



White Paper

Advanced Demonstration of Fire
Protection Engineering for Steel Structures
at Chongqing Jiangbei International
Airport T3B Terminal

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Du Yong

Secretary-General of the Fire Protection and Corrosion Prevention Branch of the China Steel Structure Association

The special fire protection design for the steel structure of Chongqing Airport T3B Terminal, based on the conclusions of the special fire protection design assessment report, strongly supports the scientific, normative, and safety aspects of fire protection measures, setting a good example for similar projects. It is hoped that in future similar projects, designers will proactively conduct fire protection design for steel structures in accordance with the technical provisions of GB51249-2017 'Technical Code for Fire Protection of Steel Structures in Buildings.' Project owners should also optimize fire protection plans for steel structures based on this standard to enhance project economic efficiency, achieve effective resource utilization, and accurately implement fire protection measures. At the same time, we hope that fireproof coating product suppliers will actively enhance the advancement of their products, introducing more high-quality fireproof products that meet design objectives, thereby promoting significant progress in fire protection technology for steel structures in China's landmark projects and large public buildings.

Chen Zhiqiang

Deputy Chief Engineer of China Southwest Architectural Design and Research Institute

The promulgation and application of GB51249-2017 reflect a fundamental shift in the conceptual framework of fire protection design for steel structures. In the old standards, structural design and fire protection design were relatively independent, with fire protection design primarily relying on laboratory test data of fireproof materials on standard components. In contrast, the new standard organically combines structural fire resistance with structural load characteristics, emphasizing the unity of fire protection design and structural design, and pursuing a balance in overall costs rather than merely minimizing the amount of steel or coating used. This shift in design philosophy provides a more scientific and economical solution for fire protection in steel structures. During the implementation of the T3B Terminal project, all parties deepened their understanding of the new standard through extensive communication and discussion. Through relevant review processes, the core requirements of the new standard and its practical application value in engineering were ultimately clarified, facilitating the smooth implementation of the project.

Song Qianyi

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The focus of the fire protection design for the steel structure of T3B Terminal is on the application of concrete-filled steel tubes combined with intumescent fire protection coatings. Since 2016, the China Southwest Architectural Design and Research Institute has collaborated with a research team led by Professor Han Linhai from Tsinghua University to form a joint research team. They systematically conducted typical experimental studies and theoretical analyses, addressing the lack of technical basis for using intumescent fire coatings as fire protection measures for concrete-filled steel structures under fire resistance conditions of 2.0 to 3.0 hours. The research results have been adopted by national standards such as GB/T51446 and international standards like ISO 16521. In the T3B project, this research team further investigated the fire resistance performance of structural components such as circular columns, conical columns, and shuttle-shaped columns protected by intumescent fire coatings. They resolved key technical issues regarding whether the composite fire protection coating system formed by leveling materials and intumescent fire coatings could meet the fire protection requirements and reliability for a 3.0-hour fire resistance limit.

Xie Junqiao

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The fire protection design for the steel structure of T3B Terminal not only needs to meet basic safety requirements but also must consider the aesthetic appeal of the building and the owner's economic demands. We adopted different fire protection schemes for exposed and concealed steel structures to enhance economic efficiency. For the exposed steel structures, which have higher aesthetic requirements, we implemented more refined designs and took measures to ensure that the intumescent fire coating applied to the concrete-filled steel structures meets the fire resistance limit requirements. Compared to non-intumescent fire coatings, intumescent fire coatings are smoother and lighter. After thorough technical validation, they not only meet the fire protection design requirements based on fire load-bearing calculations under the new standards but also better achieve the aesthetic expression of modern architecture.

Introduction

With the rapid development of large public buildings, steel structures and concrete-filled steel tube composite structures are increasingly being applied in projects such as airport terminals, transportation hubs, and sports venues. These large buildings not only need to meet high fire resistance design requirements but also must consider visual aesthetics and cost-effectiveness, which places higher demands on fire protection for steel structures.

In this context, China introduced its first national standard for fire protection of steel structures based on fire load-bearing calculations in 2017: GB51249-2017 'Technical Code for Fire Protection of Steel Structures in Buildings.' This standard clearly requires that fire protection design for steel structures be based on the fire load-bearing capacity calculations of steel components, thereby achieving a more scientific, quantitative, and refined design methodology.

As a fire protection project strictly adhering to the technical framework of GB51249-2017, the fire protection project for the steel structure of Chongqing Jiangbei International Airport T3B Terminal (hereinafter referred to as 'T3B Terminal') has implemented the new standards in fire protection for steel structures. Throughout the processes of cost estimation, design, construction, quality inspection, and acceptance, various challenges were encountered in the implementation of the new technical system. The management methods, coating technologies, and knowledge interpretations of all parties underwent iterative upgrades, providing important technical references and lessons for future similar projects.

At the same time, the T3B Terminal fire protection project has generated new technical applications in the field of fire protection for steel structures based on its engineering characteristics. These include the validation of the application of intumescent fire coatings with leveling processes on concrete-filled steel columns to meet the 3.0-hour fire resistance limit; the selection of leveling materials compatible with fireproof and anti-corrosion coating systems;

and research on the application of intumescent fire coatings on structural components such as circular columns, conical columns, and shuttle-shaped columns to meet the 3.0-hour design fire resistance limit.

The T3B Terminal is currently the largest single satellite hall in the world, with a total construction area of approximately 360,000 square meters, consisting of a main building and four concourses. The main building has four above-ground floors and two underground floors. Once operational, Chongqing Jiangbei International Airport will accommodate an annual passenger throughput of 80 million, 580,000 aircraft takeoffs and landings, and a cargo throughput of 1.2 million tons.

The fireproof coating project for the terminal's steel structure began in February 2023 and lasted for about one year, covering the central hall roof truss, curtain wall steel structures, and indoor and outdoor steel columns in Area M. The design work for the fire protection scheme of the terminal's steel structure was led by China Southwest Architectural Design and Research Institute Co., Ltd. (hereinafter referred to as 'China Southwest Institute'), which engaged in research discussions with experts and scholars in the field of fire protection for steel structures from various universities from the design stage. They also collaborated closely with leading coating companies and construction units. The fireproof coating technology for this project was provided by PPG (NYSE: PPG), with the professional contractors being Rod Hansen (Beijing) International Construction Co., Ltd. and Beijing Urban Construction Tianning Fire Protection Co., Ltd."



01 Evolution of Fire Protection Design Methods in China

Steel structures, with their advantages of high strength, lightweight, and ease of construction, have become the core support system for ultra-high-rise buildings, large-span venues, transportation hubs, and industrial facilities in China. Their application spans landmark projects such as Beijing Daxing International Airport, Chongqing Jiangbei International Airport, and Shanghai Tower, significantly enhancing building performance, aesthetics, and construction speed. Additionally, driven by the 'dual carbon' goals, steel structures, as recyclable green building materials, are accelerating the replacement of traditional concrete structures and becoming a key force in promoting low-carbon transformation in the construction industry.

However, fire protection for steel structures is recognized as a challenging aspect of fire safety, and the design of fire protection is crucial for ensuring the safety of people's lives and property. The fire resistance of metal substrates such as steel structures and aluminum profiles is relatively low; without protection, they can reach critical temperatures in just 5 to 15 minutes. This can lead to the loss of load-bearing capacity and regional fire isolation capability, causing structural deformation and potential collapse, which obstructs escape routes and emergency rescue efforts. Therefore, fire protection engineering for steel structures is vital for safeguarding public safety.

With continuous advancements in building technology and the diversification of building forms, the fire protection design methods for steel structures in China have evolved from experimental methods to computational methods, and the technical system has gradually transitioned from local standards to national standards.

1.1 Shift in Fire Protection Design Concepts

Before the implementation of GB51249-2017, fire protection design for steel structures in China primarily relied on methods based on the conclusions of standard steel beam tests, determining the thickness of fireproof coatings based on fire tests of standard specimens (such as I36b I-beams).

This method has certain limitations, as it does not fully consider the mechanical response of steel structural components and the overall structure under fire conditions. High temperatures during a fire can not only reduce the strength of steel but also cause overall structural deformation and redistribution of internal forces, which standard specimen tests cannot accurately reflect. This method overlooks actual loads, cross-sectional differences, and the thermal coupling effects of the overall structure, leading to insufficient protection or excessive waste. Particularly for irregular steel structures in large-span buildings, directly using standard specimen fire test data may not ensure the fire safety of the actual structure.

In the early 1990s, Professor Li Guoqiang from Tongji University proposed a fire protection design method based on fire load-bearing calculations, emphasizing the need to incorporate the actual stress state of components to assess their fire load-bearing capacity. This concept marked a shift in China's fire protection design for steel structures from standard testing methods to calculation-based design methods.

In 2007, the project for GB51249 was initiated, and it was officially implemented in 2018. The standard clearly requires that fire protection design for steel structures be based on the fire load-bearing capacity calculations of steel components, achieving a more scientific and refined approach to fire protection design.

The implementation of GB51249-2017 provides detailed calculation methods for fire protection design. The new standard is applicable to various component forms such as beams, columns, and braces, and it covers different cross-sectional sizes and load conditions. Designers can use the calculation methods in the standard to accurately determine the fire protection parameters required for specific engineering needs.

This calculation-based fire load-bearing assessment not only enhances the scientific nature of the design but also significantly improves the safety of steel structures in fire situations.

The new standard also signifies the refinement and elevation of China's fire protection technology system for steel structures from local standards to national standards. In 2004, Shanghai was the first to issue local construction regulations that specified requirements for fire protection technology for building steel structures. In 2006, the China Engineering Construction Standardization Association (CECS) also released relevant technical specifications.

These standards provided initial technical support for fire protection design for steel structures, but with the rapid development and high-quality demands of building steel structures today, more advanced standards are needed to guide industry development.

It can be said that the promulgation of GB51249 has enhanced China's intellectual property rights and international discourse power in the field of fire protection design for steel structures, providing technical support for the high-quality development of steel structure engineering in China.

1.2 Implementation of GB51249-2017: A Case Study of T3B Terminal Fire Protection Engineering

The Chongqing Jiangbei International Airport T3B Terminal strictly adheres to the requirements of GB51249-2017 for large-span steel structure building projects, providing valuable practical experience for fire protection in large space steel structures. This project conducted a specialized fire safety assessment addressing the unique fire safety characteristics of the terminal's large space, which was divided into two main parts: the first part focuses on active fire protection.

That is, building fire protection design; the second part is passive fire protection, which involves the fire resistance calculations and design of steel structures in the event that active fire protection fails or does not meet expected goals.

In terms of passive fire protection, the project follows the requirements of GB51249-2017, focusing on the thermal insulation performance parameters and thickness of fireproof coatings, and ensuring the safety of the fire protection scheme through fire load-bearing capacity calculations.

Under the old standard system, the thermal insulation performance of fireproof coatings was typically assessed based on the time it takes for steel to reach a critical temperature of 540°C, making it difficult to directly incorporate the load levels and load factors of actual components into the evaluation.

Under the new regulations, fireproof coatings must undergo testing for equivalent thermal resistance parameters to achieve precise calculations based on fire load-bearing capacity. The equivalent thermal resistance parameters are unique to specific fireproof coating specifications and application thicknesses, and their third-party certification reports can be applied across projects. However, the application thickness must be determined based on the specific project's fire scenarios, temperature distribution, and the results of fire load-bearing capacity calculations, in accordance with the test or evaluation data for specific products as outlined in GB51249-2017.

The design of the steel structure and the fire protection design for the T3B Terminal both prioritize the requirements for fire resistance limits (safety), cost considerations (economy), and aesthetic requirements (appearance) as guiding design principles. Among these, safety requirements must be met through compliance with the fire load-bearing capacity calculations under the new regulations, which presents challenges across various project phases, including cost estimation, design, construction, quality inspection, and acceptance. Throughout the implementation of this technical system, the management methods, coating technologies, and knowledge interpretations of all parties involved have undergone iterative upgrades.

The fire protection project for the steel structure of T3B Terminal primarily focused on the following two technical aspects:

- Based on relevant research findings and standards (GB/T51446, ISO 16521), it was concluded that the use of intumescent fire coatings on concrete-filled steel components can achieve a fire resistance limit of no more than 3.0 hours. Further research was conducted on the effectiveness and reliability of applying intumescent fire coatings with leveling processes to concrete-filled steel columns, as well as determining which leveling materials would ensure compatibility with the coating system.
- The steel structure of the T3B Terminal involves a significant number of special-shaped concrete-filled steel columns, such as conical and shuttle-shaped columns. Building on previous research findings, further validation and refinement were conducted to determine whether the application of intumescent fire coatings on these special-shaped structural columns could meet the technical basis for a 3.0-hour design fire resistance limit.

At the same time, GB51249-2017 explicitly incorporates fire protection requirements for large-span steel structures. The standard specifically outlines technical provisions for building spaces that reach certain spans and heights, particularly for the performance-based design of prestressed steel structures.

In the practical application of the T3B Terminal, fire protection calculations based on standard fire temperature rise curves resulted in excessively high equivalent thermal resistance values, leading to fire coating thicknesses that exceeded reasonable limits, thereby affecting the durability and cost-effectiveness of the fire protection project. To address this, GB51249-2017 allows projects to use different temperature rise curves for fire resistance calculations based on the characteristics of large space fires.



02 Challenges and Solutions in Fire Protection Design for T3B Terminal

2.1 Overview of Structural Design

In the overall design of the steel structure, balancing safety, economy, and aesthetics is a key task. It is essential to avoid excessive use of expensive materials and processes in pursuit of form while ensuring that cost control does not compromise architectural aesthetics. Specifically, an economical steel truss structure is employed in large areas, while detailed designs are implemented in critical locations such as skylights and exposed structural columns to balance functionality, economy, and aesthetic needs.

The steel structure of this project is primarily divided into two parts: the first part is the steel roof system of the terminal, which features a wavy, stepped shape with a large internal span, thus high-strength steel columns are selected as vertical supports. The second part consists of the terminal's interior structure, where steel structures are used in the 'room within a room' areas and the 48-meter-long Dalian Bridge section to meet construction schedules and roofing process requirements.

The roof design combines a double-layer curved truss with a large-span spatial truss, harmonizing the overall shape with the architectural form reminiscent of a 'Kunpeng spreading its wings.' The skylight section is cleverly connected through trusses and grids, satisfying mechanical performance requirements while achieving an expression of architectural aesthetics. Additionally, for exposed steel structures, such as bearing nodes and indoor gravity column nodes, the design team conducted meticulous node designs to ensure they integrate seamlessly with the overall building, presenting a visually appealing and grand effect.

In large-span areas such as the M Zone hall, concourses, and roof edges, concrete-filled steel columns are used as vertical support structures. Concrete-filled steel columns are a special type of load-bearing component characterized by hollow steel tubes filled with concrete, allowing the steel tube and concrete to bear loads together. Compared to ordinary steel columns, they offer higher load-bearing capacity, seismic performance, and fire resistance.

2.2 Fire Protection Strategies

The design of fire protection for the steel structure of the T3B Terminal also focuses on balancing fire resistance limit requirements, cost considerations, and aesthetic demands. In traditional structural engineering practice, the primary responsibility of structural engineers is to ensure structural safety, and fire protection design is often relatively straightforward: engineers specify the fire resistance requirements for components, and subsequent work is completed by product engineers.

In the T3B Terminal project, structural engineers not only need to conduct safety designs based on fire load-bearing capacity calculations but also must consider the aesthetic appeal of the building and the economic requirements of the owner. Particularly for exposed concrete-filled steel columns with a fire protection rating of Level 1 (design fire resistance limit of 3.0 hours), balancing visual effects, construction costs, and timelines while meeting fire resistance time requirements became the focal point for the design team and a major challenge for this project.



2.2.1 Selection of Fire Protection Materials

Steel structures and steel-concrete composite structures typically require fire protection measures to meet the design fire resistance limits in practical engineering. The use of fireproof boards or wall enclosures can significantly affect the scale and aesthetics of building components, failing to meet visual effect requirements. Therefore, the design team opted for fireproof coatings as the fire protection solution for the steel structure of the T3B Terminal.

Fireproof coatings can generally be divided into two types: intumescent and non-intumescent fireproof coatings. Non-intumescent fireproof coatings (also known as thick film coatings) are inorganic materials, such as gypsum-based or cement-based coatings, whose fire resistance can meet the 3.0-hour fire resistance limit by increasing the thickness of the coating.

Although they are cost-effective, their appearance is relatively rough and requires additional aesthetic treatment, which increases material and labor costs. For example, the appearance can be improved through decorative methods such as applying putty, but poor construction quality or significant temperature fluctuations can lead to issues such as cracking and peeling, which affect the building's aesthetics. More importantly, areas where the coating has peeled off may severely diminish fire protection performance and cause corrosion of the steel material. Additionally, thick fireproof coatings can increase the weight of the truss, placing an extra burden on the supporting structure.

Intumescent fireproof coatings are fire protection materials that expand and foam at high temperatures to form a dense carbonized layer through chemical reactions. Their main components include carbonizing agents, foaming agents, and catalysts. At room temperature, the coating appears as a thin film, and after application, the surface of the steel structure is smooth and aesthetically pleasing.

When exposed to fire conditions, the foaming agents in the coating decompose to produce gas, and the carbonizing agents, under the action of the catalysts, form a stable carbonized layer. High-performance intumescent fireproof coatings can expand to 20-40 times their original volume, creating a thick protective layer that effectively insulates against heat transfer and delays the heating and deformation of the steel.

However, the foaming mechanism of intumescent fireproof coatings also presents certain limitations. According to GB 14907-2018 'Fireproof Coatings for Steel Structures,' the recommended usage scenario for intumescent fireproof coatings on steel structural components should not exceed 2.0 hours, as the foaming layer may be at risk of cracking and peeling. Intumescent fireproof coatings with insufficient aging resistance may prematurely foam, chalk, or delaminate during the application process, leading to a decline in protective performance. In a fire, intumescent fireproof coatings must foam effectively at high temperatures to form a strong and well-bonded carbon layer to achieve sufficient insulation efficiency.

Based on the performance characteristics of the aforementioned intumescent and non-intumescent fireproof coatings, the fire protection project for the steel structure of the T3B Terminal adopted differentiated fire protection methods for the steel structures in different areas. To achieve a balance of functionality, aesthetics, and economy, more economical non-intumescent fireproof coatings were selected for the hidden steel structures that are covered by decorative finishes. For exposed steel structures that are within the passengers' line of sight and significantly impact visual effects, such as columns and certain roof trusses, intumescent fireproof coatings that meet aesthetic requirements were used.

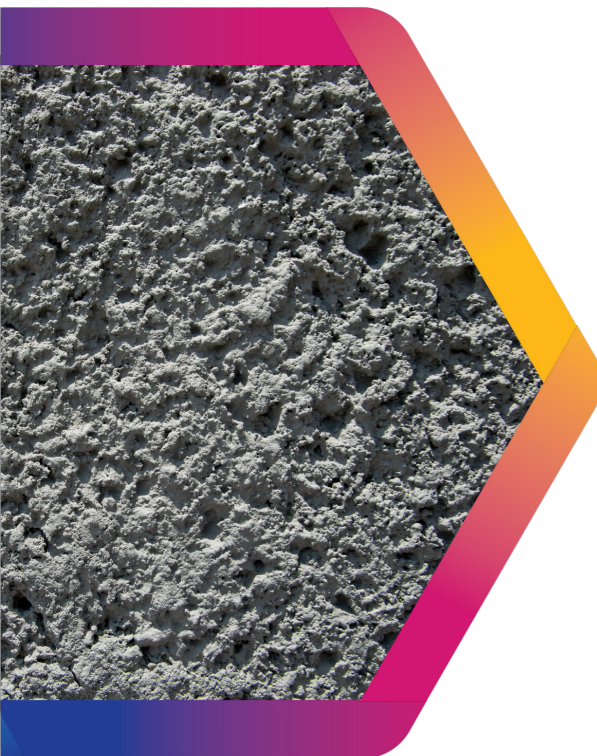
This approach also presented challenges. As mentioned earlier, the use of intumescent fireproof coatings on steel structural components is generally not recommended to exceed 2.0 hours, while the design fire resistance limit for the exposed concrete-filled steel columns supporting the hall and concourses of the T3B Terminal is 3.0 hours. To address this issue, the project utilized a combination of steel and concrete materials to enhance the fire resistance of the structural columns, and then applied intumescent fireproof coatings as the fire protection layer.

Additionally, in practice, the larger concrete-filled steel columns consist of multiple segments of pipe and plate splices, with noticeable exposed weld heights in certain areas that are difficult to grind. The coating technical solution must achieve a level surface on the steel structure and provide a substrate for the application of fireproof coatings, but the current standards lack corresponding technical provisions.

Under this technical requirement, intumescent fireproof coatings were selected as the fire protection material, forming a composite coating structure in conjunction with anti-corrosion measures and an additional leveling material layer. The effectiveness and reliability of the protected concrete-filled steel columns in meeting the 3.0-hour design fire resistance limit, as well as whether the selected leveling materials can work well with the fireproof and anti-corrosion layers at high temperatures to ensure the fire safety of the building structure, became the focal point of this project's validation.

2.2.2 Key Focus on Fire Protection Materials

Compared to pure steel structures, concrete-filled steel columns benefit from a synergistic load-bearing mechanism between the core concrete and the steel. The concrete can absorb heat conducted to the steel components during a fire, thereby delaying the temperature rise of the steel components, which results in a higher fire resistance limit than that of pure steel components. Given the high fire resistance limit requirements for the T3B Terminal project, concrete-filled steel columns still require additional fire protection measures to meet the 3.0-hour design fire resistance limit, while also satisfying high aesthetic standards.



Intumescent fireproof coatings have demonstrated performance advantages as fire protection measures for concrete-filled steel structures, supported by certain theoretical research findings and practical application experiences. Since 2016, the China Southwest Architectural Design and Research Institute has collaborated with a research team led by Professor Han Linhai from Tsinghua University to form a research team. Starting with the Qingdao Jiaodong International Airport, and continuing through the Beijing-Zhangjiakou High-Speed Railway Qinghe Station and Chengdu Tianfu International Airport, this team has conducted a series of related research and validation efforts for the T3B Terminal project at Chongqing Jiangbei International Airport.

The data and experimental and theoretical research results obtained from these efforts have addressed the lack of technical basis for using intumescent fire coatings as fire protection measures for concrete-filled steel structures under fire resistance conditions of 2.0 to 3.0 hours, providing strong support for the implementation of this technical solution. The relevant research findings have been adopted by GB/T51446 'Technical Standards for Concrete-Filled Steel Tubular Hybrid Structures' published in 2021 and the International Organization for Standardization standard ISO 16521 'Design of Concrete-Filled Steel Tubular (CFST) Hybrid Structures' published in 2024, supporting the conclusion that concrete-filled steel components using intumescent fire coatings can achieve a design fire resistance limit of 3.0 hours.

Based on these research results, the T3B terminal steel structure fire protection project further demonstrated the following two focuses:

Focus 1: During the manufacturing and processing of large steel structural components, due to the massive size of the structures (such as columns that are 20 meters high and 2-3 meters in diameter),

it is typically not feasible to achieve seamless integrated forming in the factory; instead, segmental processing and on-site assembly are required. This process generates a large number of transverse and longitudinal welds. Due to processing precision and techniques, the local excess weld height of the welds may reach 3-5 millimeters or even higher, making it difficult to adequately grind them on-site.

Under these conditions, if intumescent fire coatings are directly applied, the thin film of the coating may struggle to cover the raised portions of the welds. If the intumescent fire coating is used for leveling directly, it may result in an uneven coating that affects the overall stability of the expansion and foaming, necessitating additional leveling treatment.

The design of the intumescent fire coating application has strict regulations and features an integrated coating system. Current standards do not provide technical provisions for the joint implementation of intumescent fire coatings with coatings other than those for anti-corrosion. Furthermore, relevant certification tests or standard fire test reports do not consider additional coating materials. When designing the leveling coating, it is necessary to consider the compatibility of the leveling materials, fireproof coatings, and anti-corrosion layers (primer, intermediate paint, and topcoat), as well as to assess the impact of the leveling materials on the overall fire protection performance.

The research team proposed various processes and structural schemes and conducted fire resistance limit tests on concrete-filled steel columns protected by a composite coating formed by the leveling coating, intumescent fire coating, and accompanying anti-corrosion paint, to verify whether the layered coating scheme could achieve a smooth appearance and meet the 3.0-hour design fire resistance limit.

Based on the validation research, a layered coating structure that meets the design fire resistance limit requirements was proposed, demonstrating the compatibility of the selected leveling materials with the intumescent fire coating and the accompanying anti-corrosion paint.

Focus 2: Fire safety performance is primarily influenced by two factors: the rate of temperature rise and temperature distribution of the components during a fire, and the degradation characteristics of mechanical performance parameters such as strength and elastic modulus of the structural materials during heating, as well as the redistribution of internal forces under the combined action of steel and concrete. Unlike previous projects that mainly focused on uniform cross-section columns, the T3B project features a variety of structural column types, including uniform cross-section columns, conical columns (thicker at the base and thinner at the top), and shuttle-shaped columns (thinner at both ends and thicker in the middle). These columns exhibit significant differences in geometric characteristics, load conditions, and boundary constraints, leading to varying stress states and temperature rise patterns.

To ensure that the special-shaped structures can safely bear external loads within the 3.0-hour time frame, the research team designed fire tests for typical conical and shuttle-shaped columns, conducting load limit tests under loading conditions and collecting data on the temperature rise patterns and temperature field distribution of the components during standard fire conditions.

Based on the experimental data, the research team established finite element analysis models to conduct detailed calculations and analyses of components with different diameters, heights, and constraint conditions. The research findings provide reliable technical support for the fire protection design of structural columns in practical engineering.





2.2.3 Fire protective coating scheme for steel structure of T3B terminal

The passive fire protection scheme for the T3B Terminal project selected PPG STEELGUARD® FM550 intumescent fireproof coating, which is applied in areas including the 80m × 552m roof truss of the central hall in Area M, the 48m Dalian Bridge, and the indoor and outdoor concrete-filled steel columns.

To ensure that its performance meets the fire protection requirements for the terminal's steel structure, the design team conducted a specialized assessment and performed fire load-bearing capacity calculations. Based on the calculation results, the design parameters and structure for the PPG *Steelguard* FM550 intumescent fireproof coating were finalized.

Regarding the issue of excess weld dimensions that require leveling, the proposed coating system includes: applying leveling materials, intumescent fireproof coatings, polished topcoat materials, and weather-resistant fluorocarbon and polyurethane topcoats sequentially over the anti-corrosion primer and intermediate paint.

During this process, PPG provided third-party certified equivalent thermal resistance design parameters, which effectively supported the load-bearing capacity calculations for the fire protection of the steel structure.

2.3 Implementation Challenges and Solutions

In the context of implementing GB51249-2017 "Technical Code for Fire Protection of Steel Structures in Buildings," the Chongqing Airport T3B Terminal project faced numerous challenges during the design, construction, and acceptance phases. The introduction of the new standard marks a shift in China's fire protection design for steel structures from traditional empirical models to a more scientific approach, but it also brings complex issues during the transition from old to new standards.

2.3.1 Cost estimation phase

Under the implementation of GB51249-2017, traditional cost estimation units often base their cost indicators or estimates on the experiences summarized from the old standards. Directly applying these to the new standards may lead to discrepancies. For example, the new standard requires the cost estimation department to adjust the cost of fireproof coatings based on equivalent thermal resistance parameters, but due to the lack of corresponding guiding prices, the cost estimation department finds it difficult to execute.

To address this issue, the design team optimized the structural design during the drawing phase. Taking the truss structure as an example, the normal equivalent thermal resistance required for design is 0.3. However, if measured against the traditional standard of a 1.5-hour fire resistance limit, the coating thickness would need to be increased by 1.5 to 2 times, leading to a significant cost increase and making implementation challenging.

Therefore, the design team utilized the temperature rise curve of large space fires, which is characteristic of airport terminal buildings. Generally, the standard fire temperature rise curve (e.g., reaching over 600°C within 30 minutes) is more applicable to indoor spaces with a height of 3-4 meters. In contrast, large space buildings like airport terminals, due to their high ceilings, good ventilation, and limited combustible materials, experience a slower fire temperature rise (e.g., reaching less than 400°C within 30 minutes), significantly reducing the thermal load pressure on components.

Since the standard fire conditions are more stringent than what may actually occur in civilian large space building structures, designing fire protection for steel structures in large spaces based on standard fire conditions has a considerable economic impact. Through expert validation, the design team adopted a temperature rise curve suitable for this project and combined it with the fire load-bearing capacity calculation methods outlined in GB51249-2017,

optimizing the equivalent thermal resistance and coating scheme for the fireproof coatings on the truss roof steel components, achieving the fire protection design goals within the established cost range. Therefore, using temperature rise curves that align with the fire characteristics of different building spaces is an effective way to enhance the scientific and economic aspects of fire protection design for large space steel structures.

2.3.2 Bidding process

The bidding phase for fireproof coatings in this project encountered similar issues to those in the cost estimation phase, specifically regarding the transitional challenges in the application and implementation of the equivalent thermal resistance parameters in the new national standards.

In traditional design paradigms, coating manufacturers primarily focus on fire resistance limits measured in time under standard fire conditions. As a key parameter introduced in the new standards, equivalent thermal resistance represents a completely new dimension for all parties, making it difficult to become a direct pricing standard in a short time.

Thus, during the bidding phase, even though the design drawings specified the equivalent thermal resistance parameters as required by the standards, the existing quotas were difficult to apply directly during the preparation of the cost estimates. For example, different components require different equivalent thermal resistances under the same fire resistance limit, which directly affects the thickness and cost of the fireproof coatings. If construction units or material manufacturers bid according to the old standards, they may face either positive or negative cost deviations. The resolution of this issue relies on communication and discussion among all parties. Through multiple reviews and coordination, the project was ultimately ensured to progress smoothly and meet high-quality standards.

Currently, not all fireproof coating manufacturers possess complete technical data, so the design team needs to base their decisions on the mainstream products available in the market.

Chongqing Jiangbei Airport T3B Terminal uses six PPG products to form a protection system on the main steel structure, including:

- PPG SIGMACOVER® 410 high solid epoxy paint
- PPG STEELGUARD® FM 550 intumescent coating
- PPG PSX® 500 engineered siloxane coating
- PPG SIGMADUR™ 2800 fluorocarbon paint
- PPG SIGMADUR™ 550 polyurethane coating
- PPG SIGMACOVER® 1100 with excellent coating crack resistance



Initial designs are conducted based on the conventional technical standards of the products, followed by detailed adjustments according to specific manufacturers. The current quota system needs to further clarify the specific pricing methods for equivalent thermal resistance to address the challenges encountered in the practical implementation of the new standards.

For coating manufacturers, the implementation of the new standards means that they need to provide complete technical documentation that complies with the new regulatory framework to design institutes and owners. Compared to the old standards, the new system significantly increases the requirements for manufacturers' documentation, as it must cover detailed data under various combinations of application conditions, resulting in a substantial increase in the overall data volume.

At the same time, the application of equivalent thermal resistance also imposes higher performance requirements on manufacturers regarding coatings, including broadening the range of equivalent thermal resistance for intumescent fireproof coatings, for example, exploring values beyond the current 0.28 and 0.3 to meet more complex design needs. Additionally, high-quality manufacturers can provide technical parameters and aesthetic effects achievable at different costs, helping design teams balance structural safety, cost control, and aesthetic enhancement. This raises the overall capability requirements for material suppliers.

2.3.3 Quality Inspection and Acceptance Phase

During the bidding and acceptance processes as well as during the validation of fire protection schemes, corresponding fire resistance tests must be conducted by qualified testing organizations. Traditional formal testing reports typically use the I36B standard component specified in GB14907-2018 "Fireproof Coatings for Steel Structures" for fire resistance testing. In the implementation of GB51249-2017, to align with the fire protection design concept based on fire load-bearing capacity calculations, it is necessary to convert the results obtained from traditional formal testing, which are measured in terms of fire resistance time, into equivalent thermal resistance parameters using standard formulas.

As the implementation progresses, issues gradually emerge. Due to the incomplete establishment of the new standards, many manufacturers' experimental data do not yet cover the equivalent thermal resistance ranges required for design, leading to discrepancies in practical applications. Additionally, testing equipment may not meet the testing requirements for large components, such as the load ratios for two-point or three-point bending tests not matching actual engineering conditions.

For manufacturers, generating parameters that comply with the new standards and conducting tests under conditions where supporting products and coating performance verification have not fully transitioned to the new standards is an urgent issue that needs to be resolved. Strictly speaking, testing must be conducted by qualified testing units that issue authoritative reports, and a significant amount of data must be collected through extensive testing, which requires considerable time and resource investment.

In the T3B Terminal project, PPG, as the coating manufacturer, collaborated with the professional teams from Guangxi University and China Southwest Architectural Design and Research Institute to conduct fire resistance tests on concrete-filled steel columns at the Tianjin Fire Research Institute. The fire resistance testing cycle is lengthy, taking over a year from sample preparation, combustion testing, to final review and obtaining the validation report.

After the completion of the fireproof coatings, decorative leveling materials, and topcoats, a curing period of 60 to 90 days is required. Additionally, the combustion testing phase requires queuing at the testing institution, and after testing is completed, there is a waiting period for the issuance of the testing report, which typically takes two weeks to three weeks.

Once the testing report is issued, it must be further analyzed and evaluated by experts from universities. After the report is formally submitted to the command center, third-party experts are invited to review it, and only after a comprehensive assessment of the data in the report can a final conclusion be reached.





The 'integrated' three elements demonstrated in the fire protection project for the steel structure of the T3B Terminal at Chongqing Airport are not only factors contributing to the success of the project but also represent an important development direction for the future of fire protection in steel structures.

3.1 Merging Structural and Fire Protection Design

Based on fire load-bearing capacity calculations, structural fire protection design is a refined, differentiated, and quantitative design method that is essential for ensuring the fire safety of structures and the scientific and rational nature of fire protection design.

Before the implementation of GB 51249-2017, fire safety issues for large space steel structures were primarily addressed through performance-based fire protection design approaches. The specific methods were based on component fire resistance tests to assess whether the fire load-bearing capacity of building steel structures met safety requirements.

The implementation of GB51249-2017 introduced more advanced fire protection design concepts, requiring the overall building space and structural stress states to be included in fire resistance calculations, and fireproof coating schemes to be selected based on fire resistance limit requirements. This represents a significant departure from the previous model, which only specified fire resistance ratings in design drawings.

In the traditional model, the work of structural designers and fire protection product engineers was relatively independent. However, the new standards require designers to complete overall fire protection calculations during the design phase and reflect the calculation results in the drawings. This shift is technically more advanced and places higher demands on all parties involved in the project.

Currently, the conceptual shift of GB51249-2017 has gradually been accepted by the industry, but its implementation still requires structural engineers to enforce it in engineering design. The experiences gained from the T3B project will help promote further refinement of the standards.

For example, since GB51249-2017 does not yet clearly specify how to accurately obtain the equivalent thermal resistance parameters for intumescent fire coatings, especially for specific values related to different cross-section components, there is a certain complexity in engineering practice. Although GB14907-2018 "Fireproof Coatings for Steel Structures" provides experimental methods for type testing, the standard steel beam cross-section shapes and load conditions do not fully cover the diverse design conditions and parameters of steel components in actual engineering. Therefore, the equivalent thermal resistance parameters proposed during the design phase may be contentious and require further improvement through standard upgrades or supplementary experimental methods.

Additionally, there are industry standards such as CECS that have discrepancies with national standards in certain details. Design institutes typically prioritize national standards, but upstream and downstream units, including manufacturers, cost estimation, and acceptance units, still need to continuously adapt to the implementation of the new national standards.

3.2 Integration of Production, Education, Research and Application in Fire Protection

The enhancement of technical concepts in the new standards means that the implementation process requires extensive learning and practical experience accumulation, involving close communication among various entities, including owners, design institutes, cost estimation departments, research institutions, product manufacturers, construction parties, acceptance organizations, and industry associations. The T3B Terminal project has built a bridge between standards and engineering applications through multi-party collaboration, while also exposing some issues of "disconnection" in certain industrial links.

For instance, domestic universities still have deficiencies in teaching the fundamental theories of structural fire protection, making it difficult to adapt to the rapid development of structural fire protection engineering applications. Particularly in undergraduate or higher-level education, there has been a long-standing absence of systematic courses related to the fire resistance of structures.

The inadequacies in the education system necessitate strengthening the knowledge base of structural engineers regarding the fire resistance performance of steel structures. Currently, knowledge related to fire protection for steel structures is still primarily held by research teams in higher education institutions or engineering consulting companies with international experience.

Moreover, under the technical framework of GB51249-2017, coating manufacturers need to provide design institutes and owners with more detailed product performance reference data. However, this involves a substantial amount of product development work and third-party testing data, placing higher demands on both manufacturers and testing units. How to improve the product performance indicator system within this framework and develop new products that meet engineering requirements is a significant challenge faced by coating companies.

To further promote the development of fire protection technology for steel structures, it is essential to strengthen the connection between education and industry, encouraging universities to develop courses on structural fire resistance to address the shortcomings in the education system. At the same time, coating companies should be encouraged to refine product performance indicators under the GB51249-2017 technical framework and develop new products that meet engineering application needs, facilitating close integration of the upstream and downstream industrial chains.

Additionally, collaboration between design institutes and research institutions is crucial. In recent years, design institutes have increasingly collaborated with domestic and international research institutions, university research teams (such as those from Tongji University and Tsinghua University), and relevant units like the Tianjin Fire Research Institute and Sichuan Fire Research Institute under the Ministry of Emergency Management. Together, they have promoted the formulation, revision, and improvement of relevant standards during practical implementation.

As engineering practices continue to evolve and the integration of production, education, research, and application progresses, related issues will gradually be resolved and improved.



Today, the technology of intumescent fireproof coatings has made significant progress and is a key driving force for industry development. Without continuously updated and iterated fireproof coating products, the design intentions of many ultra-high-rise buildings, especially those with exposed steel components, would be difficult to achieve. Architects may conceive aesthetically pleasing shapes during the design phase, but due to the limitations of fireproof coating performance, the final constructed effect may differ greatly from the original design intent.

One engineer expressed to me that if they had known earlier about the availability of intumescent fireproof coatings with higher fire resistance limits and excellent aesthetics, the spatial effects of some completed projects would have been even more perfect. For example, in one project, the slender hanging column structure was ultimately required to adopt other fire protection measures due to the limitations of the fireproof coating's performance, resulting in the hanging column appearing more robust. The designer felt deeply regretful about this.

– **Du Yong, Secretary-General of the Fire Protection and Corrosion Prevention Branch of the China Steel Structure Association**

3.3 Unifying Fire Protection, Corrosion Prevention and Decorative Coating Designs

In the last century, intumescent fireproof coatings were explicitly prohibited for use in steel structure projects with a fire resistance limit exceeding 1.5 hours. However, with the development of the industry and the support of third-party testing data, technologically advanced intumescent fireproof coatings have gradually been accepted and applied in projects with a fire resistance limit of 2.0 hours, and they have met the requirements for a 3.0-hour design fire resistance limit in the T3B Terminal project for concrete-filled steel structures.

Currently, the coating systems for steel structures have gradually evolved into a product system that integrates anti-corrosion, fire protection, and decorative functions. In line with the trend of integrated coating design, corresponding anti-corrosion, fireproof, and decorative coatings are designed based on the characteristics of the steel structure's application environment to ensure the safety, aesthetics, and durability of the steel structure. This trend aligns closely with China's advocated high-quality building development concept and the development concept of "four types of airports" as major transportation hubs. The Chinese steel structure industry is progressing from being a "large country" to a "strong country," and advancements in fireproof coating technology provide important support for this transformation.



Fireproof paint, along with anti-corrosion primer and topcoat, typically forms the protective coating system for steel structures, providing corrosion resistance, fire protection, and decorative performance. Extensive testing and practical experience have demonstrated that the fireproof coating itself also affects the corrosion resistance and aesthetic performance of the entire protective coating system, either enhancing or weakening it. In the T3B Terminal project, the selection and validation of leveling materials also highlighted the importance of overall protective performance. Therefore, during the fire protection design phase, it is essential to comprehensively assess the overall performance of the protective coating system, including the fireproof coating. PPG integrates different coating functional requirements into a comprehensive management approach during the design phase, effectively and accurately reflecting the designer's intent while controlling coating costs.

– **Ma Shaohua, PPG Sales Director for Protective Coatings, Asia-Pacific Region**

Table 1: Example Focusing Only on Anti-corrosion Coating Design

Sequence Number	Coating Sequence	Name of Paint or Coating	Number of Coats	Application Method	Application Location	Dry Film Thickness (Microns)
1	Primer	Epoxy Zinc-Rich, Zinc Content ≥ 80%	1	Airless spraying	Factory Workshop	80
2	Intermediate Coat	Epoxy Mica Iron, Non-volatile Content ≥ 80%	1	Airless spraying	Factory Workshop	100
3	Topcoat	Fluorocarbon Resin or Polysiloxane	2/1	Airless spraying	Construction Site	80/100

Table 2: Example of "Integrated Anti-corrosion and Fireproof Performance" Coating System

Sequence Number	Coating Sequence	Name of Paint or Coating	Number of Coats	Application Method	Application Location	Dry Film Thickness (Microns)
1	Primer	Epoxy Zinc-Rich, Zinc Content ≥ 80%	1	Airless spraying	Factory	80
2	Intermediate Coat	Epoxy Mica Iron, Non-volatile Content ≥ 80%	1	Airless spraying	Factory Workshop	100
3	Fireproof Coating	Outdoor Solvent-Based Intumescent Fireproof Coating for Steel Structures	As per inspection report	Airless spraying	Construction Site	Meets fire resistance rating requirements
4	Topcoat	Fluorocarbon Resin or Polysiloxane	2/1	Airless spraying	Construction Site	80/100



Integrated coating design helps to more efficiently meet the safety, environmental, and cultural development needs of large steel structure building projects. Professional integrated coating design combines anti-corrosion, fireproof, decorative coatings, and other functional coatings into a cohesive overall coating system, thereby achieving at least five objectives:

1. Enhance safety: In addition to meeting higher fire resistance limits (even up to a 4-hour fire rating), the overall durability and service life performance of the coating system should also be considered. The durability of the entire system needs to be verified through aging tests (see Table 3), and the degree of degradation in fire protection performance after aging must also be taken into account as an important factor for safety.
2. Especially for steel structures exposed to various outdoor environments (including coastal areas), the protective coatings need to maintain excellent gloss retention, color stability, and self-cleaning properties under long-term exposure to factors such as ultraviolet light, salt, wind, rain, humidity, and temperature variations, as well as under the influence of external mechanical forces. They should also provide lasting resistance to cracking, corrosion, and impact, thereby protecting the building's appearance and safety while reducing maintenance costs, allowing the building to maintain its youthful appearance.

3. Owners and designers should pay more comprehensive attention to sustainable development, considering environmental protection requirements at all stages, from coating production to construction. They should choose fireproof and protective coatings that have lower pollution and lower VOC (volatile organic compound) emissions. High-performance, high-solids coatings can help buildings to meet stringent environmental protection regulations.

4. In response to the national design and construction concept of 'four types of airports,' verified new technologies, processes, and materials should be selected to completely eliminate leveling coatings and polishable coatings, retaining only the three-layer coating system of anti-corrosion, fireproof, and topcoat. For example, the application of intumescent fireproof coatings included in the CECS24 standard will further optimize the integrated design of steel structure coatings.

By replacing and reasonably matching coatings, the types of coatings and coating structures included in the same steel structure coating system will be simplified, which helps improve the fire safety of steel structures, reduce the complexity of the coating process, and significantly decrease engineering quality risks, making building steel structures safer, more durable, and aesthetically pleasing, thereby creating greater social and economic benefits.

5. A greater variety of topcoats in different colors will continue to emerge in the market. Combining the integrated coating design concept mentioned in this article with the rapidly evolving applications of new topcoat technologies will help designers more easily achieve the desired visual effects and artistic aesthetics of building exteriors while considering performance and safety.

Whether it is high gloss, matte, semi-matte, or diffuse finishes, as well as various thematic colors such as gradients and magical effects, along with brilliant metallic colors and culturally significant antique colors, all these topcoat colors and effects can be integrated to meet the fire protection and anti-corrosion design requirements for steel structures, closely aligning the architectural design outcomes with the overall protective and fireproof functions.

Table 3: Comparison of Weather Resistance and Durability Testing Standards for Fireproof Coating Systems

ETAG 018	BS 8202	GB 14907
<ul style="list-style-type: none"> • C1 Very Low (Z2) • C2 Low (Z1) • C3 Medium (Z1) • C4 High (Y) • C5 Very High 	<ul style="list-style-type: none"> • Indoor • Outdoor during construction, indoor during use • Semi-Outdoor Environment • Outdoor Environment 	<ul style="list-style-type: none"> • Indoor Type • Outdoor Type
<ul style="list-style-type: none"> • Im1 Freshwater Immersion • Im2 Seawater or Saltwater Immersion (without cathodic protection) • Im3 Buried 	<ul style="list-style-type: none"> • During testing, high humidity, weather resistance and salt spray accelerated aging tests reach 1000-2000 hours 	<ul style="list-style-type: none"> • Outdoor type accelerated aging salt spray resistance only 720 hours



04 Future Outlook: Diversification of Fire Protection Materials and Quality Assurance in Projects



Fire protection materials for steel structures are evolving towards high performance to meet diverse engineering needs. Innovations in structural materials (such as steel-concrete composite structures and fire-resistant steel) complement the enhancement of fire protection material performance, driving industry progress. At the same time, the industry needs to address shortcomings by establishing product quality standards, standardizing construction processes, and implementing quality assurance mechanisms to support high-quality development.

4.1 Trends and Demands for Diverse Fire Protection Materials

In engineering design and construction practices, the demand and supply for fire protection are showing a diversified trend. In the future, fire protection materials will see richer application demands tailored to different types of engineering projects.

For example, to address the rapid performance decline of pure steel structures at high temperatures, innovations in structural materials have brought changes to fire protection needs. Taking steel columns and concrete-filled steel columns as examples, under the same dimensions and wall thickness conditions, concrete-filled steel columns can achieve higher fire resistance limits when using the same intumescent fire coating, and the required coating thickness is thinner. This phenomenon indicates that innovations in structural materials and enhancements in fire protection material performance are complementary.

On the other hand, fire protection materials need to continuously improve their performance to meet different fire resistance limits and other requirements, such as the increasingly emphasized environmental protection needs. Intumescent fire coatings are gradually transitioning from traditional solvent-based formulations to sustainably advantaged water-based fire coatings. In particular, epoxy fire coatings, which were originally mainly used in the petrochemical industry, are now increasingly being promoted in civil construction. This transition not only responds to environmental protection requirements but also provides more options for building fire protection.

4.2 Establishing a Comprehensive Quality Assurance System for Coating Projects

Under the guidance of the "Quality Strong Nation" strategy, the high-quality development of the steel structure protection industry has become an important goal. However, the industry currently faces numerous challenges, including the evaluation of coating product quality, assessment of coating capabilities, training for coating professionals, and the improvement of insurance and guarantee systems. Addressing these issues will provide significant support for the high-quality development of the industry.

1. Establish a Standardized Quality System for Fireproof Coating Products

To ensure the quality of fireproof coating products, an access mechanism and evaluation system need to be established. Through standardized quality evaluation, the performance of coating products can be effectively enhanced to meet the needs of different types of projects. For example, the 2023 CCTV "3.15" Gala severely criticized the chaos in the steel structure fireproof coating market, highlighting the necessity of establishing an access mechanism. The access mechanism for shipbuilding steel structures can serve as a reference for creating an access evaluation system for building steel structure coating products.

2. Establish Standardized Construction Process for Fireproof Coatings

Standardizing the coating process is key to ensuring project quality. Currently, the coating construction processes lack unified standards, leading to inconsistent construction quality. Therefore, standardized construction processes need to be developed, and professional skills training for coating workers and inspectors should be strengthened, establishing a regular pathway for professional capability enhancement.

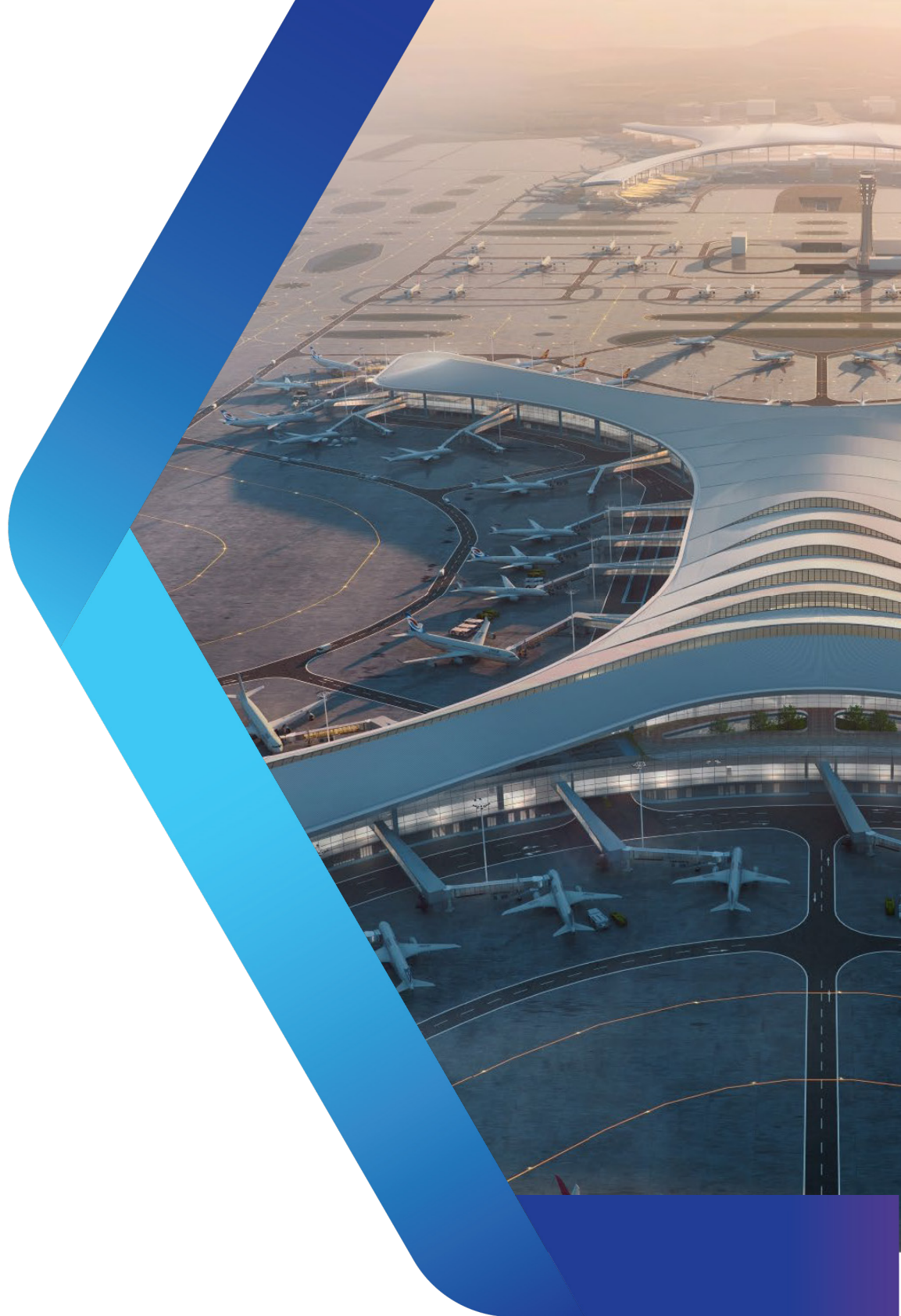
3. Establish a Construction Quality Insurance Mechanism

The responsibility for quality issues in coating projects is often unclear, and traditional retention systems cannot provide long-term guarantees. Drawing on the market mechanisms of developed countries, the introduction of quality insurance for coating projects or third-party guarantee systems can address the shortcomings of traditional retention systems and form a closed-loop assurance system.



would like to express my sincere gratitude to all the staff and professional teams involved in the Chongqing Airport T3B Terminal project, as well as to the anti-corrosion and fireproof coating product supplier, PPG. This is a mutually beneficial collaboration, and I hope that all parties can keep pace with the development and work together to build high-quality engineering projects.

– Du Yong, Secretary-General of the Fire Protection and Corrosion Prevention Branch of the China Steel Structure Association



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