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The Research and Application of Innovative High Efficient Construction Technologies in Super High Rise Steel Structure Building

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Abstract

The super high rise building construction is characterized by a large quantity of engineering works and structural components, high demanding of construction technology and complex cross operations. As the height of super high rise building increases, the construction difficulties increase, it is challenging the steel structural building construction technology. In this paper, the key technologies in the construction of Chinese modern super high rise steel structure building have been studied. The innovative tower crane supporting frame suspension disassembly technology has been developed to allow the crane supporting frame to turnover in the air without occupying materials stockyard. A new self-elevating platform technique which is capable of striding over structural barriers has been developed. This new technology allows the platform to be self-elevated along variable cross section column with a maximum 600 mm size change. A new automatic submerged arc welding technology has also been developed to ensure the process continuity and quality stability of welding job on the construction site.

Keywords: Super high rise steel structure, Construction, Suspension, Self-elevating, Automatic welding

1. Instruction

The super high rise building (SHRB) in China boomed in 1990s. More and more super high rise steel structure buildings (SHRSSB) have been built after the China first SHRSSB, Shenzhen Developing Center, was built in 1985. The Asia highest building, Shenzhen imperial estate building (383.95 m), was constructed in 1996. Shanghai World Finance Centre (492 m), the world highest building (in 2008) people can reach at the top, was constructed in 2008. According to the statistics by CTBUH, there are 44 SHRB (over 400 m) in the world, in which 27 are located in China. To a certain extent SHRB represents not only the prosperity of a nation or a city, but the level of modern science technology development. By summarizing the engineering innovation practices, some of key modern SHR SSB technologies of China Construction Steel Structure Corporation (CCSSC) have been introduced in this paper, which provide good reference for future SHRB construction.

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2. Tower Crane Supporting Frame Suspension Disassembly Technology for SHRSSB

Structure combination of concrete frame-core tube system, outrigger and mega frame column are a type of structure which is widely used in the high-rise buildings (Li et al., 2012). As a most important device to transport equipment vertically, the efficiency of tower crane affects the whole processes of construction. Typically, there are two types of tower crane, external attached type and internal climbing type. For the restriction of structure and material, the height limit of general external attached crane is about 200 m. As a result, internal climbing crane are widely used in buildings higher than 200 m (Huang, 2012). Normally 2-4 internal climbing cranes are equipped on construction site (> 200 m), located inside or outside the frame-core tube. The supporting frame and jacking system are the main devices for fixation and jacking. In present, simple supported frame and cantilevered frame are two main types of supporting frame (see Fig. 1). For the large vertical and horizontal loading in the application, tower cranes are characterized by heavy weight, large size, large quantities of joints and complex structure, leading to many difficulties and high risks for crane disassembly. Moreover, current methods for crane disassembly is of low efficient since neighboring cranes are used for hoisting. For this reason, a new suspension disassembly technology for cantilevered frame internal climbing crane has

(a) Simple supported

(b) Cantilevered

Figure 1. The supporting of tower crane.

been developed by CCSSC.

2.1. Crane jacking mechanism

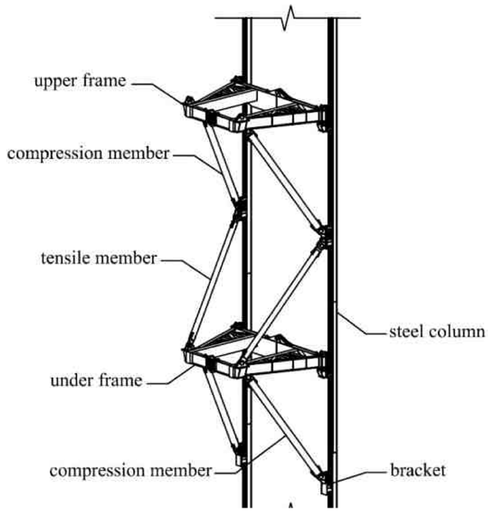
Cantilevered frame internal climbing crane uses specified supporting frame who has three supporting brackets. The crane is attached on the outer surface of frame-core tube system. In the normal operation, two out of three supporting brackets are used, while in the jacking operation, three brackets are alternating operating.

2.2. Mechanical characteristic of supporting frame

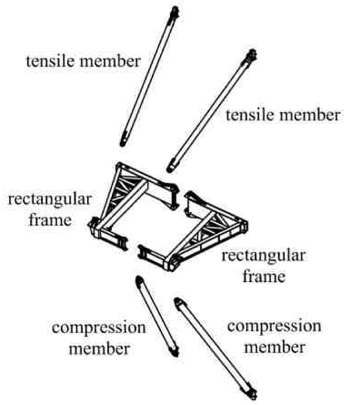
Supporting frame system is composed of supporting bracket (upper frame and under frame), embedded parts and connectors, bracket, chord (compression member and tensile member). In the normal operation, upper frame tightly holds the crane tower body, with only horizontal loading acting on it. Chord is subjected to the compressive or tensile forces. The under frame is the main loaded structure under both vertical and horizontal loading. With the combined action of the supporting brackets and chords, system will be in the equilibrium state in normal operation.

2.3. Crane supporting frame suspension disassembly

The idea of suspension disassembly is to, firstly, install a specified chain block in one end of the rigging, by which the supporting bracket A and supporting bracket C are connected. Secondly, disconnect supporting bracket A



(a) Integrated



(b) Separated

Figure 2. Supporting brackets.

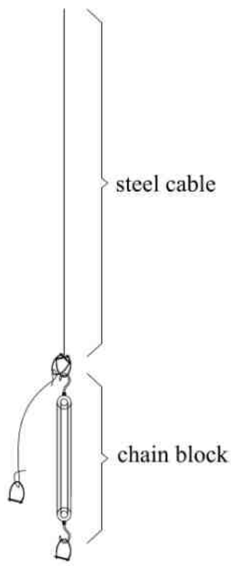


Figure 3. Rigging.

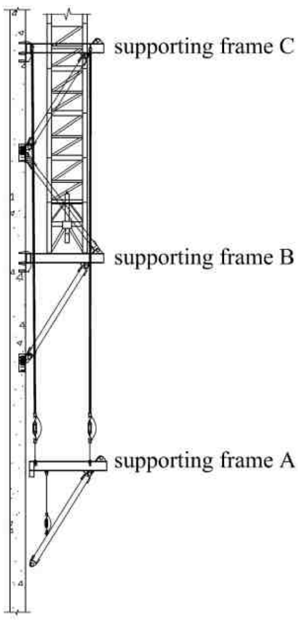


Figure 4. Supporting frame.

Figure 5. Eigneering drawing.

with frame-core tube system and then lift supporting bracket A by chain block. Thirdly, disconnect two supporting brackets. After disassembly is done, supporting bracket A is suspended in the air by the rigging and ready for use. Therefore, materials stockyard area can be reduced.

Since heavy weight of crane body is acting on supporting bracket B, while only horizontal force is acting on supporting bracket C, the rigging is designed to go through the supporting bracket B directly without any constraint. Therefore, more vertical forces are avoided to act on the supporting bracket B. The layout of tower crane supporting frame is shown in Fig. 4.

2.4. Case Application

Shenzhen Ping'an Finance Centre, with a total height

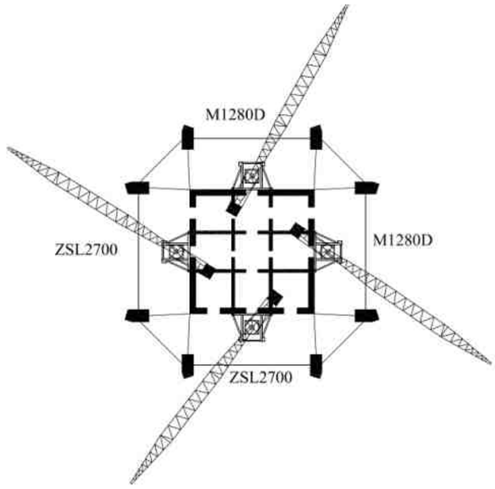


Figure 6. Layout of tower crane.

Figure 7. Disassembly.

of 660 m, will rank first in Asia and second in the world after completion (see Fig. 5). There are 4 large external attached type self-elevating cranes in this project, two of which are type M1280D and two are ZSL2700, See Fig. 6 for the layout. Each of crane equipped a supporting frame system. By the technology of integral lifting and separation of supporting brackets in the air, the disassembly was more efficient, safe and reliable. The supporting brackets were hanged in the air, providing more ground space for truck transportation and material pile up. In the whole construction period, the crane totally climbed 27 times, the supporting brackets alternated 27 times, in which 23 times were for suspension disassembly. Compared to traditional disassembly technology, it has prominent economic benefits for saving 90 working days and 600 m^2 stockyard. The suspension disassembly is shown in Fig. 7.

3. Self-Elevating Platform Technology

The scaffolding operation platform and assembled section steel platform are two most popular operation platforms in current engineering application. Though the sca-

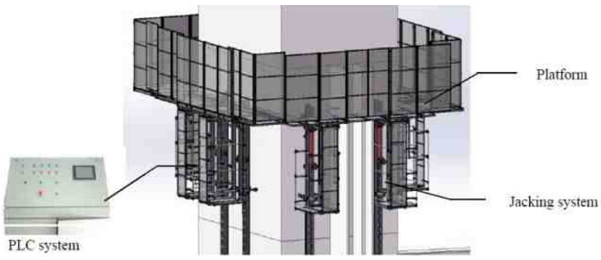


Figure 8. Self-elevating platform.

ffolding operation platform is easy for turnover, it has some drawbacks, such as large labor demand and high risk in high-altitude operations. The assembled section steel platform is compact and lightweight, but when it comes to transformation of steel column section or needs to stride over brackets, some modifications must be applied, which are inefficient and difficult for onsite operations. Moreover, these two platforms will take lots of time as much as that of steel column installation to hoist platforms, parts and components. As a result the whole construction processes will be impeded dramatically. The technology developed in this paper, which is capable of striding over structural barriers, is able to overcome drawbacks mentioned above. It not only saves working time for crane hoisting but ensures the safety of operations.

3.1. Mechanism and composition of self-elevating platform

The self-elevating platform is composed of three main systems, jacking system, platform and central control system. Jacking system is driven by two-way hydraulic and the gear system. The platform is designed to equip telescopic devices which are able to retract platform to avoid encountering steel girder. The central control system is PLC synchronous remote control (SRC) system which controls hydraulics for mechanical lifting. See Fig. 8 for self-elevating platform.

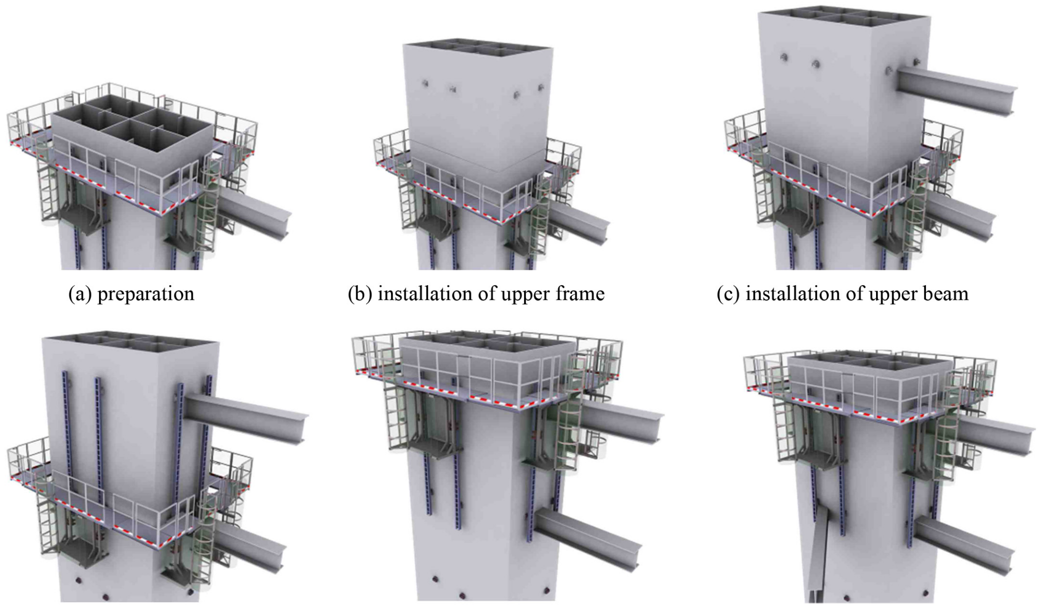
The self-elevating platform is a mechanical operation platform for steel column construction. After each segment of steel column is finished, the platform can be elevated automatically to a new installation position of upper steel column. The whole elevation processes are shown in Fig. 9.

3.2. Variable cross section column self-elevating technology

The biggest technical innovation is the technology for platform to be elevated along variable cross section column. Differed from the guide groove type hanging seat of traditional climbing equipment, concentric hanging seat is applied in our self-elevating platform, which has been proved to improve the supporting mode of the hanging seat and track, change the climbing frame hanging mode and the position on the hanging seat. Therefore, the technology allows the track and the frame to rotate freely in a very large angel around the hanging seat, making the climbing along variable cross section columns with a maximum 600 mm size change possible.

3.3. Retractable platform technology

The platform applies a retractable floor system to avoid steel beam or bracket in the elevation. The floor system is composed of fixed part and the telescopic section, as shown in Figs.11 and 12. Some advantages can be sum-



(a) preparation (b) installation of upper frame (c) installation of upper beam

(d) climbing (e) striding over the upper beam (f) installation of lower beam

Figure 9. Platform climbing processes ($a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f$).

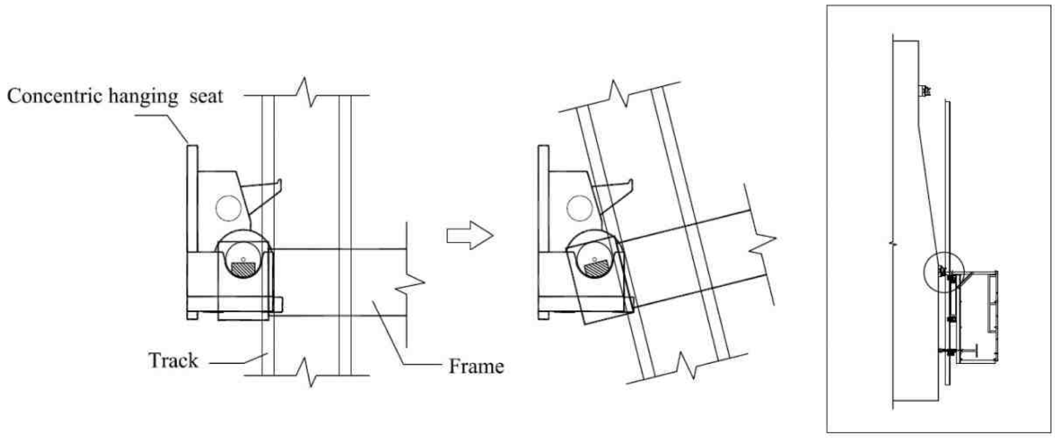


Figure 10. Concentric hanging seat, column and frame.

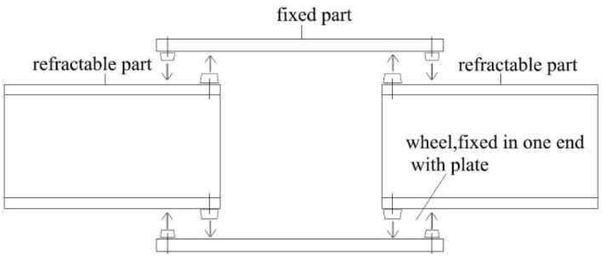


Figure 11. Retractable floor system.

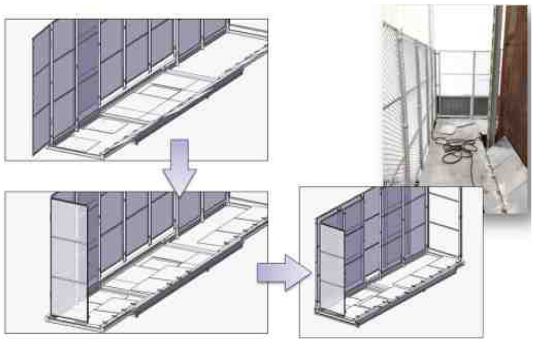


Figure 12. Retractable platform.

marized. Firstly, the platform can be adjusted to any size in a specified range, and the adjustment is independent on any other tools. Secondly, the telescopic section can be retracted completely into the fixed part, saving rooms for other application. Thirdly, safety enclosure is also retractable so that the integrity of the enclosure is maintained.

3.4. Platform elevation synchronous remote control

The jacking system is controlled by PLC system which composed of central PLC system, opening device, fixation transmitter, proportional valve and safety system, as shown in Fig. 13. Parameters from hydraulic cylinder, fixation and jacking system are digitally transmitted to central PLC control system. By analyzing these parameters in pre-installed program, PLC system will send orders to hydraulic station. With the help of proportional valves, system will control all cylinder strokes simultaneously so as to control the speed and status of jacking system.

3.5. Case application

Guangzhou East Tower is a mega frame-tube structure

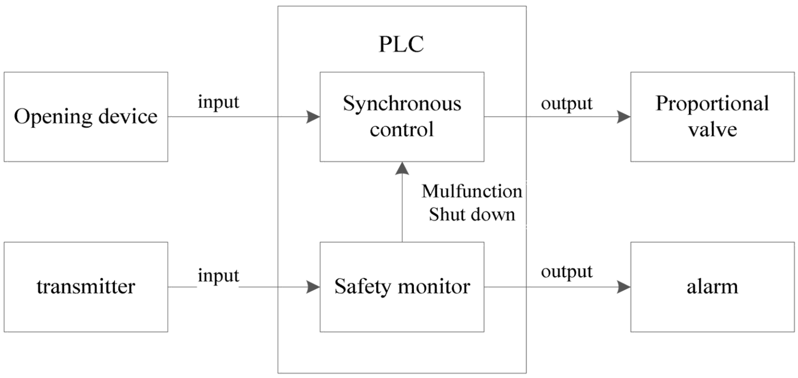


Figure 13. PLC synchronous remote control system.

Figure 14. East Tower.

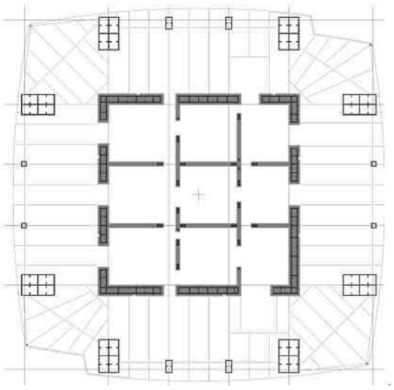


Figure 15. Layout of mega column.

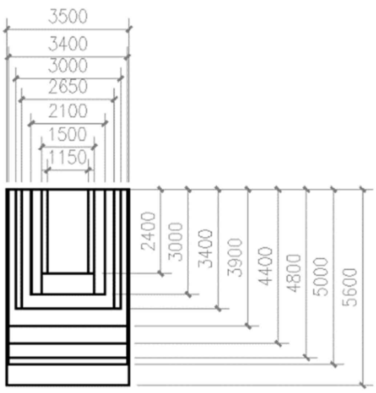


Figure 16. Transition of column.

with a height of 530 m. The outer frame is composed of eight huge rectangular steel concrete columns, with a maximum size 5600 by 3500 mm. The column contracts totally 11 times as the height increases with a total 600 mm size change. Compared to the traditional operation platform, the self-elevating operation platform in this project is independent of tower cranes, except for the installation, dismantlement and transportation in the initial stage. According to statistics, 4 times hoisting was saved for each steel column segment, totally 4 working day was saved. The technology of platform climbing along variable cross section column provided not only high efficiency for construction, but new idea for future researches on mechanization and automation of onsite construction.

4. Automatic Welding Technology in SHRSSB

Manual metal arc welding (MMA) and gas shielded arc welding (GMAW) are two most popular onsite welding methods in Chinese SHRSSB construction. MMA requires simple equipment and small space, so it is suitable for short weld in any position. But the welding quality of MMA strongly depends on the skills and physical state of workers, it is of low efficiency and high labor intensity. GMAW has the advantages of good protection effect, stable arc and concentrated heat. The strength and corrosion resistance of weld by GMAW are much better than that of MMA, it is suitable for all position welding. In recent years, the main structure and component in Chinese high-rise building become more and more giant. For example, the section areas of one mega column of Tianjin 117 project and Beijing China Statue project reach 45 m^2 and 77 m^2, respectively. Considering the manufacturing, transportation and other factors, more and more steel member sections are manufactured in factory, leading to the increase of welding and working intensity on the construction site, as a result labor cost and time cost increase. Automatic welding has the advantage to improve the efficiency and quality. However, current application and research of submerged arc welding (SAW) are mainly concentrated in the pipe manufacturing, pressure vessel manufacturing and other fields (Yu et al., 2005; Liu and Fang, 2011; Chen et al., 2013), few are applied in onsite automatic welding. In recent years, SAW technology has been applied into the construction site by CCSSC, and automatic submerged arc welding (ASAW) equipment has been creatively invented for different applications. After lots of experiments and researches, different welding process parameters are successfully obtained and applied to different engineering practices.

4.1. The system of ASAW

The automatic welding equipment is designed by the principle of SAW. The welding platform is free to move back and forth on the specific track built on the welding component, the welding wire and rosin flux are synchronous fed to the welding position. With welding process parameters, a single pass in one direction will be weld in one time. After one welding pass is completed the weld-

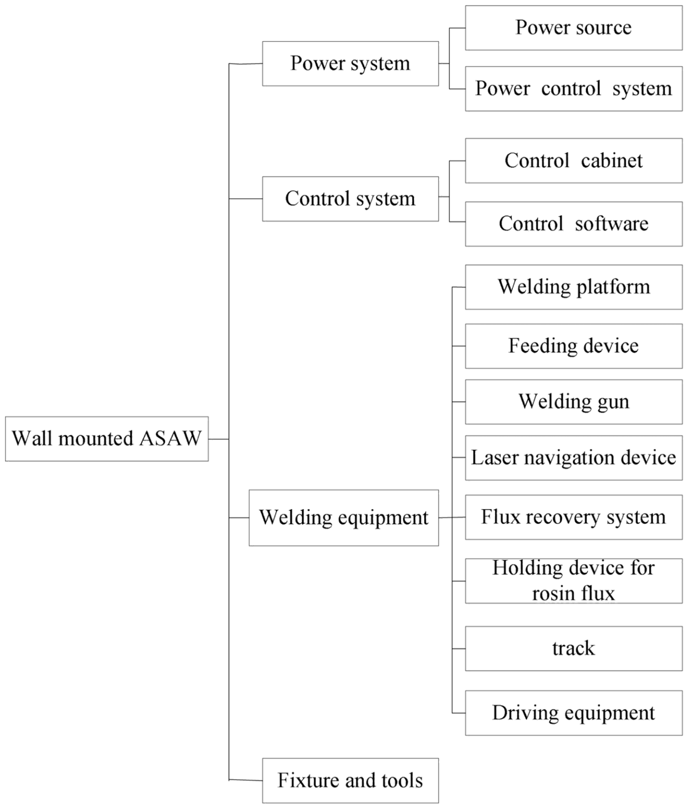


Figure 17. System composition.

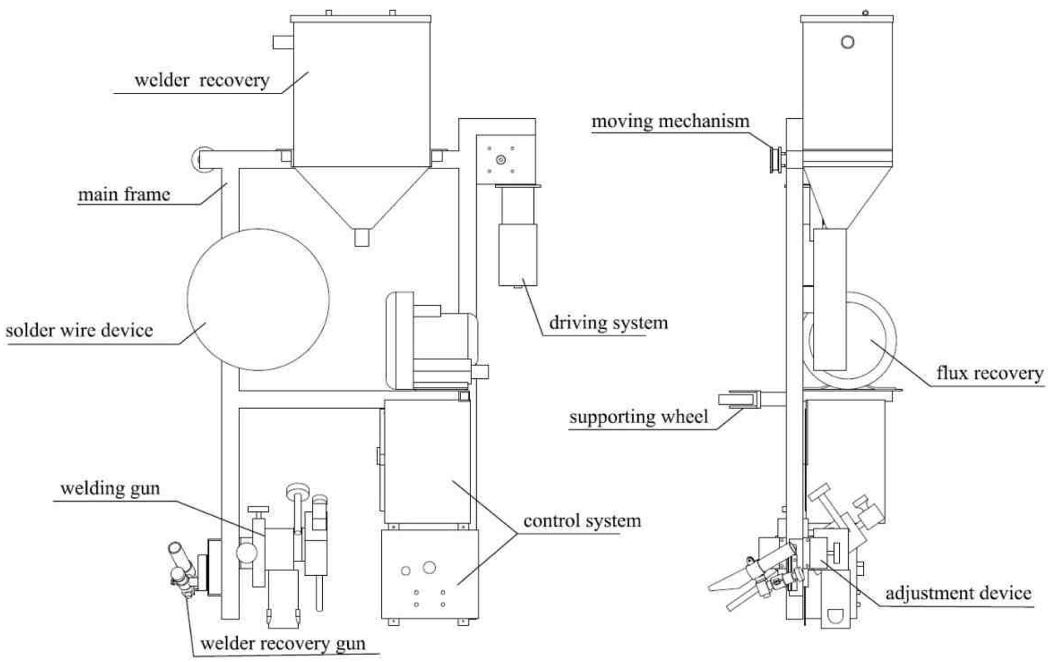


Figure 18. Drawing of ASAW equipment.

ing platform will return to the starting point to start another pass, and this process will be repeated until all passes are finished. Welding equipment is consist of welding power source system, control system, welding equipment, welding fixture and tools, as shown in Figs. 17 and 18.

The laser navigation device uses laser spot to track po-

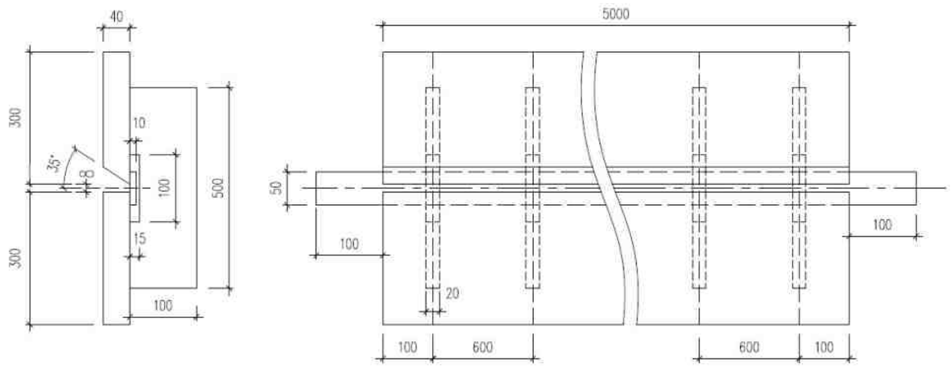


Figure 19. Drawing of welding plate.

sition. It can guide welds along any desired direction. The welding gun is equipped with angle adjusting device, allowing a 15~45 ° angle adjustment. The automatic welding flux recovery is realized by bilateral and bidirectional flux recovery devices.

4.2. Welding parameters experiment

In order to obtain the most appropriate welding parameters, including voltage, welding current, welding process and welding speed, welding experiments have been executed in 1:1 ratio.

4.2.1. Welding experiment preparation

(1) Equipment

Including welding platform, cable, welding power, waking track, etc.

(2) Material

a. Q345C steel plate.
b. Two test plates, size 5000 by 300 by 40 mm, with a single unilateral 35° groove, 8 mm groove gap, as shown in Fig. 19.
c. One backing plate, size 5200 by 50 by 10 mm.
d. Eight constraint vertical plate were spot welded on the back of steel plate in every 600 mm. The size of vertical plate is 500 by 100 by 20 mm;
e. Solder wire: H10Mn2, 3.2 mm.

4.2.2. Test processes and results

Before automatic welding, the first weld pass needs to be built up by CO2 gas shielded arc welding. Totally 21 weld passes were accounted in this experiment, the total welding time was 317 minutes (not including GMAW), which accounts for about 58.2% of whole experiment time. The overall stability, coordination and welding precision of automatic welding equipment were proved to be excellent. It was found that all welds were in flawless condition by nondestructive inspection. The time and the corresponding parameters for welding are listed in Table 1. Some onsite pictures are also shown in Fig. 20.

Table 1. Test parameters

Weld pass	Time (min)	Current (A)	Voltage (V)	Speed (mm/min)
1	20	380	31.1	63
2	20	430	32.0	71
3	15	450	30.0	73
4	17	453	29.0	68
5	17	429	39.2	75
6	16	440	27.6	72
7	16	440	28.2	68
8	16	446	27.0	82
9	18	446	28.0	75
10	17	436	28.0	91
11	17	429	29.2	75
12	16	440	27.6	72
13	16	440	28.2	68
14	16	446	27.0	82
15	16	446	28.0	85
16	17	436	28.0	91
17	12	422	28.0	119
18	14	443	28.0	102
19	13	437	28.6	112
20	12	431	28.5	115
21	12	422	28.2	114

4.2.3. Welding parameters

Optimized welding parameters are listed in Table 2 for different plate thicknesses.

4.3. Case Application

ASAW technology not only ensures the welding quality, but also enhances the welding efficiency since it is not influenced by the working space and the technical level of welders. With this technology, the primary welding qualification of Guangzhou East Tower mega column reached 100%. Taking 5600 mm by 3500 mm giant column as an example, the longest unilateral weld is 5.6 m, plate thickness is 50 mm, steel material is Q345C. According to estimates, 10 man days are needed to weld single section columns using CO2 GMAW, amounts to 80 hours welding

(a) First weld pass

(b) Second weld pass

(c) Third weld pass

(d) Final weld pass

Figure 20. Weld passes in experiment.

Table 2. Welding parameters for different plate thickness

Thickness (mm)	Current (A)	Voltage (V)	Speed (mm/min)	Gun angle	Weld Pass
10-14	320-350	26-27	380-420	15-45°	1
	450-480	27-29	480-520		2
16-22	380-420	26-27	380-450	15-45°	1
	450-480	27-29	480-520		2
	450-520	28-31	500-650		3
24-30	380-420	26-27	380-450	15-45°	1
	450-480	27-29	480-520		2
	450-520	28-31	500-650		3
	470-520	28-31	550-650		4
	480-520	28-31	560-650		5
32-50	380-420	26-27	380-450	15-45°	1
	450-480	27-29	480-520		2
	450-520	28-31	500-650		3
	470-520	28-31	550-650		4
	470-520	28-31	550-650		5
	480-520	28-31	580-650		6-7
55-80	380-420	26-27	380-450	15-45°	1
	450-480	27-29	480-520		2
	450-520	28-31	500-650		3-10
	470-520	28-31	550-650		11-14
	480-520	28-31	580-650		15

time. Two automatic welding machines were used for the same job, only 16 hours were used, the efficiency had been improved by 2.5 times. The weld quality is shown in Fig. 21.

Figure 21. Weld after completion.

5. Conclusion

This paper studied the key technologies for Chinese modern high-rise steel structures. The tower crane supporting frame suspension disassembly technology has successfully realized the turnover of the supporting frame in the air without occupying materials stockyard, which is proved to improve the working efficiency. The barrier avoiding technology of self-elevating tower crane platform reduced the occupancy time of other tower cranes, realized the climbing along variable cross-section steel columns with a size change in a range of 600 mm. The automatic submerged arc welding technology ensured the continuity and stability of welds, improved welding efficiency. It should be said that, after nearly 30 years of development, Chinese high-rise steel structure construction technology has made great progress, some construction technologies have advanced into top ranks in the world. But with the land crisis more and more serious, future super high-rise buildings in China will become higher and higher. These are challenging the construction technologies of steel structure, especially in the construction quality assurance and construction efficiency. Today, with the globalization of information, the development direction of intelligent, flexible and detailed technology and management is the mainstream of future development of steel structure construction.

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