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# A study on technological advancement and performance calculation of railing systems for railway bridge maintenance walkways

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## Abstract

**Purpose** – The expansion of the railway network and the increase in operation and maintenance intensity have rendered the durability, applicability and standardization of bridge guardrails key bottlenecks for ensuring personnel safety, improving the efficiency of maintenance windows, reducing the full life cycle cost, and promoting the high-quality development of railways. It is urgent to systematically sort out the domestic technological evolution, quantitatively evaluate the material performance, establish a full life cycle management framework, fill the gaps in the current standards regarding material selection, manufacturing and acceptance, and provide a scientific basis for the formulation of new standards.

**Design/methodology/approach** – (1) Literature and case study research - summarize the application characteristics and failure modes of steel, concrete, and fiber composite materials. (2) Material and process testing - measure the mechanical, corrosion resistance, and aging resistance properties of polyurethane pultruded composite materials. (3) Structural calculation - check the displacement of each railing post and handrail, and verify the safety margin. (4) Standard comparison - identify the gaps between domestic and international standards and the improvement paths.

**Findings** – Polyurethane railings are lightweight, high-strength, weather-resistant, maintenance-free, have minimal deformation and are suitable for coastal and cold regions. Steel railings corrode rapidly, are costly to repaint, and are difficult to maintain. Concrete is prone to cracking, frost peeling and rust expansion, and has a short lifespan. The current standards lack durability indicators, process control and full-life cycle evaluation, which restricts the promotion of new materials.

**Originality/value** – Establish polyurethane as the preferred option in complex environments; offer optimization directions for steel and concrete anti-corrosion structures; supplement durability indicators, process key points and cost models, and promote the standardization, lightweighting and long service life of ancillary facilities.

**Keywords** Bridge, Rail structures, Resilience and sustainability

**Paper type** Research article

## 1. Overview

### *1.1 Research background and significance*

Railway transportation, as the backbone of China's integrated transportation system, has core advantages such as large capacity, high efficiency, low energy consumption and low pollution. Its safe and stable operation depends on the long-term reliable service of railway infrastructure. Railway Bridges, as key structures of the railway line, not only have to bear the vertical action of train loads, but also have to withstand wind loads, seismic actions, temperature changes and complex environmental erosion (such as high salt fog along the coast, freeze-thaw in cold regions, strong ultraviolet rays, etc.), and bridge deck ancillary facilities, as

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an important component of the bridge system, The performance of the bridge directly affects the safety of operation and maintenance and the durability of the main structure of the bridge.

The core functions of railings and supports for railway bridge operation channels are reflected in two dimensions: First, the safety protection function, providing a stable working boundary for railway patrol and maintenance personnel, preventing personnel from falling or maintenance equipment from sliding, is a key barrier to ensure the life safety of operation and maintenance personnel; The second is the load-bearing support function, providing a reliable platform for the temporary stacking of maintenance tools and materials, avoiding damage to the bridge deck pavement due to concentrated loads, and at the same time providing a convenient movement passage for the workers. According to the explicit requirements of the "Code for Design of Railway Bridges and Culverts" (National Railway Administration of the People 's Republic of China, 2017), the railings of the operation passage must meet the load standard of "bearing a horizontal thrust of no less than 1.0kN/m at the height of the handrail", and must adapt to the differentiated environmental conditions in different regions. This imposes strict requirements on the material selection, structural design and anti-corrosion process of railings and supports.

In recent years, China's railway construction has entered a stage of "high-speed, networked and intelligent" development. By 2024, the national railway operating mileage has exceeded 150,000 kilometers, including more than 45,000 kilometers of high-speed railway mileage, covering over 95% of cities with a population of over one million, forming a high-speed railway main channel network of "eight verticals and eight horizontals" (China railway development report 2024). With the increase in the operating time of railway Bridges, the early-built bridge deck ancillary facilities have gradually revealed durability problems: steel railings are prone to rust and coating peeling, requiring regular rust removal and repainting maintenance, with an average annual maintenance cost of about 8%-12% of the initial cost, and maintenance work takes up line window time, affecting the normal operation of the railway; Reinforced concrete railings are prone to surface cracks, exposed steel bars, and concrete spalling due to factors such as concrete carbonation, chloride ion intrusion, and freeze-thaw cycles (Jin, Lü, Zhao, & Gan, 2007). In severe cases, they need to be dismantled and rebuilt, which not only increases the life cycle cost but also poses safety hazards.

Against this backdrop, the development and application of new materials and new processes have become the core approach to solving the durability problem of railings. Fiber composites, as a new type of engineering material, have the characteristics of high specific strength (about 3–5 times that of steel), strong corrosion resistance, excellent anti-aging performance and good insulation, and have been gradually promoted and applied in the field of civil engineering since the 1990s (Wu, Wang & Shi, 2020). Among them, polyurethane pultrusion composites have achieved a synergistic optimization of "material performance - structural form - production efficiency" through the continuous pultrusion molding process and have shown significant advantages in railway bridge ancillary facilities.

By reviewing the technological development history of fiber composite railings, domestic and international engineering application cases, and verifying their performance indicators through structural mechanics calculations, this paper aims to provide technical basis for the standardized design, manufacture and acceptance of railings and supports for railway bridge operation channels, Promoting the development of railway infrastructure operation and maintenance towards "lightweight, maintenance-free, long service life" is of great practical significance for reducing railway operation costs and enhancing the safety guarantee capacity of infrastructure.

### *1.2 Technical background*

*1.2.1 Mainstream railing and support materials and application status.* The selection of materials for railings and supports of railway Bridges in China is closely related to the beam type of the bridge, the operating environment and the construction year. Currently, the mainstream types can be divided into three major categories: steel structure, reinforced concrete structure and fiber composite material structure, forming a technical pattern of "optimization and upgrading of traditional materials + gradual promotion of new materials".

1.2.1.1 Steel railings and supports. Steel railings and supports are widely used in railway concrete T-beams and some box girder projects due to their stable mechanical properties and convenient construction, as shown in Figure 1. Steel supports and steel railings are mostly used for railway concrete T-beams in China. The material is mostly Q235 or Q355 carbon structural steel, and the integral frame is formed by welding or bolt connection. Early steel railings mainly used hot-dip galvanizing for anti-corrosion, but in high salt spray and high humidity environments, the galvanized layer is prone to corrosion and peeling, causing the steel to rust. To enhance the anti-corrosion performance, "Protective coating and paint for steel structures and components of railway Bridges - Part 3: "Auxiliary steel structures" (China State Railway Group Co., LTD., 2020) explicitly requires the use of PCA composite diffusion technology (multi-element powder co-diffusion + arc spraying of zinc-aluminum at welds + passivation) for T-beam steel crossbeams, supports and box girder steel railings to increase the anti-corrosion life of steel components from 5–8 years to 15–20 years.

The advantages of steel railings and brackets lie in their strong load-bearing capacity and high structural rigidity, making them suitable for heavy-haul railways or operation scenarios with large personnel and material loads. But the disadvantages are also obvious. One is that they are heavier (about 3–4 times the weight of composite materials), which increases the additional load on the bridge; Second, regular maintenance is required and the maintenance costs are high; Third, there is still a risk of corrosion in harsh environments such as coastal areas and high cold, which affects the safety and durability of the structure.

1.2.1.2 Reinforced concrete railings. Reinforced concrete railings are mainly used in railway box girder projects, as shown in Figure 2, and are divided into prefabricated and cast-in-place types. Among them, prefabricated reinforced concrete railings are most widely used in high-speed railway box girders due to their high construction efficiency and easy quality control. The precast reinforced concrete railings are usually made of C40-C50 fine aggregate concrete, with HRB400 grade reinforcing bars embedded inside. The cross-section forms are mostly rectangular or L-shaped, and they are fixed to the box girder flange plates through embedded bolts (Chen, Wang, Pan, Lin, & Chen, 2021).

According to the 2019 national railway statistics, concrete railings for high-speed railway box girders account for about 71.3%, and their advantages lie in lower cost, better durability (service life can reach 20–30 years in dry conditions), and no need for anti-corrosion maintenance; But its disadvantages are also prominent. One is that it is relatively heavy (about 4–5 times the weight of composite materials), which requires a higher load-bearing capacity of the box girder flange plate; The second is poor crack resistance. Cracks are prone to occur

**Figure 1.** Railway concrete T-beam steel railings and supports. Source: Internet

**Figure 2.** Prefabricated reinforced concrete railings for railway box girders. Source: Internet

during temperature changes, loads or transportation and installation. The development of cracks can lead to the corrosion of reinforcing bars, which in turn affects structural safety. Statistics show that the crack damage rate of concrete railings is 62%. Third, the construction period is long, the process of prefabrication, transportation and installation is complex, and in the renovation of existing lines, the operation of removing old railings and installing new ones takes a long time, affecting the normal operation of the railway.

1.2.1.3 Fiber composite railings. Fiber composite railings are a new type of railing that has developed in recent years, with reinforcing materials such as glass fiber and carbon fiber, and matrix materials such as resins (unsaturated polyester resin, vinyl resin, polyurethane resin, etc.) formed through processes such as pultrusion, winding, and molding. Among them, polyurethane pultruded composite railings are the most widely used in railway Bridges due to their excellent mechanical properties and strong aging resistance (Zhang, Zhang, Liu, & *et al.*, 2020). The reinforcing material is alkali-free glass fiber, the matrix material is modified polyurethane resin, and it is manufactured by continuous pultrusion process, as shown in Figure 3. The cross-sectional form can be designed as rectangular, I-shaped or irregular according to the requirements. It has significant advantages such as light weight, high strength, corrosion and weather resistance, and maintenance-free.

The technical advantages of fiber composite railings are mainly reflected in the following aspects: First, they are light in weight, with a density of 1.9-2.1g/cm$^3$, about 1/4 of that of steel and 1/2 of that of concrete, significantly reducing the additional load on the bridge; 2. High

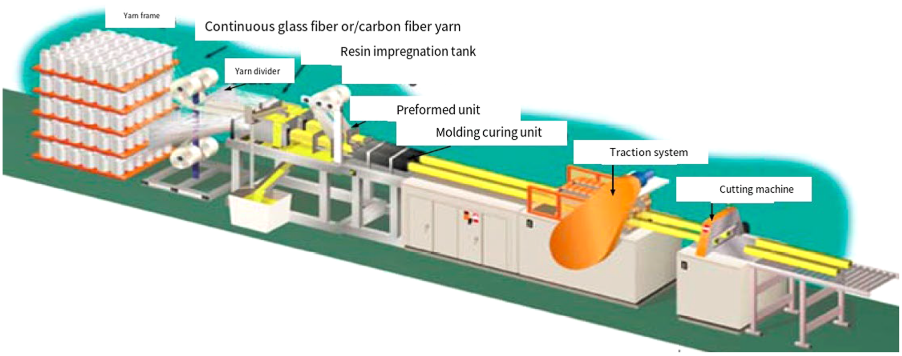



**Figure 3.** Continuous pultrusion process for composite materials. Source: Internet

strength, as shown in Table 1, tensile ultimate strength of 800-1200MPa, flexural ultimate strength of 1000-1500MPa, mechanical properties superior to traditional fiberglass products; Third, it has good durability, does not absorb water, is resistant to ultraviolet rays and corrosion, and has a service life of more than 50 years in harsh environments such as high salt spray along the coast and strong ultraviolet rays, and requires no maintenance. Fourth, it is easy to install. It can be prefabricated in the factory and assembled on site. The installation efficiency is 30%-50% higher than that of steel or concrete railings, and it causes less disturbance to the operation of existing lines.

At present, fiber composite material railings have been successfully applied in actual projects, with good usage effects and no corrosion or cracking and other diseases, verifying their applicability and reliability in railway bridges.

*1.2.2 History of the development of fiber composite technology.* The development of fiber composites began in the 1940s. With the invention of forming processes such as pultrusion and winding, composites gradually shifted from the military field to the civilian field and were applied in industries such as shipping, chemical engineering, and aerospace.

Since the 1990s, the application of composites in the field of civil engineering has entered a stage of rapid development. As composites can meet the demands of modern structures for large spans, high heights, heavy loads, light weight, high strength and working in harsh conditions, and adapt to the requirements of modern industrialized construction, their application scope has gradually expanded to civil buildings, Bridges, highways, Marine, wind power, hydraulic engineering, underground structures and other fields. For example, in 1996, the United States built the world's first all-composite highway Bridge (Florida I-75 Bridge), using glass fiber reinforced composites for the main beams and bridge decks; After 2000, Japan applied composite materials to the ancillary structures of railway Bridges, such as cable troughs and sound barriers, and achieved good results.

In the field of railway engineering, foreign countries have attempted to use composite materials to make main structures or ancillary structures earlier in order to solve the problem of structural durability and reduce the interference of construction to operation. Dura Composites Ltd. in the UK is a representative enterprise in the application of composite materials in railways. Its products include ballast block systems for steel beam ballasted bridge decks, pedestrian Bridges, grid walkways between railway lines, platform end steps and safety fences, as shown in Figure 4, which have been applied in the UK railway network for more than 2,000 kilometers. The longest-serving project has been in service for 15 years without showing obvious signs of aging or damage.

Research and application of railway composites in China began in the early 21st century, mainly for non-load-bearing structures such as cable troughs and sound barriers in the early days. After 2010, with the advancement of composite material technology, domestic research began to explore its application in load-bearing structures such as composite material bridge sleepers and railings. In 2017, the China Academy of Railway Sciences conducted a

**Table 1.** Mechanical properties of polyurethane pultruded composite profiles

| Serial numbers | Project | Units | Indicators |
|---|---|---|---|
| 1 | Notch-free impact toughness | kJ/m2 | 350~600 |
| 2 | Surface Barcol hardness | – | 45~60 |
| 3 | Tensile ultimate strength | MPa | 800~1,200 |
| 4 | Tensile elastic modulus | GPa | 40~55 |
| 5 | Bending ultimate strength | MPa | 1,000~1,500 |
| 6 | Bending elastic modulus | GPa | 40~55 |
| 7 | Density | g/cm3 | 1.9~2.1 |

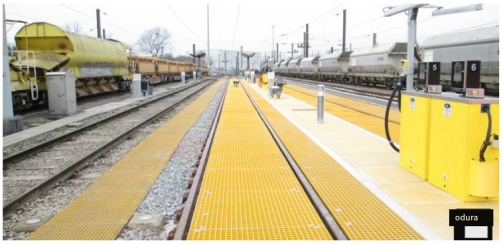
**Source(s):** Testing Report of China Polyurethane Industry Association)

Ballast retaining system for steel beam ballasted deck

**(a)**

Bradkirk Pedestrian Bridge in the UK

**(b)**



Composite grating walkways between railway lines

**(c)**

Composite platform end steps, safety doors and fences

**(d)**

**Figure 4.** Application of fiber composite products in railway engineering (Dura Composites LTD., UK).
Source: Internet

systematic study on the materials, structures and processes of composite railings for railway box girders and developed polyurethane pultruded composite railings, which are reinforced with alkali-free glass fiber and polyurethane as the matrix material and formed by continuous pultrusion + winding process, with mechanical properties and aging resistance reaching the international advanced level. The related results were accepted by the Science and Information

Department of China State Railway Group in October 2019. As of 2024, more than 31,000 composite material bridge sleepers have been used on over 110 existing railway steel beams across the country, with good results and significantly reduced maintenance and repair work. Among them, the composite material bridge sleepers on the South Canal Bridge of Shuohuang Railway have carried a cumulative volume of over 1.5 billion tons, verifying the reliability of composite materials in heavy-haul railway environments.

## 2. Calculation and analysis of railing performance

*2.1 Basis of calculation and basic assumptions*

*2.1.1 Calculation basis.* The railing performance calculation is mainly based on the following specifications, standards and technical documents to ensure the compliance and reliability of the calculation results:

(1) Code for Design of Railway Bridges and Culverts: Determine the design load (horizontal thrust, vertical load) and stiffness control index of the railings;

(2) Mechanical Safety - Fixed facilities for entering machinery - Part 3: Stairs, steps and guardrails: Specifies the maximum deformation limit of guardrail posts and handrails under load (≤30mm);

(3) Structural Mechanics (Long Yuqiu, Bao Shihua, Yuan Si.): Use classical structural mechanics theory to calculate the displacement of columns as cantilever beams and handrails as simply supported beams;

(4) General Reference drawings for railway engineering: including General Bridge (2024) 8188-I, General Bridge (2024) 8388A-I, General Bridge (2017) 2201-I, Special Bridge 8145 (1990), etc. Obtain the cross-sectional dimensions, material parameters and structural forms of different types of railings;

*2.1.2 Basic assumptions.* To simplify the computational model while ensuring computational accuracy, the following basic assumptions are proposed:

(1) The railing structure is a linear elastic body, and the mechanical properties of the material conform to Hooke's law, without considering the nonlinear behavior of the material (applicable to displacement calculation under normal service limit state);

(2) The connection between the posts and the base is fixed end constraint, ignoring the slight rotation of the connection between the base and the bridge deck (in actual engineering, the posts are rigidly connected to the bridge deck through embedded bolts, and the rotation constraint is relatively strong);

(3) The handrail is hinged to the post. The handrail only transmits vertical and horizontal loads and does not transmit bending moments (conforming to the connection structure of most railings, such as bolt connection or slot connection);

(4) The load acting is a static concentrated load, without considering the influence of dynamic loads (such as impact loads), and in actual engineering, dynamic effects are considered through load component coefficients (1.2–1.4);

(5) Ignore the effect of the crossbars of the railings and only calculate the displacement between the posts and the handrails (the crossbars contribute less to the overall stiffness and mainly affect the local stability, and the impact on the overall displacement can be ignored).

*2.2 Calculation parameters and formulas*

*2.2.1 Design load determination.* According to the "Code for Design of Railway Bridges and Culverts" and engineering practice experience, the main control load of the guardrail is the horizontal thrust load (resulting from the leaning of personnel or the collision of machinery), and the vertical load (resulting from the standing of personnel or the stacking of materials) is relatively small and has a limited impact on the stiffness of the guardrail. Therefore, this calculation focuses on analyzing the displacement performance under the action of horizontal loads.

The values of horizontal loads follow the following principles:

Horizontal load on the column ($F_c$): Apply a horizontal concentrated force at the height of the column handrail, $F_c = \max(1.0, 0.75L)$kN, where L is the center distance between two adjacent columns (unit: m). $F_c = 1.0$kN when $L \leq 1.33$m; When $L > 1.33$m, $F_c = 0.75L$ kN, ensuring that the load increases reasonably as the column spacing increases, in accordance with the actual force conditions.

Handrail horizontal load ($F_h$): Apply a horizontal concentrated force at the midspan position of the handrail, $F_h = \max(1.0, 0.75L)$kN, consistent with the values of the column horizontal load to ensure uniformity in load calculation.

*2.2.2 Calculation formula.*

(1) Horizontal displacement of the column

Apply a horizontal force $F_c$ at the height of the handrail of the column, and the maximum horizontal displacement $f_c$ at the loading point shall be ≤h1/100.

$F_c = \max(1.0, 0.75L)$kN, where L is the center distance between two adjacent posts and $h_1$ is the height of the handrail, and both L and $h_1$ are in meters (m).

(2) Handrail mid-span displacement

Apply an external force $F_h$ in the middle of the handrail span, with the maximum displacement $f_h$ at the loading point ≤ L/200. $F_h = \max(1.0, 0.75L)$kN, L in meters (m).

Note: The group has calculated the stiffness of the existing railings and supplemented the relevant information. In terms of the key performance parameters of the railing posts, with safety as the main consideration, there are two main control indicators: 1) Deformation at the handrail of the post under the action of human thrust; 2) Deformation of the handrail of the railing under the effect of human thrust. With reference to classical structural mechanics, the calculation formula is as follows:

The column is regarded as a cantilever beam for calculation, and the displacement at the beam end is

$$f_{\mathrm{c}} = \frac{F_c h^3}{3E_h I_h}$$

The handrail is counted as a simply supported beam, with a mid-span displacement of

$$f_{\mathrm{h}} = \frac{F_h L^3}{48 E_f I_f}$$

In the formula, $F_{\mathrm{c}} = F_{\mathrm{h}} = \max(1.0, 0.75L)$kN, where $L$ is the center distance between two adjacent columns, $h$ is the height from the column handrail to the base, and $E$ and $I$ are the material of the column and handrail and the moment of inertia of the cross-section, in meters (m).

*2.3 Calculation results and analysis*

This calculation selects seven types of railings commonly used in railway Bridges in China as calculation objects, including concrete and steel pipe composite railings, steel railings, and composite material railings, covering different beam types (T-beams, box girders) and design reference drawings, and is representative. The specific calculation objects and parameter values are as follows:

*2.3.1 List of calculation objects.*

(1) Concrete and steel pipe composite railings in Tongqiao (2024) 8188-I (box girders for passenger and freight co-occupancy)

(2) Steel railings in Tongqiao (2024) 8188-I (passenger and cargo Co-line box girders);

(3) Steel railings in Tongqiao (2024) 8388A-I (high-speed railway box girders);

(4) Concrete and steel pipe composite railings in Tongqiao (2024) 8388A-I (high-speed rail box girders);

(5) Composite railings in Tongqiao (2024) 8388A-I (high-speed rail box girders);

(6) Steel railings in Tongqiao (2017) 2201-I (passenger and freight Co-track T-beams);

(7) Steel railings (existing line T-beams) in Special Bridge 8145 (1990).

*2.3.2 Calculation results of horizontal displacement of posts.* Based on the above formulas and parameters, the horizontal displacements of the posts of the 7 types of railings were calculated, and the results are shown in Table 2:

Analysis conclusions:

(1) The horizontal displacement of the posts of all calculated objects met the limit requirements of $f_c \le h1/100$. Among them, the displacement of the concrete and steel pipe combined railings was the smallest (0.33-0.42mm), and the stiffness was the greatest. This was due to the large moment of inertia of the cross-section of the concrete material, and the combined work with the steel pipes enhanced the overall stiffness.

(2) The displacement of the steel railings was in the middle (0.90-8.92mm), among which the displacement of the Tongqiao (2017) 2201-I steel railing was the largest (8.92mm), corresponding fc/h = 1/147, which was the lowest stiffness among all the calculated objects, but this type of railing has been widely used throughout the road. There was no adverse feedback of insufficient rigidity of the posts during operation, indicating that the rigidity met the actual usage requirements;

(3) The displacement of the composite railing is 6.36mm, $f_c/h = 1/163$, and the stiffness is superior to Tongqiao (2017) 2201-I steel railing. Although its elastic modulus (4000mpa) is lower than that of steel (210,000mpa), sufficient moment of inertia is guaranteed by optimizing the cross-sectional form (increasing the cross-sectional height to 180mm). Thus meeting the stiffness requirements;

(4) Based on the calculation results and engineering application feedback, it is recommended that in the series of standards on railings and supports for railway bridge operation channels, the stiffness index of all railing posts be uniformly stipulated as “a horizontal force $F_c$ is applied at the height of the handrail, and the maximum horizontal displacement $f_c$ at the loading point is ≤h/100”, which ensures safety and reliability as well as engineering feasibility.

*2.3.3 Calculation results of mid-span displacement of the handrail.* Similarly, the mid-span displacements of the handrails of the 7 types of railings were calculated, and the results are shown in Table 3:

Analysis conclusions:

(1) The mid-span displacements of the handrails of all calculated objects met the limit requirements of $f_h \le L/200$ (L = 2000mm, limit of 10mm), among which the

**Table 2.** Key parameters and calculation results of railing posts for each working condition

| Number | Object | Column section (mm×mm) | Cross-sectional moment of inertia in the bridge direction (mm4) | Material elastic modulus (MPa) | Materials | Handrail height *h* (mm | Load (kN) | Column displacement *f* (mm) | *f*/*h* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Concrete and steel tube composite railings in Bridge (2024) 8188-I (2024) | 140 × 140 | 32,013,333 | 34,000 | C40 fine stone Concrete | 970 | 1.5 | 0.42 | 1/2313 |
| 2 | Bridge (2024) 8188-I Steel railings in (2024) | Variable cross-section | / | 210,000 | Steel | 960 | 1.5 | 0.90 | 1/1,078 |
| 3 | Tongqiao (2024) 8388A-I (2024) steel railings | Variable cross-section | / | 210,000 | Steel | 1,050 | 1.5 | 0.97 | 1/1,082 |
| 4 | Tongqiao (2024) 8388A-I (2024) A combination of concrete and steel pipe railings | 150 × 150 | 42,187,500 | 34,000 | C40 fine stone Concrete | 980 | 1.5 | 0.33 | 1/2987 |
| 5 | Bridge (2024) 8388A-I (2024) Composite railings | 100 × 180 × 4 | 2,211,100 | 40,000 | Composites | 1,040 | 1.5 | 6.36 | 1/163 |
| 6 | Bridge - 2017–2201-I Steel railings | L75 × 75 × 8 | 600,000 | 210,000 | Steel | 1,310 | 1.5 | 8.92 | 1/147 |
| 7 | Steel railings in Special Bridge 8145 (1990) | L75 × 75 × 8 | 600,000 | 210,000 | Steel | 1,066 | 1.5 | 4.81 | 1/222 |

**Source(s):** Author’s own work

**Table 3.** Key parameters and calculation results of handrails for each working condition

| Number | Object | Handrail cross-section (mm×mm) | Cross-sectional bending stiffness in the bridge direction (mm4) | Material elastic modulus (MPa) | Materials | Column spacing *L* (mm) | Load (kN) | Handrail displacement *f* (mm | $f_h/L$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Bridge (2024) 8188-I (2024) Concrete and steel tube composite railings | 60 × 4 | 277,260 | 210,000 | Steel | 2,000 | 1.5 | 4.29 | 1/465 |
| 2 | Bridge (2024) 8188-I Steel railings in (2024) | 80 × 4 | 691,450 | 210,000 | Steel | 2,000 | 1.5 | 1.72 | 1/1,162 |
| 3 | Tongqiao (2024) 8388A-I (2024) steel railings | 63 × 2.5 | 217,770 | 210,000 | Steel | 2,000 | 1.5 | 5.47 | 1/365 |
| 4 | Tongqiao (2024) 8388A-I (2024) A combination of concrete and steel pipe railings | 63 × 2.5 | 217,770 | 210,000 | Steel | 2,000 | 1.5 | 5.47 | 1/365 |
| 5 | Tongqiao (2024) 8388A-I (2024) Composite railings | 70 × 6 | 542,420 | 40,000 | Composites | 2,000 | 1.5 | 10.03 | 1/200 |
| 6 | Bridge - 2017–2201-I Steel railings | L75 × 75 × 6 | 470,000 | 210,000 | Steel | 2,000 | 1.5 | 2.53 | 1/790 |
| 7 | Steel railings in Special Bridge 8145 (1990) | L75 × 75 × 6 | 470,000 | 210,000 | Steel | 2,000 | 1.5 | 2.53 | 1/790 |

**Source(s):** Author’s own work

displacement of the steel handrail of the bridge (2024) 8188-I was the smallest (1.72mm), and the stiffness was the largest due to the larger cross-sectional size of the handrail (80 × 4mm) The moment of inertia was significantly higher than that of other types of handrails;

(2) The handrail displacement of the composite material railing is the maximum (10.03mm), just meeting the limit requirement (10mm), because the elastic modulus of the composite material (4000mpa) is only about 1/5 of that of steel. Although the moment of inertia of its section ($542420mm^4$) is higher than that of some steel handrails (such as 217,770mm $^4$ of 63 × 2.5mm steel pipe), the difference in elastic modulus causes the displacement to be close to the limit;

(3) The maximum deformation of the posts and handrails under load should not exceed 30mm in accordance with the requirements of mechanical safety access to fixed facilities for machinery - Part 3: Stairs, steps and guardrails (GB 17888.3–2008). Check the total deformation (handrail displacement + post displacement) of the composite railings: When a load of 1.5kN was applied in the middle of the handrail span, the force at the positions of the handrails on both sides of the posts was 0.75kN. According to the post displacement formula, the deflection of the posts was calculated to be 3.18mm, and the total deformation was 10.03 + 3.18 = 13.21mm, which was much less than the limit of 30mm and met the safety requirements;

(4) Based on the calculation results, it is recommended that in the series of standards for railings and supports of railway bridge operation channels, the stiffness index of all railings and handrails be uniformly stipulated as "when a horizontal force $F_h$ is applied in the middle of the handrail span, the maximum displacement $f_h$ at the loading point is $\leq$L/200", among which the displacement of the composite material handrail just reaches the limit, and other types of handrails have a certain safety reserve. This ensures the uniformity of the standards while taking into account the characteristics of different materials.

## 3. Conclusions and recommendations

### *3.1 Main conclusions*

(1) Material properties comparison: Polyurethane pultruded composite railings stand out in terms of light weight, high strength, weather resistance, corrosion resistance and maintenance-free properties, with a density of only 1.9-2.1g/cm$^3$, a tensile ultimate strength of 800–1,200 mpa, a service life of over 50 years, and no need for regular anti-corrosion maintenance compared to steel railings (maintenance cycle 5–8 years) and concrete railings (prone to cracking), It is more suitable for harsh environments such as coastal areas and cold regions;

(2) Engineering application effect: Fiber composite railings have been successfully applied in projects, with a cumulative length of over 3,000 m. No corrosion, cracking, deformation or other diseases have occurred during operation, verifying their applicability in railway Bridges, especially in heavy-haul railways, the advantages are more obvious;

(3) Stiffness performance verification: Through structural mechanics calculations, the horizontal displacement of the posts of the seven mainstream railings met $f_c \leq h/100$, the mid-span displacement of the handrails met $f_h \leq L/200$, and the total deformation was much less than the 30mm limit specified. Among them, the concrete and steel pipe combined railings had the greatest stiffness, and the composite material railings met the stiffness requirements and had the advantage of being lightweight. Steel railings have a moderate stiffness but require regular maintenance;

*3.2 Recommendations*

(1) Advancing standard development and implementation: Accelerate the development of the series of standards (concrete box girder steel railings, concrete box girder composite railings, concrete T-beam steel railings and supports) to specify material requirements, manufacturing processes, installation procedures and acceptance criteria for railings of different materials, especially to supplement the test methods for long-term performance (such as aging resistance and fatigue resistance) of composite railings Ensure the scientific and operational nature of the standards;

(2) Promote the application of composite railings: Prioritize the promotion of polyurethane pultruded composite railings in harsh environments such as high salt spray along the coast, strong ultraviolet rays, heavy loads, or existing line renovation projects to reduce the life-cycle cost and minimize the disruption of operation and maintenance to the normal operation of railways; At the same time, strengthen the industrialization of composite railings, optimize the production process and reduce manufacturing costs;

(3) Optimize traditional railing technology: For steel railings, promote PCA composite infiltration anti-corrosion technology to further extend the anti-corrosion life; For concrete railings, use fiber-reinforced concrete (such as polypropylene fiber, steel fiber) to enhance crack resistance and reduce crack damage;

(4) Strengthen long-term performance monitoring: Establish a long-term performance monitoring system for railway bridge railings, track and monitor railings of different materials and in different environments, collect data on mechanical property degradation, disease development, etc., to provide a basis for standard revision and technical optimization;

(5) Conduct technological innovation research: Develop high-performance composites (such as carbon fiber reinforced composites) to further enhance the strength and durability of railings; Explore intelligent railings technology that integrates displacement monitoring and corrosion monitoring sensors to achieve “state perception - early warning - maintenance” integration and enhance the intelligence level of railway infrastructure.

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