Frontiers of Engineering Management
DOI 10.15302/J-FEM-2016013

ENGINEERING MANAGEMENT REPORTS

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Practice and Experience of Canton Tower Project Management

Abstract This paper presents a brief introduction about the preliminary consulting and tender agent of Canton Tower, the basic situation of the whole-process supervision on the construction site, and a general summary of the Canton Tower project management. What's more, the author suggests that some guidelines be formed for supervision enterprises involved in large-scale project management.

Keywords: Canton Tower, consultation, tender agent, whole-process, supervision

1 Project overview

Near Chigang Pagoda, Canton Tower stands at the intersection between the central axis of Guangzhou new city zone and the landscape axis of Pearl River. It faces Haixinsha Island and Pearl River Newtown, the central business district (CBD) of Guangzhou city. With Metro Line 3 and Pearl River Newtown light rail going through North to South across the region by its west side, Canton Tower is a tourism-oriented TV tower, with the functions of radio and television transmission, cultural entertainment and sightseeing.

Canton Tower is invested by Guangzhou Construction and Investment Group Co., Ltd., whose subordinate institution — Guangzhou New TV Tower Construction Co., Ltd. is responsible for construction and operation management. Guangzhou Construction Engineering Supervision Co., Ltd. (GCES) is responsible for the pre-construction consultation, tender agent work and the whole-process construction supervision. Guangzhou Municipal Construction Group Co., Ltd. and Shanghai Construction Group (SCG) are responsible for the body structure construction and engineering procurement construction. Jiangsu Huning Steel Mechanism Co., Ltd., Zhejiang South-east Space Frame Co., Ltd., Zhejiang Jinggong Steel Structure Co., Ltd., Jiangsu CUMT Dazheng Surface Engineering Technology Co., Ltd., China Construction Installation Engineering Co., Ltd., Guangdong Industrial Equipment Installation Co., Ltd. and other companies are involved in the construction of Canton Tower.

The construction of Canton Tower is achieved by a designing team consisting of three parts: architect Mark Hemel and Barbara Kuit, Information Based Architecture (IBA) (responsible for architecture), Ove Arup and Parters (HK) Ltd. (responsible for structure, equipment, and electrical design). Guangzhou Urban Planning and Survey Research Institute is responsible for geological survey. Design and Research Institute of CMG Radio, and Beijing Institute of Architectural Design Consortium are responsible for design and construction review; Ove Arup Parters and Guangzhou Design Institute consortium are responsible for designing (Ove Arup Parters, for preliminary design; Canton Design Institute, for construction design).

"New Climate of Guangzhou" is the theme of Canton Tower's architectural design. Its structure is a rotary ellipsoid reticulated steel shell. In comparison with the bottom and the top of the tower, "the waist" of the tower is very slender and with vivid posture. The steel tube frame and the reinforced concrete core tube are composed of oblique steel column, oblique support, and ring beam, and there are horizontal connecting floors between the two buildings, which fully demonstrate the building style. Looked at from different directions, different shapes of the tower will appear (Wu, Liang, & Chen, 2011).

Canton Tower is originally designed 610 m high, including 454 m (platform center) of the main tower body and 156 m of the high antenna mast (Yu, Yang, & Zhou, 2010). But Canton Tower is in the flight area of the airplanes. According to relevant regulations, obstacles are not allowed within 300 m from the location of the on-

Manuscript received July 20, 2015; accepted October 30, 2015

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course aircraft, and the flight height above Canton Tower is 900 m from the sea level. To ensure flight safety, tower-mounted antenna was made to decrease 10 m in June, 2010, so the final height of the Tower was 600 m.

The main tower is 448.8 m, with a core tube of 88 floors. The oval core tube within Canton Tower is the main vertical transport connection. There are five functional districts: A, B, C, D, and E, including 37 floors for sightseeing, restaurants, TV broadcast and entertainment. There are two floors underground. The second negative floor, mainly serving as the garage, is 10 m high; and the first negative floor is 5 m high, serving for exhibition, dining and parking lot.

2 Preliminary project consulting and technology demonstration

2.1 Preliminary consulting

In June 2004, GCES began to undertake the preliminary engineering work which ranged from pre-construction research to the beginning of the actual construction, for example, we provided advisory and consultant service like making early plans and implementation programs for the construction of the engineering management institution (Guangzhou New TV Tower Construction Co., Ltd.), which included pre-construction research, related tests, designing, supervision, material equipment tender, and the official construction. Besides, we assisted relevant construction management companies to do their work.

2.2 Preliminary research and demonstration

To make sure that the project can advance smoothly, GCES assisted to survey and research a lot, for example, the bid for the construction of Canton Tower (including steel production factories, and steel frame making companies), the experts seminar about steel selection and steel processing, the meeting of setting acceptance standard for Canton Tower steel engineering construction quality, the seminar of steel complex inspection group batch, the experts review meeting of steel engineering pre-deformation program, the meeting of Canton Tower BRA520C (Q420GJCW) weathering resistant steel welding test report, the evaluation meeting of BRA520C (Q420GJCW) weathering resistant steel welding process, the experts evaluation meeting of steel making and processing, the experts review meeting of M900D crane installation cum structure fill strong program, and the review meeting of Canton Tower antenna mast construction program, which provided effective technology support for steel procurement supply, enrollment bid, steel component making and processing, and site construction.

2.3 Test and study

As a tall tower mast structure, the construction of Canton Tower must strictly observe the regulation the *Provisions on the Management of the Seismic Fortification of the High-rise Buildings* (Ministry of Construction of the P.R. C., 2002). To improve buildings' seismic performance, when the designing standard and disciplines of anti-seismic criterion are relatively unclear, GCES assisted relevant organizations to complete the following tests, to be specific, the wind tunnel force balance test on Canton Tower structure (completed by State Key Laboratory of Disaster Reduction in Civil Engineering, Tongji University) (Gu, Huang, Zhu, & Pan, 2009; Zhou, Gu, Zhu, & Huang, 2009), the shaking table test for the structural model of Canton Tower (completed by Earthquake Engineering Research Test Center, Guangzhou University) (Pan, Zhou, & Liang, 2008; Zhou, 2006), the experimental investigation on stability of the exterior steel frame and waist portion of Canton Tower (completed by Tsinghua University) (Guo, Liu, Wang, Lin, Pan, & Liang, 2008), the experimental research on bidirectional hinge joints in Canton Tower (completed by College of Civil Engineering, Tongji University) (Chen, Zhao, & Wang, 2007), the advisory report of long-term corrosion resistance and protection technology about Canton Tower (completed by Central Iron & Steel Research Institute, CISRI), the advisory report of steel pipe production process for steel structure analysis (completed by Beijing Yuanda International Project Management Consulting Co., Ltd.), and vibrating stress relief test on welded steel tube of Canton Tower (completed by Shanghai Jiao Tong University), the test on Φ 1000 mm $\times$ 50 mm hot forging hemisphere of Canton Tower (completed by Jiangsu Huning Steel Mechanism Co., Ltd.), the experimental study on atmosphere corrosion resisting structural steel of BRA520C (Q420GJCW) of Canton Tower (completed by Central Research Institute of Building and Construction Co., Ltd., MCC Group).

3 Project bidding agency

3.1 Planning detailed bids in advance

Canton Tower construction project is very difficult. For smooth project, it requires top domestic organizations and experts to form a high-quality project team, so GCES made an overall planning at early advisory stage for project tender, prepared tender program, developed the tender schedule for relevant companies, divided tenders and conformed the contract relationship and management relationship between companies, decided the biding patterns of different biding periods, set key points and controlling programs during tender process, and finally made detail analysis about biding time and condition. By

making an overall planning and specific implementation of the work, we achieved a better control of the whole construction project.

3.2 Setting clear biding goals

With large steel volume, many construction links, and long construction cycle, this project is complex and difficult. So it requires high quality construction units. The bidding for the project general contractor is the most important one. We need to achieve three targets: introducing companies which have the most advanced technologies, and are experienced in constructing tall buildings and good at integrated management. Guangzhou Tower was constructed by Guangzhou New Television Tower Group. Canton Tower is designed by the Dutch Architects Mark Hemel and Barbara Kuit from Information Based Architecture, together with Arup, an international designing, engineering and business consulting firm headquartered in London, UK. In 2004, Information Based Architecture and Arup won the international competition, during which many international large architectural offices participated.

3.3 Conducting sufficient tender research

To achieve the above three goals, GCES and the relevant organizations have formed a special tender team half a year before the official biding began. On the one hand, we conducted some survey and research on domestic large construction enterprises, steel processing and making factories, supporting steel control tube factories to study their qualifications, performances, technological equipments, human resources, and integrated management capacities, so as to get an overall understanding of domestic first-class construction enterprises; on the other hand, we surveyed and researched a series of domestic large-scale steel projects and the super high-rise building projects, and had in-depth discussions with the project persons in charge so as to learn from their experiences in construction management. Combined with the current technological features and construction of the project, we formed a basic pattern of the bidding.

The outer cylinder is made of steel pipe columns. Once we had various opinions about whether the processing and installation of steel structure should be included in the project general contractor biding. After lots of research, repeated discussions and analyses, we finally decided not, so as to guarantee the precision and quality of the steel components. Steel processing and making will get a separate biding, while steel installation is in the general contractor's charge as it is closely related to civil engineering. The company as the general contractor is responsible for the welding and installation of the on-site steel component. This could prevent the general contract bidder from choosing weaker steel processing companies, and also ensure the compatibility and combination between the steel structure installation and civil construction program. The following practice verified that this approach was very successful. All other processes underwent the similar pattern of survey and research, discussion and analysis, such as the selection and arrangement of tower cranes and construction elevators, the choice of scaffolding solutions, the solution of steel component erections, the plan of concrete core wall construction, the scheme of antenna mast installation, and the preparing for the general schedule of the program.

3.4 General construction management mode of the project

When preparing the tender file, GCES repeatedly discussed and finally determined the framework *Management Approach for Canton Tower Construction General Contracting*. We clearly defined the obligation, the range of work and management for the general contractor bidder, and the right to audit other professional construction projects; and included the responsibility the general contractor should take for weak management of related areas of construction.

By establishing contract management regulations and management patterns during implementation phase of the project, we made the various approaches and systems practicable, and incorporated them within the framework of the contract. Therefore, the general contractor company was able to play an important role in the entire project according to the general contract management practices that had been developed.

3.5 Risk analysis and control in advance to get greatest freedom from risk

When writing tender files, contract terms, and engineering volume listings, we paid much attention to pre-controlling, analyzed various policy risks, market risks and management risks in advance, made series of pre-control measures, management approaches and reward measures, listed them into the contract terms, so as to constrain the behavior of the contract parties and guarantee maximum interests of the construction companies.

For example, in the initial stage of project construction, the price of steel had large fluctuations, and for such a project with immense steel volume and relatively lengthy construction cycle. The negative effects of the steel market fluctuations on engineering implementation were minimized. GCES created a tender for steel structure production, and minimized bid requirements. Steel manufacturers signed steel procurement (supply) contract letters of intent and steel procurement (supply) commitment book. These were attached in the bid files. With such confinements, the steel price was locked by the bid quotes, and allowed no adjustment. After the winning bidders matched a bank guarantee, they could apply for not more than 50% of its steel material of preparation total, in the form of a fixed unit

price steel order from steel mills. With these measures, the risk of market price fluctuations of steel was successfully avoided.

4 Whole process supervision of project construction

4.1 High standard allocation of personnel for the project supervision department

After the winning of the bidding of Canton Tower construction supervision business, GCES assigned the chief engineer of the company to be chief supervisor, employed three senior high-rise building, steel structure and electromechanical construction experts who should work on the construction site as the consultant team. Besides, GCES founded many work groups with the backbone engineers as group leaders, in such a variety of areas as civil engineering, steel structure, measurement and security, decoration and curtain wall, investment control, and information.

4.2 Engineering quality plan

Before the bidding process, GCES prepared much: conducted market research and formulated strict bidding terms, as to ensure that the potential bidders have qualifications, achievements and reputation that well match the image of the project. The official documents and the construction contracts clearly specified that the "Luban Prize" quality must be ensured, so that the units involved in the bidding would reach a consensus. Urging contractors to set up a group project manager as the head of group, relying on post implementation management, construction quality was under control. Based on actual project situation, GCES prepared the corresponding approval standards of concrete structural engineering, steel structure engineering, curtain wall engineering, and in some aspects the construction quality approval standards set were stricter than the current national norms and standards for acceptance of construction quality. In the construction, the following techniques were given the priority of application: concrete crack control technology, super high concrete pumping technology, big span spatial structure and big span steel of overall top rise technology, layout balanced technology, intelligent building system debugging technology, building equipment monitoring technology, and construction process monitoring and control technology. 10 big technologies, and 24 small new technologies were employed, together with many independent innovations of GCES, such as construction simulation analysis technology, pre-distortion technique for steel structure of space, three dimensional measuring technology, external climbing construction technology of heavy tower crane (Yu, Chen, Wu, & Shao, 2009), overall hoisting steel platform construction technology, computer controlled integral lift technique of antenna mast and other technologies.

4.3 Construction quality control

1) In the process of Canton Tower construction, the parties involved in the construction all took the quality responsibility strictly according to the national *Engineering Quality Management Processes*, and other regulations, provisions of contracts, agreements and professional documents.

2) Effective measures were taken for quality control concerning construction preparation, construction process, and middle and completion acceptance, according to contract files, design drawings, and regulations and laws, acceptance standards, specification procedures issued by the national and local institutions, to guarantee that construction met the requirements and standards at every stage and in every aspect.

3) Efforts were made to implement the ISO standards strengthened project quality awareness, establish quality management agencies, and implement the permission to quality management, and perfect the quality management system.

4) During the construction process monitoring, a "three-check" system was carried out strictly for each process to all hand-over procedures and all required reworking items, as to fully meet the standard required. The construction teams were not permitted to leave until their work met the entire requested construction standard.

5) A project management framework was prepared, a series of institutions were established and implemented, concerning three-level technical disclosures, basic model provisions, quality assurance meetings, engineering quality inspection and acceptance at all levels, and materials entry testing.

6) Quality control was exercised upon raw materials, so that the qualifications of the suppliers, the product quality guarantee documents, the product quality check certifications, and the designed life span of the products, could well conform to the requirements. Raw materials were let in only when they passed the required retesting and inspection, in order to guarantee that the project used quality material.

7) According to the characteristics of the project, determination was made of the key areas, key processes, and special procedures, and site supervision was conducted for the whole process of continuous monitoring, as to strengthen quality control.

8) Procedures were developed and implemented, of acceptance of concealed work and part acceptance process of the project, and quality control. Before checking and ratifying, none of the hidden works was allowed to the next working procedure of construction.

4.4 Construction progress control

Canton Tower construction began on November 25, 2005,

and completed on September 8, 2010 with a total duration of 1,617 days, meeting all contract requirements.

Our Project Supervision Department, seriously audited the progress plans of the construction companies, and according to the actual progress, helped the total package company to make analysis of the restricting factors and engineering difficulties, and to make reasonable arrangements for the construction process, highlighting the mainstream construction lines of steel concrete core tube and steel structure, and promoting the perfection of computer-controlled overall upgrade steel platform and super high performance concrete pump-assisted construction technology.

GCES took measures to enhance coordination, in order to create a favorable external environment for the contractors, getting in touch timely with the designing, constructing and other institutions to help the contractors to determine design drawings and obtain construction licenses as soon as possible. For example, the earth excavation and transportation was massive, with a large quantity (of more than 100,000 tons) and a relatively short work time (4 months). Making use of the favorable conditions of the nearby water piers, GCES made active coordination with the terminal and other related companies for the transportation of the unearthed waste, to shorten the work time.

GCES cooperated actively with the contractor of the construction and inspection. For working at night and holidays, GCES assigned supervisors on duty for inspection, site supervision or coordination. For concealed work, the supervisors could make timely acceptance and acknowledgment, which ensured the smooth progress of construction.

GCES sent station-in project management groups to manufacturers to conduct supervision on the actual manufacturing process, by way of project tracking, forecasting, timely correction of deviations, and proposals of a solution.

4.5 Investment control

Staffs at the investment control department were all familiar with contracts and bidding documents and could cooperate closely with the site supervision engineer of the project department while carrying out investment control work. Meanwhile, they have to actively assist the construction unit promote the investment control and contract control of the project and review the project visa to achieve the desired objectives of investment control.

As soon as the project construction began, investment control supervision engineers decomposed the project investment objectives according to the requirements of the ISO management of the supervision company. And, they also set up the measurements of investment control ledger to make the investment control work planned and visualized.

During the course of construction, GCES kept close contact with the field representatives of the construction companies, by way of active communication and coordination, helping them to deal with such various matters concerning construction. In addition, for monthly quantitative measurement of engineering activities, GCES had coordination and cooperation with field engineers, conducting careful verification of the image progress of the project, full review the contractors' declaration of physical quantities, and in-depth site examination of the actual progress of the project, and monthly auditing of the measurement, as to ensure that the measurement did not hold progress back.

As for the monthly measurement of steel structure producer, GCES clearly defined the differences of the amount of engineering work suggested by construction drawings and revised by the producer, and took efforts to measure the amount of work in strict accordance with the tender documents, the relevant provisions of the construction contract, and the quantitative prescriptions of auditors of construction. GCES gave investment control engineers unified calculation tables concerning steel parts, so that they could cooperate with the supervision department in the monthly measurement.

Through the supervision practice of Canton Tower, GCES had in-depth understanding of the importance of investment control. To have effective project investment control, especially control of the total project investment within the established goals, it is necessary to make full preparation, in order to reach the control targets.

4.6 Supervision of production safety

4.6.1 Priorities and difficulties of safe and civilized construction

Guangzhou Tower construction process was featured with super height, massive weight of steel structure hoisting, narrow core tube working space, restriction of vertical transportation and large amount of impending operation, and these brought great difficulties to safety management. Priority was given to and difficulty appeared with the digging of deep foundation pits and pile holes, the operation of the plug-in M900D cranes, the ascension of the 670-ton antenna masts, the shaping of the whole lifting steel platforms and the super-high steel pipe operation platforms, the paint coating of the outer cylinder, the making of the air ladder parts, the installation of temporary fire-proof facilities, the prevention from super high-altitude outdoor disaster climates and dust pollution.

4.6.2 Specific measures taken by the supervision department

In view of specialness of the engineering and importance of its safety management, GCES attached great importance to

the work safety supervision, placing construction safety monitoring in the first place, adhering to the principle of "safety first, prevention first" and the procedure of "censoring first, checking second, correction third, reporting fourth." GCES conducted safety supervision with fineness and wholeness, curbing effectively the occurrence of serious safety accidents, and reaching the expected control targets safe and civilized construction. The project supervision department mainly took the following control measures:

1) Improvement of the safety supervision framework, establishing a safety supervision group with registered safety engineer as the leader, the Guangdong provincial security director as one of the team members.

2) Detection and assessment of the major hazard sources and the major factors of impacts upon the environment and occupational health, according to the safety management system concerning environment and occupational health, organizing the formulation of the corresponding control measures, clarifying the responsibilities and authorities of each supervisor, and aiming at meeting the requirements of environmental protection of the construction site.

3) Reinforcement of regular inspection, setting up the system of daily, weekly, monthly and quarterly inspections, and weekly safety conferences.

4) Establishment of safety system of shot exposures and slideshow reports of violations against safety construction rules.

5) Establishment of quarterly and annual safety assessment and reward.

6) Implementation of complete safety monitoring and site supervision for the experiments and the operations of all new techniques and new facilities.

7) Management of information collection and reporting, concerning foundation pit monitoring, structural health monitoring, weather and weather, physical examination for the high altitude operators, and qualifications of the special equipment operators and special situation operators.

5 Conclusions

The construction project of Canton Tower brought unprecedented opportunities to participation parties of the investment, project management, consultancy, design, tender agent, supervision, construction and test, bringing these parties and their personnel to an upper level of technology and management, preparing them for still greater projects of construction.

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