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# Key technological innovations in the construction of the main terminal of Beijing Daxing International Airport

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**Designer:** Beijing Institute of Architectural Design

**Supervisor:** Beijing Huacheng Construction Supervision Co., Ltd.

**Construction Contractor:** Beijing Urban Construction Group Co., Ltd.

## 1 Outline

Beijing Daxing International Airport, a major landmark project in China and a new driver for national development, will represent the direction for the development of civil aviation airports in China. The airport, situated in the junction of Nangezhuang, Daxing District, Beijing City and Gu'an County, Hebei Province, has seen its north terminal area and north terminal built in the first phase, covering a total construction area of about 1.4 million m<sup>2</sup>. The north terminal area is designed to have an annual throughput of 45 million passengers.

Terminal construction is the core project of the airport. The terminal is currently the world's largest single terminal, the world's largest single shock mitigation and absorption building, the world's first airport terminal with high-speed rail underpass, and the world's first terminal with three-story departure and two-story arrival featuring a convenient system of "three departures and two arrivals". The terminal core area is part of the super project with the most complex structure, the most powerful

function, and the greatest construction difficulty. The terminal features new functional layout and flow design, as well as a centralized configuration planning to regulate the flow of passengers. A super-large floor plane arrangement is adopted in the building design. The concrete layer of the first floor of the main terminal, 565 m wide and 437 m long in the shape of a square, covers an area of about 160000 m<sup>2</sup>. The main terminal has a construction area of 600000 m<sup>2</sup>. There are two floors underground and four floors above ground (five floors in some places). The projected area of the roof is 180000 m<sup>2</sup>, and the highest elevation of the roof reaches 50.9 m. The interior is characterized by super-large plane and super-large space. The aerial view of the terminal is shown in Fig. 1.

In the course of construction, there arose lots of contradictions and conflicts due to heavy engineering tasks, unique design scheme, massive participants, advanced and complex technology, big risks of many sources, as well as sharp ethical questions, especially contradiction between schedule targets under limited conditions and engineering safety and ecological protection. In the face of unprecedented challenges, the construction team alleviated conflicts of interests through technological innovation, making breakthroughs in key technology of construction on super-large plane concrete structure, super-large plane integrated technique of interlayer shock mitigation, construction technique of roof of curved-surface steel mesh structure with a super-large plane complex space, construction technique of bilayer energy-saving metal roof with super-large plane irregular curved surface, key construction technology for decoration of large ceiling of super-large plane terminal roof, and comprehensive installation technology for electromechanical engineering of super-large multi-purpose terminal. By coordinating the relationship between various stakeholders and taking into account economic, social and environmental benefits of the project, the team completed construction as scheduled in a secure and environmentally-friendly manner, providing a "Chinese approach" to world-class problems facing airport construction, and achieved remarkable results.

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**Fig. 1** Aerial view of Beijing Daxing International Airport Terminal.

## 2 Highly efficient and fine construction technologies for super-large complex foundation engineering

The super-large foundation pit of the main terminal featured complex geology, many working procedures of great mutual influence, and difficulty facing the construction organization. The construction team used Global Navigation Satellite System (GNSS) rapid dynamic single base station with real time kinematic (RTK) measurement technology and developed the pile position rapid dynamic control lofting technology under the super-large plane and large-scale mechanical operation environment. The technology proved effective in the complex environment of pile foundation construction. According to the measurement and evaluation after pile foundation excavation, the accuracy was up to design and specification standards, while saving a lot of manpower and material resources, with satisfying project implementation effect. The dewatering plan of “drainage outside and unwatering inside” eschewed the effect of post-grouting of foundation pile and anchor bolt construction on dewatering in deep groove area. The high-precision Building Information Modeling (BIM) solved the conflict between slope protection pile and prestressed anchor in deep zone and foundation pile in shallow zone. Successful application of the self-developed secondary split grouting technology solved the problem of low tension of anchor bolt in peat soil layer. Innovative adoption of polymer mud wall protection and secondary hole cleaning in bored pile construction put the hole wall collapse and sediment thickness in fine sand layer under control, securing improved efficiency and enhanced quality of pile foundation.

## 3 Key construction technologies on super-large plane concrete structure

Given the super-long and super-wide plane of the concrete structure of the main terminal, innovative application of a series of comprehensive technologies successfully controls the cracks of concrete members. The main measures are as follows: (1) in addition to 1 meter-wide construction post-cast strips with intervals of 40 m, there are 4–6 meter-wide steel-disconnecting structure post-cast strips 150 m apart; (2) use of anti-crack rebar; (3) use of fiber reinforced concrete; (4) use of compensated shrinkage concrete (polypropylene fiber, fly ash, united expansion agent, and water reducing agent); (5) installing unbonded temperature prestressed bars; (6) building inducing joint onto the super-long wall; (7) setting a large diameter rubber isolation bearing at the top of the structure column under the  $\pm 0.000$  floor slab, and controlling floor cracks caused by the shrinkage stress and temperature stress of super-large plane concrete by the technique of interlayer shock isolation.

Digit-based simulation of temperature field and site layout of monitoring points, and study of the effect of seasonal temperature variation on super-large plane structure were performed to inform the sealing time and sequence of structure post-cast strip, ensuring smooth construction, which constitute the core innovation technologies of this project.

Because the terminal features large-space design, a plane layout with underground high-speed railway tunnel, and high seismic performance requirements, the floors of the main terminal are reinforced with lots of stiffened steel structure, the total weight of which is more than 10000 t. Given the complicated connections of stiffened rebar and steel structure, digital construction technology

was fully adopted, and a new stiffened-structure joint construction technology route was developed: Applying BIM technology to model the joint of steel structure and rebar → determining the arrangement of rebar around the steel frame → finishing numerical controlled trepanning of steel bone and welding of steel connector in steel structure processing stage → using 3D BIM to dynamically display rebar installation sequence and guide site construction. BIM technology is used to simulate and optimize the hoisting of overweight members and the cross-construction process of stiffened members and concrete, thus achieving optimal construction scheme of stiffened structure, improved construction pre-control and efficiency, and reduced cost. For complex nodes, a fast connection joint is invented, solving a series of problems, such as difficult rebar arrangement at beam-column joints of stiffened beam-column structure, poor joint connection, complicated onsite connection operation, and multi-layer arrangement and dense cross of rebar with beam-column joints in non-orthogonal state. Finite element analysis of joints and test of joint type are conducted to prove the safety of stress bearing and force transmission of the joints.

#### 4 Integrated technique of interlayer shock isolation for super-large plane

The main terminal is super long and large and with a complex steel structure. The underground high-speed rail requires shock absorption and isolation. For these reasons, shock isolation technology is used in the core area of the main terminal. Shock isolation layer is set between the first underground floor and the first floor of the terminal. 1124 shock isolation rubber bearings are provided at the head of the structure column under  $\pm 0.000$  floor slab, along with 108 sets of elastic sliding plate bearings and 144 sets of viscous dampers, making the terminal as the world's largest shock isolation building.

In view of the main terminal's massive shock isolation system, BIM technology is used in the construction simulation of nearly 20 processes of shock isolation bearings to enhance the visibility and accuracy of techniques, make construction personnel better informed of the construction node, and shorten the process disclosure time. Considering the potential damages to shock isolation bearings caused by earthquake, fire and other external factors, a complete set of shock isolation bearing replacement technology is developed and tested.

As shock isolation layer is located between the inner floors of the building, there appears discontinuous setting on the top of the outer wall between the first floor and the underground floor. Also, the hang-down setting of stairs, elevators and escalators in the building by the first-floor structure make them completely separated from the

underground structure. To ensure adjacent but disconnected structures fit the deformation space, the main terminal is equipped with a large number of shock isolation trenches and seams. In the process of construction, a world's leading complete set of limited slip shock isolation trench devices are developed, consisting mainly of steel box isolation cover plate, pin hinge support, omnidirectional sliding ball support, limit adjustment wedge plate, and decorative cover plate.

#### 5 Construction technique of super-large plane roof with complex curved-surface steel mesh structure

The steel structure of the main terminal roof has a projected area of 180000 m<sup>2</sup>. As a spatial grid structure with free curved-surface, it is supported by 8 C-shaped columns, 12 sets of support tubes, 6 steel pipe columns and 5 sets of curtain wall columns. The roof has a maximum span of 180 m. The roof has a steel structure of large span, complex curve changes, high requirements for configuration control accuracy, and complex split-layer of underside concrete structure. Therefore, after comparison of multiple schemes and stress and deformation analysis with finite element calculation software, the construction principle of "partition installation, partition unloading, configuration control, deformation coordination and overall closing" is determined. Installation of the whole roof steel structure involved 26 times of block lifting, 13 times of in-situ assembly, 31 times of small closure, 7 times of unloading and one time of large closure. The length of the closure reaches 9008 m, and the number of docking interface is 8274, meeting design and specification requirements in docking accuracy. The weld length is about 190000 linear meters, and the qualified rate of spot weld inspection is 100%. The closing welding gap is less than 10 mm, and misalignment is less than 2 mm. In view of the big number of rod pieces of the roof's steel structure, the construction team developed prefabricated assembly technology of steel structure based on BIM and Internet of Things (IoT), integrated BIM, 3D laser scanning, and IoT sensors into an intelligent virtual installation system, and developed APP mobile platform and two-dimensional code recognition system, achieving real-time display of component status in BIM. In addition, a high-precision 3D engineering control network was established by combining 3D laser scanning technology with lofting robot with reference to BIM. Strictly control over configuration of grid erection, lifting and other stages ensures that the final configuration is consistent with the design model. Major innovation in steel structure processing and installation scheme is the key to the successful installation of roof truss in four months. Figure 2 shows the actual picture of spatial grid steel roof structure construction.



Fig. 2 Actual picture of steel structure roof truss construction.

## 6 Construction technique of super-large plane bilayer energy-saving metal roof with irregular curved surface

The roof of the main terminal is 568 m long from east to west and 455 m long from north to south, with a total area of about 180000 m<sup>2</sup>. There are 6 skylights and a central skylight roof, dividing the metal roof into 6 independent sections. The shape adopts free hyperbolic design, and the highest elevation of the roof is 50.9 m. The drop of the main terminal roof is about 20 m. Roof structure features a double-layer energy-saving metal roof. Technology innovation in the process of construction includes reverse modeling measurement techniques, achieving high altitude type finding and measurement and rapid lofting for roof with free-form surface. Moreover, purlin thermal stress reduction construction technology is developed to erase adverse effect of purlin system on roof steel structure caused by roof system temperature stress. High performance wind-resistant new bearing and plate construction technology passed the wind uncovering and high-speed wind tunnel test. The drainage technology of irregular free-form surface roof is studied through simulation and real test, and the roof drainage system has withstood the test of many rainy seasons. Hollow aluminum mesh glass, first invented in China, enables daylighting and shading function of the skylight roof as designed.

## 7 Key construction technology for decoration of large suspended ceiling of super-large plane terminal roof

The large ceiling of the terminal features a complex free-form surface which changes with variable curvatures. The large suspended ceiling bends down to join the ground

through both sides of the end of the bar-type skylight and 8 C-shaped columns. During the whole-process digital construction of the large ceiling, a full-digital BIM construction model is built by nonuniform rational B-spline mathematical method for controlling surfaces, and considering design model, grid configuration, operability and other factors. During construction, by picking plate units from the model, a full digital construction scheme from design to factory processing and then to site installation is achieved. In the large suspended ceiling construction, suspended ceiling and roof steel structure anti-rotation welding joint is invented. Unit-modular reverse installation technology is applied to ceiling keel and panel in large space under roof, which is initiated in China. Creative application of complex free-form surface roof large ceiling module unit space triangulation positioning installation technology, followed by adoption of 3D laser scanning leveling detection technology, ensured quality inspection and acceptance of curved-surface ceiling construction. The spatial curved-surface effect in the architectural design is achieved, perfectly materializing the modeling design concept of the roof. Figure 3 is a real photo of indoor large suspended ceiling.

## 8 Comprehensive installation technology for electromechanical engineering of super-large multi-purpose terminal

In view of the architectural features like large plane, large space, interlayer shock isolation, and “three departures and two arrivals” of the terminal, and the goals of being green and low-carbon, warm and comfortable, and intelligent and convenient, the whole process of electromechanical engineering construction adopts BIM technology which is coupled with problem-oriented approach and scientific research and innovation, realizing the perfect integration of safety, function and comfort. Figure 4 is

the BIM model of the electromechanical system on B1 floor.

### 8.1 Rain drainage for complex roof with super-large plane

Of the six relatively independent sections of the roof, the two pieces of roofing in the north area are symmetrical in east-west direction, and the four pieces of roofing in the south area are circumferentially symmetrical along the central point. Roof rain drainage technology featuring overall planning, zoning organization, orderly diversion, slice collection and siphon discharge is adopted to solve the problems of large catchment area, irregular flow direction, rapid water flow, and strong wind influence. The roof, according to its features, is equipped with gutter diversion sheet, overflow cofferdam, snow blocking

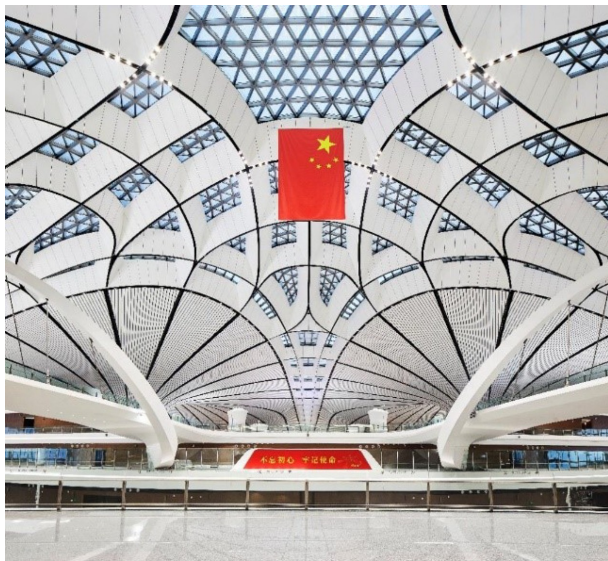


Fig. 3 Actual picture of large indoor suspended ceiling.

facilities, and snow melting cable. Safe combination of drainage structure and roof load, as well as integration of piping installation with roof steel grid enables the organic unity of safety and beauty, forming a complete set of installation technology for super-large plane complex roof drainage and snow-melting.

### 8.2 Displacement compensation of interlayer shock isolation electromechanical pipeline

The terminal’s electromechanical engineering, involving a total of 108 systems, features large amount of engineering and complex system. Most of the machine rooms are located in the shock isolation interlayer of B1 floor, with isolation bearings to completely separate the underground from the above-ground concrete structure. The maximum horizontal displacement between floors is designed to be 600 mm, requiring the electromechanical system to match the displacement between floors of the building structure to ensure the stability of the electromechanical system. Since there are no relevant technical standards and typical cases in China, the concept of “isolation compensation unit” is put forward, an engineering innovation that combines market compensation products and invention patents. By virtue of deepened combination, simulation and third-party testing, the construction team achieves large displacement compensation through the isolation layer and across the isolation joint, ensuring normal operation of electromechanical pipeline under the designed shockproof displacement, and filling the structural gap of shock isolation and large displacement compensation in China.

### 8.3 Modular assembly mechanical and electrical installation

In order to actively respond to national policies, advance

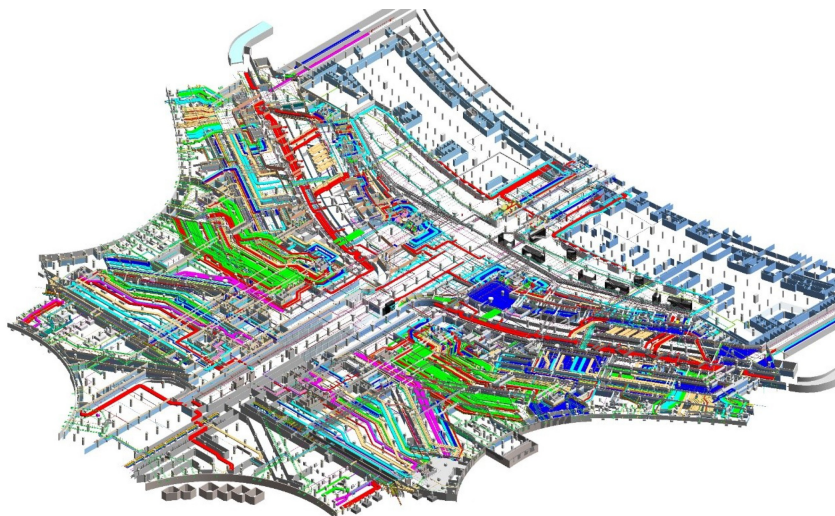


Fig. 4 BIM model of the electromechanical system on B1 floor.

modular prefabrication and assembly of electromechanical engineering, and improve installation accuracy and construction efficiency, innovative research and development is conducted in the temporary housing and the plumbing room of the terminal. For air conditioning and hot water supply for temporary housing, air source heat pump, circulating water pump, distribution box cabinet, control device and other equipment are effectively combined into a new energy module box for central cooling, heating and hot water supply that matches the end-use load. The module box is convenient to install and disassemble, highly efficient and energy-saving, and with a high reuse rate, which could ensure energy supply for office and living of more than 8000 people in the peak period of construction, directly saving electric energy of nearly 17 million yuan during construction. 3D deepening, 4D simulation, point cloud scanning, and IoT technology are applied to the plumbing room of the terminal. In-depth research on surveying and mapping lofting, remote control, error processing and other links gave birth to a complete standard procedure for modular assembly electromechanical installation and construction. Systematic study on module integration principle and module assembly error processing led to a series of patents on new energy integrated module box, module frame pump limiter, and prefabricated pipeline transportation device.

#### 8.4 Electromechanical installation and commissioning in super-large space

The core area of the terminal is a large-space environment consisting of large plane and multiple altitude differences, where port entry, check-in, security check, departure, and baggage claim, among other building functions are divided by region. Personnel density in each region changes dynamically with time, inbound and outbound flow, and flight allocation. Based on research, calculation,

summary, and simulation, the lighting distribution, control, installation and debugging technology of super-large space based on different functions is developed, which, coupled with natural lighting, ceiling diffuse reflection, and flight dynamic demand, maximizes the realization of green lighting. Based on large space temperature and humidity field simulation, air conditioning layout form in inner and outer areas, large-section fresh air delivery, large temperature difference air conditioning water and air transmission, and installation, control and commissioning techniques for terminal equipment are developed according to temperature, humidity, air quality and other requirements, creating a comfortable environment that is low-carbon and energy-saving.

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### 9 Safety supervision and intervention technology of terminal construction behaviors

Due to the large volume of the terminal, complex construction conditions, participants as many as 43000, and difficult interface management, security risks are relatively prominent. To effectively supervise on-site workers' operation behavior, the project team developed safety management information platform and intelligent site management system, used unsafe behavior monitoring technology based on computer vision, and put procedures with high risk in the construction process under all-round, real-time supervision. Regular assessment of management layer's safety leadership and safety culture exposed the corresponding management deficiencies behind high-frequency risk behaviors. Targeted interventions were devised to improve safety leadership and safety culture of project management team and strengthen management behavior, finally reducing unsafe operation behaviors. During the whole construction, no deaths occurred.