organizing Committee of

2009 Shanghai International Conference on Technology of Architecture and Structure

CONTENTS

Construction Technology

Robot Assisted Manufacture Technique of Latticed Shell with Shapped Steel

WU Xinzhi
(Shanghai Machinery and Construction Limited Corporation)

Abstract World Expo 2010 will be held in Shanghai, "Sun Valley" stands in the expo campus as a symbol construction. It is complicated latticed shell with over 30000 bars in different sizes and 10000 connecting joints, which makes it rather difficult to process connecting joints. In order to overcome this difficulty, a new technique, called "robot assisted manufacture technique of latticed shell with shaped steel", is invented by combining robot assist and computer aid with conventional production process. As a result, all of connecting joints are finished on time with higher accuracy.

Keywords sun valley, connecting joints, robot assist, latticed shell

1 Introduction

Walking into the campus of World Expo 2010 Shanghai, you can see six translucent "Sun Valley" standing on the World Expo Axis in different shapes[1].

"Sun Valley" is single-layer steel latticed shell composed of rectangular bars and fitted to irregular cylinder surface by arbitrary triangle of different sizes, like a "funnel". Its height is 41.5 m, the largest diameter on the top is 90m and the bottom diameter is less than 20m. "Sun Valley" steel latticed shell uses Q345B steel, six "Sun Valley" weight about 3,075t in total. Components are welding box joints (some joints are solid and castiron), the height of cross-section is 180 ~ 500mm, width 65 ~ 140mm, bar length 1.00 ~ 3.5m, the total number of bars is 30738 with 10, 348 joints in different shapes. Bars and joints are welded together in working field.

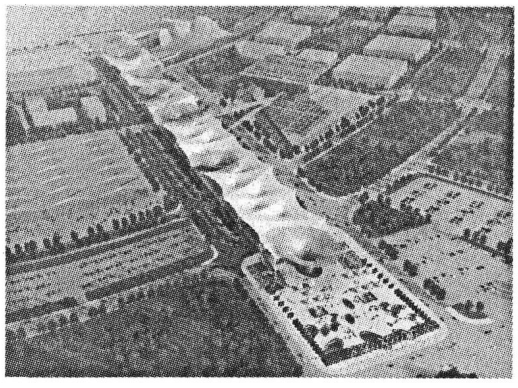

Fig. 1 Airview of "World Expo Axis"

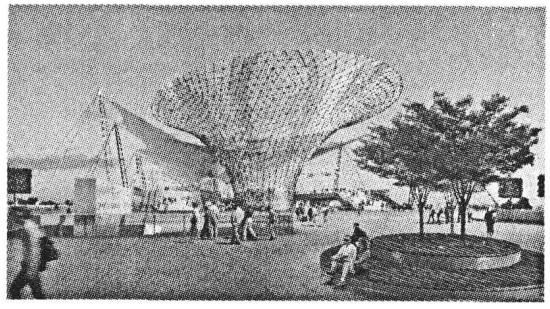

Fig. 2 Effect drawing of "Sun Valley"

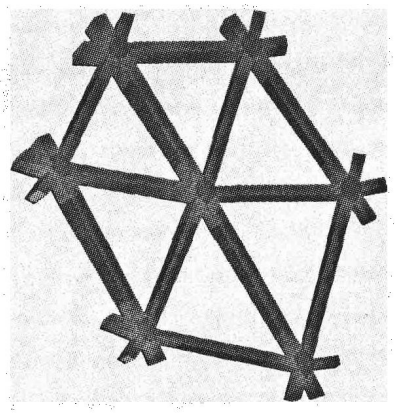

Fig. 3 Schematic diagram of the local structure

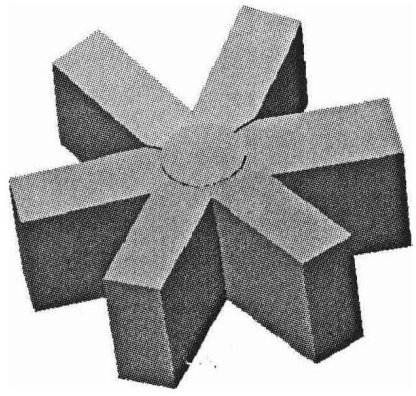

Fig. 4 Joint model

Since the six sun valleys have different shapes, the cross-sections of bars have different sizes and specifications in different parts. Multi-intersection joint has 4 to 5 intersections, the number of intersection is even up to eight. The angles between the bars vary accompanying with torsion, over ten thousand joints belong to thousands different kinds, which makes the joint processing more difficult than usual.

Meanwhile it demands higher production accuracy than normal steel structure. The errors of joints between characteristic points are controlled in millimeter, especially their end faces connecting bars need processing accuracy of 0. 1 millimeter, only CNC machine tools can meet the requirements. In order to distinguish from normal steel structure, it is named as "fine steel structure".

According to conventional processing methods, each welding joint needs to be decomposed into 30 to 40 components, so that the detail drawings of optical components of the whole structure count on tens of thousands. However, "Sun Valley" steel latticed shell has only about six moths to complete, even foreign companies that are experienced in product processing also looked reluctant to such a short project time. At that time, the manufacturing process and equipment of such complex high-precision joints are "blank", all needs to be started from the "zero".

Taking all above mentioned condition into consideration, we decide to use the "robot assisting processing" technique invented by Tianjin University, which belongs to its intelligence property. With combination of casting, welding and accurate detection of three-dimensional coordinates, we create a whole series of technique and equipment-"Robot Assisted Manufacture Technique of Latticed Shell with Shaped Steel"— in the shortest time, to meet the requirement of construction of World Expo axis.

2 Technical Details

"Multi-purpose production and processing robot" is Tianjin University's patented technique, the "robot" has multi-dimensional and high-precision operating capacity and can carry out many automated processes, such as complex cross-section of metal welding cutting, milling machining oper-

ations and so on [2]. It has been marketing abroad.

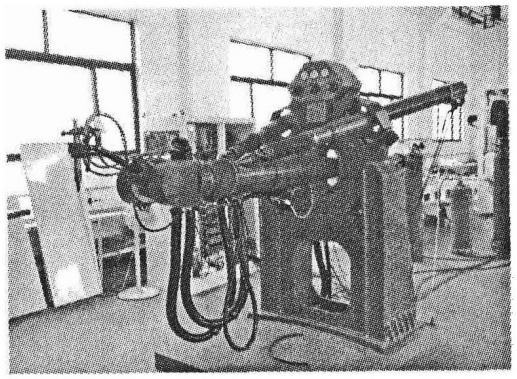

Fig. 5 Multi-purpose production and processing robot

In order to use "Robot" to produce complex joints of steel latticed shell, firstly, we categorized all joints into two groups: vierendeel joints use welding combination technique and solid joints use casting technique. Secondly, the method to decompose the welding joint into many pieces of plate welding unit before welding is changed as well as the method to use traditional wood-mold for casting joints, in our technique joints are decomposed into several standard components, such as central joint cylindrical and rectangular connectors, and then joints can be formed by the combination of various types of components in an orderly manner. The processing procedure is thus simplified by this combination of standard components, which creates conditions for the inclusion of "robot" and greatly simplifies the difficulty of process control to ensure the machining accuracy, the work efficiency is then further increased.

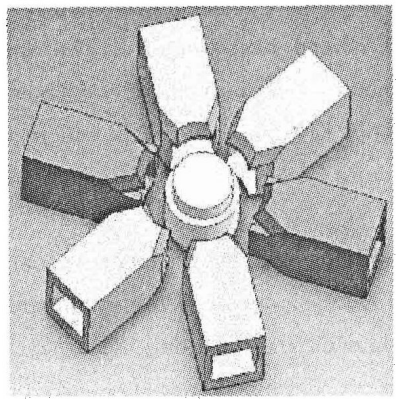

Fig. 6 Decomposition of the joint components

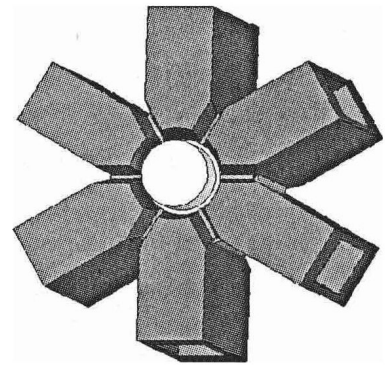

Fig. 7 Joint after the combination

To deal with welding compositing joints, we first cut the material for components connecting bars under NC and use automatic submerged arc welding to weld them into rectangular pieces[3], they are then cut into standard blocks, the center cylinders are manufactured by rolls-steel machine; then based on processing parameters of different joints, the plasma cutting process of inner sides of the standard rectangular blocks is carried out by "robot"; in next step, on a special platform, rectangular connecting components which cutting surface are already cleaned up and central parts are assembled together through exact positioning; after passing the accuracy test by measuring, they are welded together according to the provisions of welding order; after passing welding non-destructive test, the welding stress on welds need to be eliminated; the last step to produce joints is CNC surface milling on the joint faces between joints and bars. After surface treatment, coating and numbering, joints are sent out of factory.

For castiron joints, we use combination mold and casting-mold-losing technique[4]. That is,

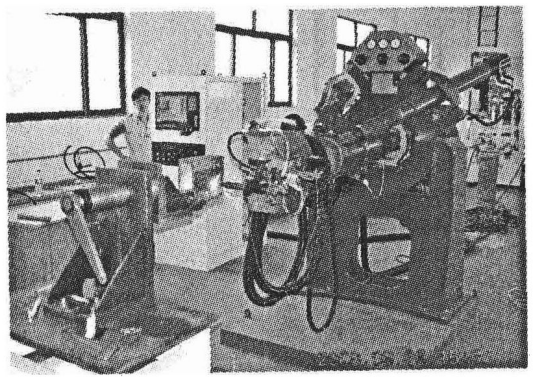

Fig. 8 "Robot" for plasma cutting

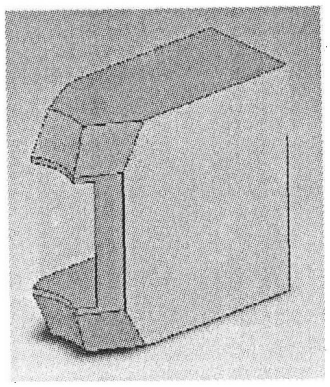

Fig. 9 Schematic diagram of the parts after cutting

according to the sizes of joints and bars, we process special aluminum alloy pressure injection molds and produce standard foam blocks for rectangular connecting components and central cylinders; then using "robot" to execute electric cutting on matching surface of standard rectangular blocks, components are thus formed; in next step, corresponding components are assembled into joint molds on the assembling platform; by painting and sand blasting, the shells of mold are formed and then processed into semi-finished products by roasting at high temperature, casting and surface cleaning; casting stress will be eliminated through heat treatment, after passing non-destructive testing, connecting end surface is treated through CNC milling, the completed joints are then re-painted, numbered and sent out.

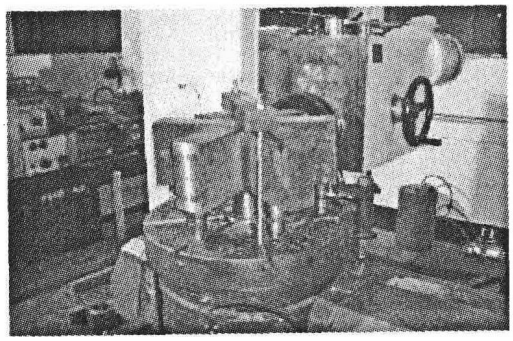

Fig. 10 CNC machine tools milling end face of joints

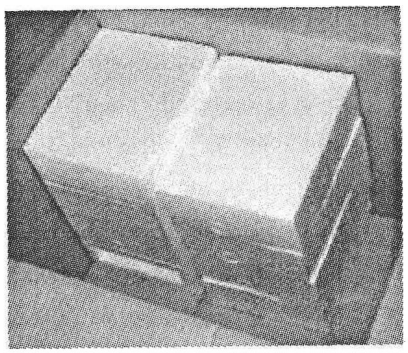

Fig. 11 standard foam blocks

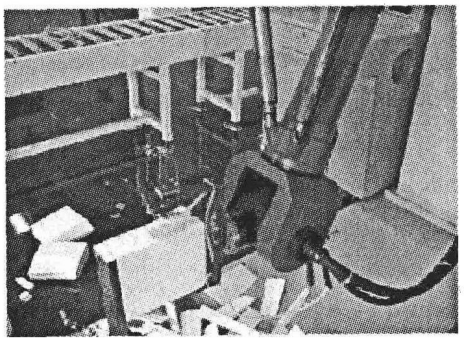

Fig. 12 "Robot" CNC cutting foam block

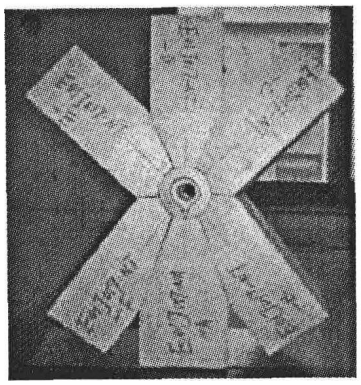

Fig. 13 Joint foam mold

Fig. 14 cast steel joint

In order to ensure the processing accuracy of the "fine steel" joint, in addition to improve technique and strict control, high-precision inspection equipment must be equipped. Since conventional measurement is unable to meet the requirements to inspect processing for this kind of joint, we choose a high-precision three dimensional coordinate detector and compile operation standard for inspection, so that the correlated precision problems between different machining surfaces can be solved out.

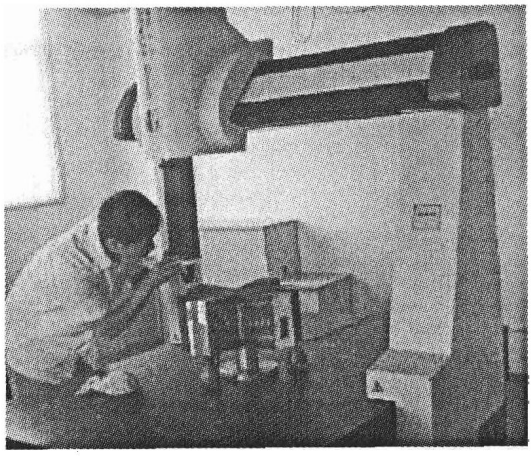

Fig. 15 Three-dimensional coordinates detection of the joint

In order to match "robot" assisted machining, simplify the production management and improve the efficiency of the production process, while developing processing technique, we explore computer-aid "paperless" technique for the entire procedure of joint processing. That is, we developed computer software, once the design of structural models is established, a virtual three-dimensional entity model can be automatically generated according to electronic design documents. Therefore, the basic geometric features of the component itself as well as between various components are first defined, such as the spatial relationship between strong, weak axis and curve of each rectangular bar, norm direction of joints and so on; and general rules for composition of certain joints (bars) are created, such as if bars with different cross-section heights are connected to the same joint, then the connecting components inside joint domain take the maximum height as unified height and the cross-sections of bars between different joints with different heights use linear transition. In order to create entity models, geometry relationship with the "Sun Valley" glass curtain wall, as well as the connecting structure etc need to be taken into account.

After the three-dimensional entity model is automatically generated, the size of the joint domain will be determined in accordance with the requirements of processing and installation and the

joint number (code) rules will also be set up. Then, computer automatically read database composed of relevant parameters of joint processing and send it directly to "robot" as basis for processing. When the "robot" operates, the operators only need to inform "robot" the corresponding joint ID, then "robot" will automatically work as requested, manual errors that might arise can be eliminated.

Date from database of joint processing is also directly sent to the five-dimensional degree of freedom CNC machine tools to control the milling on end-to-joint surface.

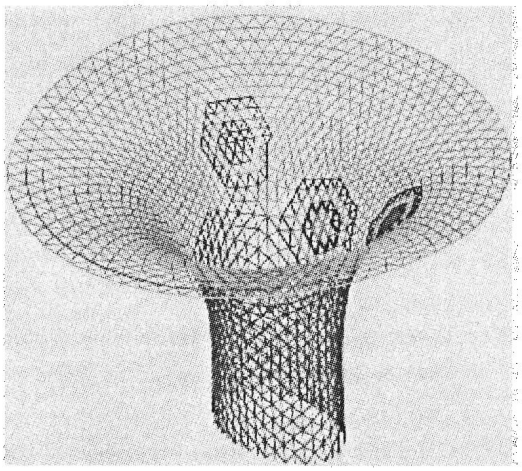

Fig. 16 Model of a single Sun Valley entity

So far, except that the data from components-combining-joint processing needs to be checked manually, all the other computer date from other manufacturing procedures has achieved the "seamless connection", which is very close to "paperless processing during the whole procedure".

In order to check relevant parameters of joint processing read by computer automatically, we also developed a virtual latticed shell assembly software. Through computer simulation technique, all the data is checked in a reverse way to assure absolutely safe.

Furthermore, after the completion of the joint processing, inspection of three-dimensional coordinates and determination of product quality, as well as the results from inspection can also be printed in a "seamless" way through computer aid. Namely, the coordinates of all critical feature points from the inspected components are detected by the use of three-dimensional coordinate inspector (when inspected, the reference coordinate system can be determined arbitrarily, but it can not changed during the whole detecting procedure), thus the virtual three-dimensional model of the real product can be generated, this model is then handled by computer and compared with corresponding designed model, the accuracy of product processing can be assessed by evaluating the bias between both models. The data from inspection can be directly printed into product quality table, thus manual intervention can be avoided and the authenticity of data is guaranteed.

3 Conclusion

After adopting the techniques of "robot" assist and components-combining-joint processing, the number of processing blueprints is largely reduced. Even that, we still invite a group of experts from Tongji University to develop specialized software to handle all the processing blueprints in order to achieve the completed process from entity model creation to automatic blueprint drawing.

In order to make breakthrough in the technique of Robot Assisted Manufacture Technique of Latticed Shell with Shaped Steel, we create specific corresponding computer procedures, as well as specific digital control machine tools, to ensure that "sun valley" steel structure can be completed on time.