

Comparison of Typical Structural Forms and Selection Recommendations for Long Approach Viaducts of Major River Crossings

Wei Zhao 

China Design Group Co., Ltd., Nanjing 210014, Jiangsu Province, China.
Correspondence: 106399227@qq.com

Abstract: Long approach viaducts of major river crossings are characterized by extensive lengths, tall piers, substantial longitudinal variation in pier height, and large capital investment. Their structural selection directly affects structural behavior, construction safety, project economics, and durability in service. In this study, the approach viaducts of four Yangtze River bridges in Jiangsu Province—the Husutong, Wufengshan, Changtai, and Zhangjinggao bridges—were examined. A systematic comparison was conducted in terms of their mechanical behavior, spanning capability, economics, aesthetics, adaptability to construction conditions, and ease of operation and maintenance. A tiered span-selection framework for zones with low, medium-height, and tall piers was developed, and preferred structural forms for land-based approach viaducts were identified. A quantitative evaluation model based on the analytic hierarchy process was also established. These findings provide reference data for scheme comparison and design optimization in similar projects.

Keywords: bridge engineering; major river crossings; long approach viaducts; structural selection; span selection; analytic hierarchy process

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1 Introduction

The Yangtze River is a major east–west waterway and a key artery of China's integrated transport system. Bridges across the river are essential for regional multimodal transport networks and coordinated economic development. As modern bridge engineering advances toward longer spans, higher traffic speeds, and heavier loads, major river crossings increasingly feature large main spans, demanding navigation clearance requirements, long approach viaducts, and complex construction environments. Approach viaducts connect the main bridge to the approach roads on both banks, providing alignment transitions, load transfer, and accommodation of spatial constraints. The appropriate selection of their structural forms directly affects the overall structural performance, construction safety, life-cycle economics, durability, and operation and maintenance costs of the bridge.

Common structural forms for approach viaducts of major river crossings include precast T-girders, precast small box girders, prestressed concrete box girders, steel–concrete composite girders, and steel box girders. These systems differ substantially in terms of their spanning capability, structural behavior, construction methods, applicability, and cost control. Existing research has two main limitations. First, systematic comparisons specifically addressing long approach viaducts remain insufficient. Most studies focus on structural innovation and construction techniques for main bridges, whereas comparisons of approach-viaduct systems are generally qualitative or based on experience from individual projects. Comprehensive comparisons of alternative schemes under different pier heights, spans, and deck widths are lacking. Second, quantitative analysis requires further development.

Current selection decisions depend mainly on engineering analogy and qualitative experience. A unified quantitative framework incorporating structural behavior, economics, adaptability to construction conditions, visual harmony, and ease of operation and maintenance is still needed to improve the comparability and broader applicability of selection outcomes.

Long approach viaducts of major river crossings also differ substantially from those of conventional urban or highway bridges in terms of their selection methods, governing factors, and design challenges. (1) Regarding selection methods, conventional bridges have limited variations in span and pier height and are highly standardized; schemes can generally be determined using standard drawings, predominantly for spans of 20–40 m. In contrast, approach viaducts of major river crossings are extensive, exhibit steep longitudinal gradients in pier height, and require span arrangements beyond conventional practice, often exceeding 50 m and sometimes reaching approximately 100 m. Section-by-section comparisons considering geology, construction, aesthetics, and economics are therefore needed, and standard drawings cannot readily be applied directly. (2) Conventional bridges are governed primarily by economics and construction convenience. Approach viaducts of major river crossings must additionally address the construction risks associated with tall piers, the structural behavior of long continuous units, visual harmony with the main bridge and the urban or ecological setting, and operational convenience and durability over an extended alignment. (3) Regarding design challenges, conventional bridges require mainly structural calculations and appropriate detailing. For approach viaducts of major river crossings, the central challenge is to jointly optimize pier–span structural interactions under substantial changes in pier height, rapid precast construction, and life-cycle economics.

Accordingly, this study examined the approach viaducts of the Husutong, Wufengshan, Changtai, and Zhangjinggao Yangtze River bridges, which have been completed or are under construction in Jiangsu Province over the past decade. The suitable spans for different pier heights, preferred bridge types within each span range, and their technical characteristics were systematically reviewed. A comprehensive comparison was conducted in terms of mechanical behavior, spanning capability, economics, adaptability to construction conditions, and compatibility with the surrounding environment. Key factors governing structural selection were identified, and practical selection recommendations are proposed. The findings provide a theoretical reference and technical support for scheme comparison and design optimization of similar long approach viaducts.

2 Overall Research Framework

Key design requirements of major river crossings, including substantial navigation clearance beneath the main bridge, gentle longitudinal gradients, and deep main girders, generally result in long approach viaducts with tall piers, pronounced variations in pier height along the alignment, and large capital investment. Under these conditions, scheme comparison and optimization must satisfy the fundamental requirements of transport functionality, structural safety, and durability. Project economics, visual harmony, and technological advancement must also be considered to achieve an overall balance among safety, economy, aesthetics, and technical feasibility.

For project economics, span parameters and structural systems should be selected to suit project conditions and paired with mature, efficient construction methods. Factory precasting and on-site assembly should be prioritized for the superstructure, enabling effective cost control through large-scale standardized construction. For visual harmony, key parameters, including span proportions, girder depth, and cross-sectional form, should be coordinated with the architectural

characteristics of the main bridge, the ecological setting, and the urban environment along the route. Excessive variation in structural form should be avoided to maintain a coherent bridge appearance and integrate the road and bridge with their surroundings. With respect to technological advancement, structural forms with established engineering applications and superior performance should be prioritized, together with efficient construction methods.

These design principles ultimately converge on two key tasks: selecting the span arrangement and selecting the superstructure girder type. Site geology, construction conditions, aesthetic requirements, and economic indicators should first be considered when determining an economical span compatible with pier height and the intended visual effect. With the span established, typical girder systems should then be compared systematically in terms of structural performance, construction difficulty, project cost, and environmental compatibility to identify the scheme best suited to the project. This study therefore compared span selection and superstructure selection, clarified the applicability of different structural systems under different project conditions, and identified the governing principles and design logic. The overall technical framework for approach-viaduct structural selection is shown in Figure 1.

Overall Technical Framework for Structural Selection of Long Approach Viaducts for Major River Crossings

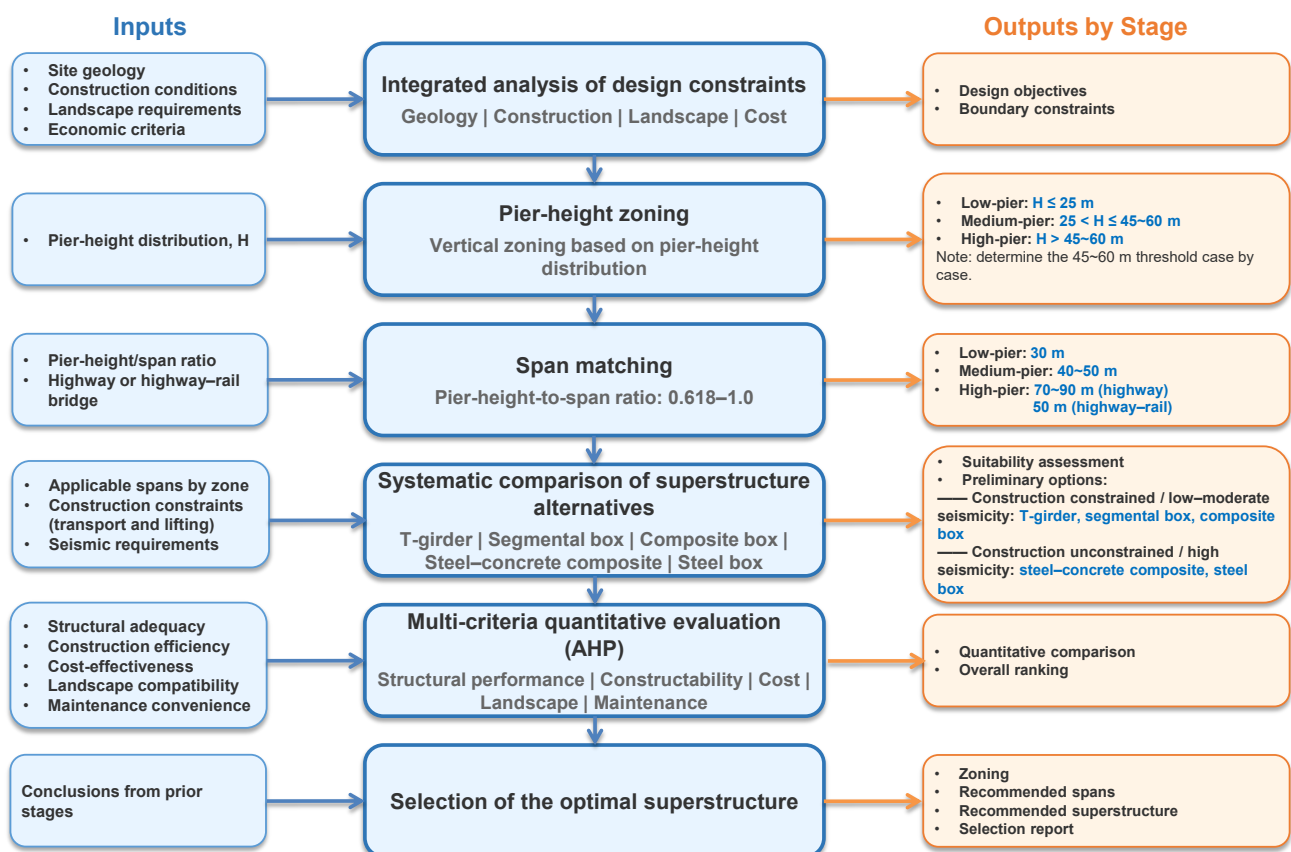


Figure 1 Overall technical framework for structural selection of long approach viaducts of major river crossings

3 Suitable Spans for Approach Viaducts of Major River Crossings

3.1 Key Engineering Characteristics

Recent expressway river-crossing projects in Jiangsu Province (Figure 2) indicate that long approach viaducts are typically characterized by extensive lengths,

tall piers, and substantial variations in pier height. Pronounced spatial gradients in pier height require differentiated structural layouts, resulting in structural systems that differ from those of conventional bridges over inland rivers.

Pier heights in these expressway approach viaducts generally decrease from the main bridge toward the abutment, with a gradual transition along the longitudinal profile. For single-level expressway approach viaducts, the maximum pier heights measured to deck level are generally 50–70 m, whereas the minimum height near the abutment is only approximately 6 m. The resulting height difference is substantial, with distinct transitions between zones. Double-deck river crossings carry an expressway on the upper level and an ordinary highway or railway on the lower level. Compared with those of single-level bridges, their substructures must support loads from multiple levels, requiring greater vertical pier dimensions and substantially taller approach structures. For example, the expressway approach viaducts of the Husutong Yangtze River Bridge, a combined road–rail bridge, have a maximum pier height of 79 m [1,2], whereas the single-level expressway approach viaducts of the Zhangjinggao Yangtze River Bridge reach 67 m [3]. These examples illustrate the tall and variable-height piers typical of approach viaducts in Jiangsu Province.

As primary load-bearing components of approach viaducts, piers govern construction difficulty, equipment requirements, material consumption, and capital investment. The appropriate matching of pier height and span is essential for structural safety, cost optimization, and visual harmony. A rational pier–span arrangement can support more standardized, efficient, and refined designs of expressway approach viaducts at major river crossings.



Figure 2 View of the Wufengshan Yangtze River Bridge project

3.2 Golden-Ratio-Based Pier–Span Proportions for Aesthetics and Economics

The relationship between the pier height and span provides a key theoretical basis for approach-viaduct structural selection. Appropriate proportions can simultaneously satisfy the requirements for structural performance, project economics, and visual quality. *Specifications for Landscape Design of Highway Bridges* (JTG/T 3360-03—2018) state that a golden ratio of 0.618 may be used to determine the proportions of the main bridge form or its components [4]. In their study of expressway overpass aesthetics using a proportion-based visual guidance method,

Hu et al. further proposed prioritizing the golden ratio in span arrangements. Controlling the pier-height-to-span ratio can result in balanced elevation proportions and avoid the visual incongruity caused by disproportionate spans and pier heights [5].

On the basis of these studies, maintaining the pier-height-to-span ratio within the golden-ratio-based range of 0.618–1.0 can produce balanced overall proportions and a visually coherent load-bearing form. This range helps avoid the crowded appearance of tall piers with short spans and the heavy appearance of low piers with long spans, thereby improving visual harmony. Extensive engineering experience also indicates that this ratio range is economically favorable, allowing for aesthetic and economic objectives to be achieved together. The range of 0.618–1.0 applies primarily to long approach viaducts with conventional spans of 30–90 m and pier heights of 25–90 m. For exceptionally tall piers ($H > 90$ m), combined road-rail bridges, and other special cases, the range may be relaxed to account for structural stiffness, local geology, and differences in visual rhythm, subject to project-specific assessment.

Using this recommended proportion (pier height/span = 0.618–1) and the standard spans commonly adopted for approach viaducts in Jiangsu Province, an optimal range of pier heights can be determined for each standard span. These ranges provide a basis for selecting pier–span combinations during preliminary design, as shown in Table 1.

Table 1 Suitable pier height ranges for different spans

Standard span (m)	Suitable pier height (m)	Applicability
30	19–30	Low-pier zones; balanced appearance and low cost
40	25–40	Transition between low- and medium-pier zones; balanced overall performance
50	31–50	Medium-pier zones; widest applicability
60	37–60	Transition between medium- and tall-pier zones
70	43–70	Tall-pier zones; favorable structural behavior
80–90	49–90	Exceptionally tall-pier zones; suitable for long-span arrangements

These ranges balance structural safety, visual harmony, and project economics and provide a basic reference for pier–span arrangements in approach viaducts in Jiangsu Province.

3.3 Pier Height Zoning on the Basis of Economic Comparison

Once suitable pier–span proportions have been established, approach viaducts should be divided into zones according to the actual pier height to reduce costs, improve efficiency, and standardize design. Matching each zone with an appropriate combination of span and bridge type enables more refined structural design. Experience from existing major river crossings in Jiangsu Province has established a pier height of 25 m as the boundary between low- and medium-pier zones. A unified, well-established engineering criterion for the boundary between medium- and tall-pier zones has yet to be developed [2,3,6,7].

To establish an appropriate boundary between the medium- and tall-pier zones, a project-specific economic comparison was conducted using the approach viaducts of the Husutong Yangtze River Bridge [2]. The site geology and construction conditions were considered. Continuous girders with spans of 50 and 75 m, which are widely used in Jiangsu approach viaducts, were compared at four representative actual pier heights: 40, 50, 60, and 70 m. The results are presented in Table 2.

Table 2 Economic comparison of spans and pier heights for the approach viaducts of the Husutong Yangtze River Bridge

Pier height	40 m		50 m		60 m		70 m	
Span	50 m	75 m	50 m	75 m	50 m	75 m	50 m	75 m
Superstructure concrete (m ³ /m ²)	0.65	0.85	0.65	0.85	0.65	0.85	0.65	0.85
Prestressing strands (kg/m ²)	40.6	45.5	40.6	45.5	40.6	45.5	40.6	45.5
Pier and pile-cap concrete (m ³ /m ²)	0.55	0.8	0.8	0.85	1.1	0.9	1.45	1.05
Pile-foundation concrete (m ³ /m ²)	0.8	1.3	0.95	1.35	1.2	1.4	2	1.5
Relative construction and installation cost	0.7	1	0.85	1	0.98	1	1.08	1

Note: Concrete quantities are expressed as the volume per square meter of bridge deck, and prestressing strand quantities are expressed as the mass in kilograms per square meter of bridge deck.

The economic comparison indicates that at a pier height of 60 m, the 50- and 75-m span schemes have approximately equal economic indicators, representing their economic crossover points. Below 60 m, the shorter 50-m span is less costly and easier to construct, providing a clear economic advantage. Above 60 m, the 75-m span reduces the number of piers and the risks associated with tall pier construction, resulting in better overall economics.

On the basis of this comparison, expressway approach viaducts can be divided into three pier height zones: a low-pier zone at ≤ 25 m, a medium-pier zone at 25–60 m, and a tall-pier zone at ≥ 60 m, as shown in Figure 3.

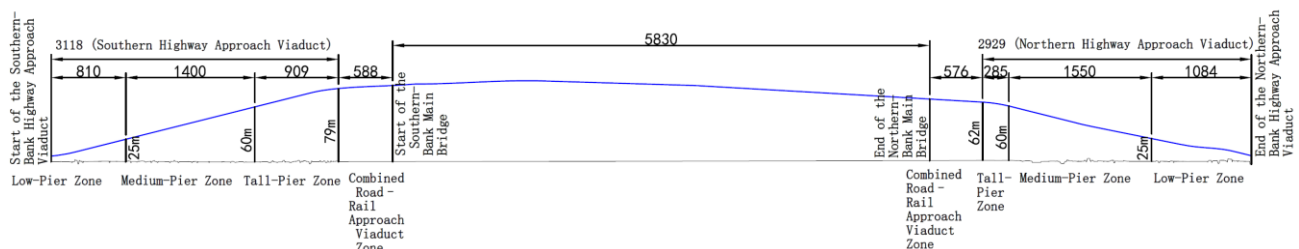


Figure 3 Pier height zoning of the approach viaducts of the Husutong Yangtze River Bridge (unit: m)

Differences in topography, geology, hydrology, and construction conditions between river crossing sites can affect the economic comparison of span schemes. Comparative studies of several approach viaducts in Jiangsu Province indicate that a reasonable boundary between medium- and tall-pier zones lies within 45–60 m. This range provides a general reference for similar projects.

3.4 Span Selection Principles and Engineering Examples for Different Pier Height Zones

3.4.1 Pier–Span Matching Principles and Representative Projects

The recommended pier-height-to-span ratio of 0.618–1.0, together with the classification into low-, medium-, and tall-pier zones, defines suitable span ranges for each zone. This approach coordinates pier–girder structural behavior, project economics, and aesthetics. The general selection principle is to prioritize a standard span of 30 m for low-pier zones, intermediate spans of 40–60 m for medium-pier zones, and longer spans of 70–90 m for tall-pier zones.

In practice, the optimal span arrangement must be established through a comprehensive assessment of site topography, geology, structural safety, project cost,

construction difficulty, and overall visual characteristics. The spans selected for the approach viaducts of four representative major river crossings constructed in Jiangsu Province over the past decade are summarized in Table 3 [2,3,6,7]. Different projects have adopted different standard spans even within similar pier height ranges.

Table 3 Spans selected for the approach viaducts of four representative major river crossings in Jiangsu Province

Project	Bridge type and opening status	Lanes	Approach length (m)	Max. pier height (m)	Pier height zone	Standard span
Husutong Yangtze River Bridge	Combined road–rail bridge; opened in 2020	Six, two-way	6,037	79	Low: $H \leq 25$ m	30 m
					Medium: $25 < H \leq 60$ m	50 m
					Tall: $60 < H \leq 79$ m	50 m
Wufengshan Yangtze River Bridge	Combined road–rail bridge; opened in 2021	Eight, two-way	5,061	69	Low: $H \leq 25$ m	30 m
					Medium: $25 < H \leq 50$ m	50 m
					Tall: $50 < H \leq 69$ m	50 m
Changtai Yangtze River Bridge	Combined road–rail bridge; opened in 2025	Six, two-way	10,828	52	Low: $H \leq 25$ m	30 m
					Medium: $25 < H \leq 52$ m	50 m
Zhangjinggao Yangtze River Bridge	Single-level highway bridge; under construction	Eight/six, two-way	15,063	67	Low: $H \leq 25$ m	30 m
					Medium: $25 < H \leq 45$ m	40 m
					Tall: $45 < H \leq 67$ m	70 m

Note: The maximum pier heights for the combined road–rail projects refer to the approach sections beyond the point of complete separation between the highway and railway structures. They exclude the maximum height of the expressway structure within the combined road–rail approach section.

3.4.2 Reasons for Differences in Span Selection

The main difference in Table 3 is that the three combined road–rail bridges, Husutong, Wufengshan, and Changtai, uniformly adopt 50-m spans in their medium- and tall-pier zones, whereas the highway-only Zhangjinggao Bridge adopts 40-m spans in the medium-pier zone and 70-m spans in the tall-pier zone. This difference primarily arises from whether the crossing carries both road and railway traffic or highway traffic alone.

• Span selection for combined road–rail bridges

The differences in medium- and tall-pier-zone spans between the Husutong, Wufengshan, and Changtai combined road–rail bridges and the highway-only Zhangjinggao Bridge arise from the combined constraints of loading conditions and visual harmony.

Compared with independent expressway bridges, combined road–rail bridges carry heavy railway loads, imposing more demanding structural requirements on the approach viaducts. Railway bridges in China follow a national series of standard spans. Standard simply supported girders use a calculation span of 48 m [8] and an overall girder length of 49.2 m. A mature standardized system has been developed for this span in terms of structural stiffness, vehicle–bridge coupled dynamic behavior, and precast erection. Consequently, a span of 49.2 m is typically adopted for railway approach viaducts of major river crossings [2,3,6,7]. Because the highway and railway structures share piers in the combined section (Figures 4 and 5), the highway approach spans in that section must match the railway approach spans.

Economic and structural analyses indicate that longer spans of 70–90 m are technically suitable for tall-pier zones. If different highway spans are adopted after the highway and railway approaches separate, pier positions may become misaligned, and girder soffit elevations may become incompatible. This increases the design workload and structural complexity and disrupts the consistency of bridge

elevation proportions, adversely affecting the overall appearance. For combined road–rail river crossings in Jiangsu Province, the expressway approach spans in medium- and tall-pier zones should therefore remain consistent with those in the combined section, using a standard span of 50 m (49.2 m). This arrangement maintains aligned highway and railway piers and coordinated structural proportions. Uniform spans and bridge types also facilitate factory precasting and standardized construction.



Figure 4 Rendering of the approach viaducts at the road–rail divergence and combined section

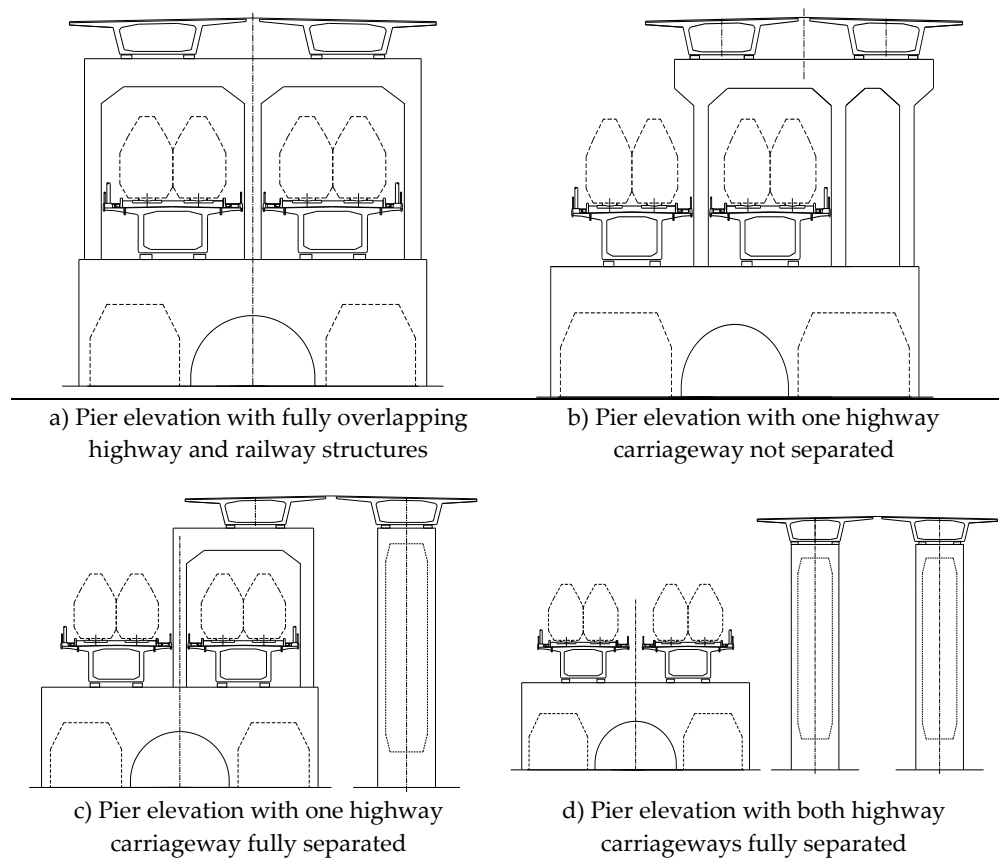


Figure 5 Progressive changes in bridge cross-sectional arrangement through the road–rail divergence and combined sections

- **Span selection for single-level highway bridges**

The Zhangjinggao Yangtze River Bridge [3] is a single-level expressway crossing without railway-related constraints, allowing for spans to be selected flexibly according to highway loading and pier height. Pier heights are 25–45 m in the medium-pier zone and 45–67 m in the tall-pier zone. Detailed structural checks were conducted for common spans of 40, 50, and 60 m in the medium-pier zone and 60, 70, and 80 m in the tall-pier zone. The alternatives were then assessed in terms of economics, technical performance, and aesthetics. The comparison results are presented in Tables 4 and 5.

Table 4 Comparison of span schemes for the medium-pier zone of the Zhangjinggao Yangtze River Bridge approach viaducts

Item/span	40 m	50 m	60 m
Feasible superstructures	T-girder/small box girder/box girder	T-girder/box girder	Box girder
Girder depth (m)	2.5/2/2.5	2.8/3	3.5
Construction method	Lifting/lifting/cast-in-place (precast)	Lifting/cast-in-place (precast)	Cast-in-place (precast)
Construction speed	Fast/fast/relatively slow (fast)	Fast/relatively slow (fast)	Relatively slow (fast)
Impact on topography and landform	Relatively large	Moderate	Relatively small
Harmony of pier height, span, and girder depth	Harmonious	Harmonious	Harmonious
Relative construction and installation cost (box-girder schemes)	1	1.03	1.27

Table 5 Comparison of span schemes for the tall-pier zone of the Zhangjinggao Yangtze River Bridge approach viaducts

Scheme	60-m box girder	70-m box girder	80-m box girder
Technical challenges	Mature technology and extensive experience		
Visual quality	More piers and relatively poorer appearance	Compatible with the main bridge; balanced span proportions, fewer piers, and good appearance	More balanced span proportions, the fewest piers, and the best appearance
Construction difficulty and risk	Mature technology and controllable project risks		Longer cantilevers create some construction difficulty
Impact on the ecological control area	32 piers on Minzhusha Island; greater wetland occupation	28 piers on the island; smaller impact	24 piers on the island; smallest impact
Relative cost	1.0	0.98	1.1

For the medium-pier zone with pier heights of 25–45 m, the 60-m box girder scheme has a high construction cost, demanding erection-equipment requirements and substantial construction difficulty, resulting in relatively poor cost-effectiveness. The overall costs of the 40- and 50-m box girder schemes differ only slightly, indicating broadly comparable economics. Although the 40-m scheme requires slightly more piers, it offers a wider choice of superstructure forms, including precast small box girders, with greater advantages in terms of overall economics and construction convenience. A standard span of 40 m was therefore selected for the medium-pier zone of this project.

For the tall-pier zone with pier heights of 45–67 m, a standard span of 70 m was selected after considering the site geology, relative costs of superstructure and substructure quantities, adaptability to curved alignments, and construction difficulty.

3.5 Summary

This section reviews the principal engineering characteristics of long approach viaducts constructed for major river crossings in Jiangsu Province over the past decade, identifying tall piers, variable pier heights, and pronounced gradients in pier-height distribution. Considering both bridge aesthetics and project economics, a recommended pier-height-to-span ratio of 0.618–1.0 was established, and suitable pier-height ranges were quantified for standard spans. Economic comparisons of representative projects support classification into low-, medium-, and tall-pier zones, with 25 m as the low-to-medium boundary and 45–60 m as the range for the medium-to-tall boundary. The four representative bridges also indicate differentiated span-selection principles. A 30-m span is preferred for low-pier zones. For combined road–rail bridges, railway constraints and structural compatibility favor a uniform 50-m span in medium- and tall-pier zones. For single-level highway bridges without railway constraints, 40- and 70-m spans are preferred for medium- and tall-pier zones, respectively. These findings provide practical selection guidance for similar projects.

4 Comprehensive Comparison of Superstructure Forms for Approach Viaducts

4.1 Applicability of Structural Forms

Superstructure selection is a key element of the overall design of approach viaducts at major river crossings. Once the span is determined, the girder scheme directly affects project cost, construction methods, and duration, as well as overall appearance, life-cycle operation and maintenance, and ecological benefits. Compared with conventional highway bridges, these approach viaducts are extensive, have widely varying pier heights and complex construction conditions, and require long service lives and demanding maintenance provisions. Superstructure selection must therefore consider span suitability, structural performance, construction convenience, construction economics, future maintenance feasibility, and visual harmony.

To clarify the applicability of different girder systems to long approach viaducts, five common superstructure forms were compared in terms of applicable spans, structural behavior, technical advantages and limitations, and construction cost: precast T-girders, precast small box girders, prestressed concrete box girders, steel–concrete composite girders, and steel box girders. A detailed comparison is presented in Table 6.

Table 6 Comparison of typical superstructure forms for approach viaducts of major river crossings

Structural form	Applicable span	Structural characteristics	Key advantages	Limitations	Construction cost
Precast T-girder	20–50 m	 A common highway girder with a simple cross-section and no bottom slab; good spanning capability and widespread application.	(1) Efficient precasting and broad applicability; no internal box cavity, facilitating quality control. (2) Convenient erection with simple methods and equipment. (3) No bottom slab, allowing for easy inspection and maintenance and favorable life-cycle economics.	(1) Limited transverse stiffness and structural integrity. (2) High lifting weight and inadequate lifting stability for long-span girders. (3) Numerous diaphragms give a less favorable appearance from below.	Low

Structural form	Applicable span	Structural characteristics	Key advantages	Limitations	Construction cost
Precast small box girder	25–40 m	 A lighter alternative to the cast-in-place box girder; a closed box section provides good torsional resistance and load capacity, with greater structural integrity than precast T-girders.	(1) Improves on the limited structural integrity and transverse stiffness of T-girders. (2) Efficient precasting, broad applicability, convenient erection, and simple methods and equipment. (3) Regular geometry and good appearance.	(1) Small internal cavities hinder detailed quality control during precasting. (2) Internal cavities cannot be inspected or repaired after completion, limiting maintenance. (3) Unsuitable for spans exceeding 40 m.	Lowest
Prestressed concrete box girder	25 m to over 90 m; maximum span of existing constant-depth precast box girders: 75 m [9]	 A mature, widely used, and highly versatile system with high overall stiffness and good structural integrity; suitable for curved alignments and variable-depth girders.	(1) High stiffness, load capacity, and structural integrity; suitable for a wide range of spans. (2) Attractive geometry and good visual compatibility. (3) Multiple construction options, including cast-in-place and segmental assembly; suitable for different structural systems, constant or variable depths, and long spans.	(1) Large cross-sections require substantial concrete and prestressing tendons, increasing construction cost. (2) Precast segmental assembly requires large lifting equipment and external prestressing, making construction control more demanding.	Relatively low
Steel–concrete composite girder	25 m to over 90 m	 Composite action uses concrete in compression and steel girders in tension, making use of material strengths to avoid cracking and instability.	(1) Low self-weight, high stiffness, and good seismic performance. (2) High degree of industrial prefabrication and limited on-site wet work, enabling efficient construction with less pollution. (3) Recyclable steel offers environmental benefits. (4) Shallow girders reduce substructure quantities and investment.	(1) Concrete tensile stresses in negative-moment regions are difficult to control, increasing construction difficulty. (2) Transport and lifting constraints require component-by-component steel-girder erection on land, limiting progress. (3) Corrosion protection is difficult in medium- and tall-pier zones, resulting in high long-term maintenance costs.	Relatively high
Steel box girder	25 m to over 90 m	 An all-steel load-bearing system with favorable material properties, low self-weight, and good stability; suitable for long-span bridges.	(1) Low self-weight, high stiffness, and good seismic performance. (2) Standardized factory fabrication provides controllable, consistent quality. (3) Low self-weight substantially reduces substructure quantities. (4) Suitable for whole-girder lifting or incremental launching, with good load capacity.	(1) Site and equipment constraints require segmental assembly on land, limiting progress; quality control of welding at height is difficult. (2) Corrosion protection is difficult in medium- and tall-pier zones, and deck-surfacing defects are common, resulting in high long-term maintenance costs. (3) All-steel construction is expensive.	High

Long approach viaducts generally use conventional spans of intermediate length. Selection should primarily consider adaptability to construction conditions, construction economics, and ease of operation and maintenance throughout the life cycle while meeting the requirements for standardized construction, rapid execution, and long-term operational safety. Under these principles, precast T-girders and precast segmental box girders are the preferred superstructure forms for long land-based approach viaducts. Precast small box girders, steel–concrete composite girders, and steel box girders have substantial limitations and are unsuitable for conventional land-based approaches.

Precast small box girders have relatively limited applicability and maintainability. Their effective span range is only 25–40 m, which is too narrow to satisfy the span requirements of medium- and tall-pier zones in long approach viaducts. Their small internal cavities also complicate the quality control of detailing and prestressing systems during precasting. After completion, the lack of accessible internal working space leaves areas that cannot be readily inspected or maintained, hindering routine defect detection and repair.

Although steel–concrete composite girders and steel box girders provide excellent mechanical performance and visual quality, their overall benefits are limited under conventional conditions for long land-based approach viaducts. First, corrosion protection work and subsequent maintenance are difficult in medium- and tall-pier zones. The limited durability of protective systems results in life-cycle maintenance costs substantially higher than those of precast concrete structures. Second, restricted sites, transport routes, and lifting conditions require large steel girders to be assembled from smaller components and segments. This slows construction and results in extensive work at height and onsite welding, increasing construction safety risks. Steel box girders are also expensive, and steel bridge decks are susceptible to defects such as cracking and water leakage, requiring substantial maintenance expenditure. These characteristics are inconsistent with the large-scale, standardized, and economical construction required for long approach viaducts. These two steel-based systems are therefore considered suitable only for special conditions, such as high seismic intensity or construction over water without lifting constraints, and are not recommended for conventional applications.

Precast T-girders offer substantial overall advantages and are well suited to long land-based approach viaducts. They are economical, use mature and straightforward construction methods, require no large specialized equipment, and allow for efficient erection and convenient site coordination. Their exposed structural surfaces also facilitate comprehensive routine inspection and maintenance. These features meet the principal requirements for the standardized, rapid construction and economical maintenance of approach viaducts.

Among continuous box-girder systems, cast-in-place box girders have high civil construction costs, involve substantial onsite wet work, and require long construction periods. Their quality and progress are strongly affected by environmental conditions and workmanship, making control more difficult. Precast segmental box girders offer a high degree of industrialization and assembly,

substantially reducing onsite wet work and improving construction efficiency. Their high stiffness, good stability, regular geometry, and favorable appearance suit both conventional spans and complex construction conditions. Their balanced structural performance, constructability, and economics make them the preferred continuous box-girder system for long approach viaducts [10].

4.2 Evidence from Regional Engineering Projects

Jiangsu Province has numerous large river-crossing bridges and extensive experience in constructing long approach viaducts, making its structural selection practices representative. From 2005–2015, precast T-girders and cast-in-place or precast box girders became the principal forms used for approach viaducts in the province. T-girders were adopted for the Jiangyin and Taizhou bridges, while box girders were used for the Runyang and Sutong bridges. Both girder systems demonstrated good engineering applicability. Over the subsequent decade (2015–2025), advances in bridge construction and increasingly diverse project settings further consolidated the dominant position of these two precast systems. The Guidelines for Structural Selection of Expressway Bridges in Jiangsu Province, issued in August 2020, likewise recommend T-girders or precast segmental box girders for approach viaducts with standard spans of 30–50 m [11], which is consistent with the findings of this study.

The superstructure forms selected for representative approach viaducts in Jiangsu Province and the corresponding selection criteria are presented in Tables 7 and 8, respectively.

Table 7 Superstructure forms selected for the approach viaducts of four representative major river crossings in Jiangsu Province

Project	Lanes	Pier-height zone	Standard span	Superstructure
Husutong Yangtze River Bridge	Six, two-way	Low: $H \leq 25$ m	30 m	T-girder
		Medium: $25 < H \leq 60$ m	50 m	T-girder
		Tall: $60 < H \leq 79$ m	50 m	T-girder
Wufengshan Yangtze River Bridge	Eight, two-way	Low: $H \leq 25$ m	30 m	Precast segmental box girder
		Medium: $25 < H \leq 50$ m	50 m	Precast segmental box girder
		Tall: $50 < H \leq 69$ m	50 m	Precast segmental box girder
Changtai Yangtze River Bridge	Six, two-way	Low: $H \leq 25$ m	30 m	Precast segmental box girder
		Medium: $25 < H \leq 52$ m	50 m	Precast segmental box girder
Zhangjinggao Yangtze River Bridge	Changes from eight to six, two-way, along the approaches	Low: $H \leq 25$ m	30 m	T-girder/small box girder
		Medium: $25 < H \leq 45$ m	40 m	T-girder
		Tall: $45 < H \leq 67$ m	70 m	Precast segmental box girder

Table 8 Basis for superstructure selection for the approach viaducts of four representative major river crossings in Jiangsu Province

Project	Basis for selection
Husutong Yangtze River Bridge	(1) The medium- and tall-pier zones use 50-m spans. Small box girders are unsuitable for spans exceeding 40 m; T-girders or box girders better support construction coordination and visual consistency. (2) The approaches are located in suburban areas with limited aesthetic requirements. (3) T-girders have advantages over box girders in economics, construction speed, and equipment requirements. Considering economics, visual quality, and construction coordination, T-girders are preferred.
Wufengshan Yangtze River Bridge	(1) The medium- and tall-pier zones use 50-m spans. Small box girders are unsuitable for spans exceeding 40 m; T-girders or box girders better support construction coordination and visual consistency. (2) The bridge has a wide deck carrying eight lanes in two directions. T-girders have limited transverse stiffness and structural integrity and are less durable than box girders. (3) The southern approach is located in an industrial park with certain aesthetic requirements. (4) Bridges at specific crossings along both approaches use box girders. Adopting the same system facilitates overall construction coordination in terms of efficiency and equipment investment. Considering structural behavior, visual quality, and construction coordination, box girders are preferred.
Changtai Yangtze River Bridge	(1) The medium- and tall-pier zones use 50-m spans. Small box girders are unsuitable for spans exceeding 40 m; T-girders or box girders better support construction coordination and visual consistency. (2) The northern approach follows Liuweigang Avenue at ground level for approximately 3 km. T-girders require large pier caps, wider piers, and substantial foundation quantities. Maintaining the avenue's traffic clearance would also require a higher bridge profile. The overall economics of T-girders and box girders are therefore comparable, favoring box girders. (3) The northern approach shares the avenue's alignment and the southern approach is in an urban area; both have certain aesthetic requirements. (4) Bridges at specific crossings along both approaches use box girders. The same system facilitates construction coordination in terms of efficiency and equipment investment. With comparable economics, visual quality and construction coordination favor box girders.
Zhangjinggao Yangtze River Bridge	(1) The tall-pier zone uses 70-m spans. Precast segmental box girders offer clear advantages over cast-in-place box girders and steel structures and are preferred for this zone. (2) The Yangtze River embankment location and longitudinal gradient leave only a short medium-pier section on the southern approach, which is therefore divided into low- and tall-pier zones. The low-pier zone uses 30-m spans, predominantly with eight lanes, and is in an urban setting with aesthetic requirements. Segmental box girders and small box girders were shortlisted. Although approximately 3 km shares the alignment of ground-level Highway S259, there is no clearance restriction. Small box girders have advantages in economics, construction speed, and equipment requirements and are preferred for the southern low-pier zone. (3) The northern approach has low-, medium-, and tall-pier zones. The low- and medium-pier zones use 30- and 40-m spans, respectively, predominantly with six lanes. They are suburban, have limited aesthetic requirements, and face no clearance restriction. With comparable economics between T-girders and small box girders, T-girders are preferred for easier inspection and better long-term life-cycle performance. Precast segmental box girders are preferred for the tall-pier zones. Under the differing conditions of the northern and southern approaches, economics and visual quality favor T-girders in the north and small box girders in the south.

A comparison of these four projects indicates that structural selection for long approach viaducts is governed by the combined effects of deck width, construction coordination, span, construction economics, and aesthetic requirements rather than pier height or span alone.

4.3 Quantitative Multicriteria Evaluation Model for Structural Selection

Sections 4.1 and 4.2 identify selection patterns from the technical applicability of structural forms and regional engineering cases, respectively. Both analyses rely mainly on qualitative judgments and accumulated experience, with the goal of improving objectivity and reproducibility. Accordingly, the principal governing factors and their relative importance were inferred from the selection processes of the four case-study bridges. The analytic hierarchy process (AHP) [12,13] was introduced to establish a quantitative model for approach-viaduct structural selection. The Changtai Yangtze River Bridge was used to demonstrate the complete calculation from individual criterion scores to overall scores and rankings, enabling quantitative and reproducible selection outcomes.

4.3.1 Evaluation Criteria

The classification of the selection criteria for the four bridges in Table 8 indicates that construction economics and construction conditions were the most important factors emphasized across all four projects. Structural suitability and aesthetics followed, with structural suitability becoming decisive under particular conditions. For example, the wide deck of the Wufengshan Bridge makes the limited transverse stiffness and durability of T-girders unfavorable. Ease of operation and maintenance had the smallest overall influence and affected only certain decisions, such as the preference for T-girders on the northern approach of the Zhangjinggao Bridge because of inspection accessibility and life-cycle economics. Five governing criteria were therefore identified: structural suitability (B1), construction conditions (B2), construction economics (B3), aesthetics (B4), and ease of operation and maintenance (B5). A three-level hierarchy comprising the goal, criteria, and alternatives was established, as shown in Table 9.

Table 9 Evaluation hierarchy for approach-viaduct superstructure selection

Goal level A	Criteria level B	Alternative level C
Optimal approach-viaduct superstructure	B1 Structural suitability	C1 Precast T-girder
	B2 Construction conditions	C2 Precast small box girder
	B3 Construction economics	C3 Precast segmental box girder
	B4 Aesthetics	C4 Steel-concrete composite girder
	B5 Ease of operation and maintenance	C5 Steel box girder

4.3.2 Determination of Criterion Weights

A pairwise comparison matrix for the criteria was constructed using the 1–9 scale (Table 10). On the basis of the common patterns in the four case studies, the criteria were ranked in descending order of importance as follows: construction economics, construction conditions, structural suitability, aesthetics, and ease of operation and maintenance.

Table 10 Pairwise comparison matrix and weights for the criteria

A	B1 Structural suitability	B2 Construction conditions	B3 Construction economics	B4 Aesthetics	B5 Ease of operation and maintenance	Weight
B1 Structural suitability	1	1/2	1/2	2	3	0.191
B2 Construction conditions	2	1	1/2	2	3	0.253
B3 Construction economics	2	2	1	2	4	0.351
B4 Aesthetics	1/2	1/2	1/2	1	2	0.132
B5 Ease of operation and maintenance	1/3	1/3	1/4	1/2	1	0.073

Using the eigenvector method (sum-product method), the criterion weights were 0.351 for construction economics, 0.253 for construction conditions, 0.191 for structural suitability, 0.132 for aesthetics, and 0.073 for ease of operation and maintenance. The maximum eigenvalue was $\lambda_{\max} = 5.117$, and the consistency ratio was $CR = 0.026 < 0.1$. The matrix therefore passed the consistency test, indicating a reasonable and reliable allocation of weights.

4.3.3 Quantitative Evaluation of the Changtai Yangtze River Bridge

The low-pier zone of the land-based approach viaducts of the Changtai Yangtze River Bridge, with 30-m spans, was selected for evaluation. Under these conditions, the northern approach follows Liuweigang Avenue for approximately 3 km, while the southern approach is located in an urban area. Each of the five structural forms was scored on a 1–9 scale, with higher scores indicating better performance (Table 11). With respect to structural suitability, box girders received the highest score of 9 because of their structural integrity, whereas precast T-girders scored 6 because of their limited transverse stiffness. With respect to construction conditions, precast T-girders and precast segmental box girders scored 8 owing to their high degree of prefabrication, whereas steel box girders scored 5 because quality control of welding at height is difficult. For construction economics, the shared alignment increases the substructure dimensions required for T-girders, reducing their economic advantage and resulting in a score of 6; steel box girders had the highest cost and a score of 3. With respect to aesthetics, box girders scored 9 for their regular geometry, whereas precast T-girders scored 4 because their numerous diaphragms produce a less favorable appearance from below. For ease of operation and maintenance, precast T-girders scored 9 because their exposed surfaces facilitate inspection, while precast small box girders scored 4 because their internal cavities are difficult to inspect.

Table 11 Individual criterion scores for five structural forms in the low-pier zone of the Changtai Yangtze River Bridge (1–9 scale)

Alternative	Structural suitability (0.191)	Construction conditions (0.253)	Construction economics (0.351)	Aesthetics (0.132)	Ease of operation and maintenance (0.073)
C1 Precast T-girder	6	8	6	4	9
C2 Precast small box girder	7	7	6	7	4
C3 Precast segmental box girder	9	8	6	9	7
C4 Steel–concrete composite girder	8	6	4	8	5
C5 Steel box girder	8	5	3	8	4

The individual criterion scores were multiplied by their respective weights and summed to obtain the overall score for each alternative (Table 12). For example, the overall score of the precast T-girder alternative (C1) was calculated as follows:

$$S(C_1) = 6 \times 0.191 + 8 \times 0.253 + 6 \times 0.351 + 4 \times 0.132 + 9 \times 0.073 = 6.46$$

Table 12 Overall scores and rankings of the five structural forms in the low-pier zone of the Changtai Yangtze River Bridge

Alternative	Structure (0.191)	Construction (0.253)	Economics (0.351)	Aesthetics (0.132)	Operation and maintenance (0.073)	Total score	Rank
C1 Precast T-girder	1.15	2.02	2.11	0.53	0.66	6.46	2
C2 Precast small box girder	1.34	1.77	2.11	0.92	0.29	6.43	3
C3 Precast segmental box girder	1.72	2.02	2.11	1.19	0.51	7.55	1
C4 Steel–concrete composite girder	1.53	1.52	1.40	1.06	0.37	5.87	4
C5 Steel box girder	1.53	1.27	1.05	1.06	0.29	5.19	5

As shown in Table 12, the alternatives for the Changtai project are ranked as follows: precast segmental box girders (7.55) > precast T-girders (6.46) > precast small box girders (6.43) > steel–concrete composite girders (5.87) > steel box girders (5.19). Precast segmental box girders received the highest overall score and were identified as the optimal alternative, which is consistent with the scheme actually adopted for the Changtai Yangtze River Bridge. This agreement supports the rationality and validity of the model. Although precast T-girders perform well in terms of construction conditions and ease of operation and maintenance, their reduced economic advantage under shared-alignment conditions and lower aesthetic score placed them second overall. Under suburban conditions without a shared alignment, restoring the T-girder economic score to 9 increased its overall score to 7.51, reducing the difference from segmental box girders (7.55) to 0.04. These findings confirm that precast T-girders and precast segmental box girders each have favorable application conditions and should be evaluated quantitatively for specific project settings.

4.4 Summary

This study presents a comprehensive comparison of superstructure forms for approach viaducts of major river crossings. First, five common structural forms—precast T-girders, precast small box girders, prestressed concrete box girders, steel–concrete composite girders, and steel box girders—were systematically compared in terms of applicable spans, structural behavior, technical advantages and limitations, and construction cost. Precast T-girders and precast segmental box girders were identified as the preferred forms for long land-based approach viaducts. Second, the Husutong, Wufengshan, Changtai, and Zhangjinggao bridges were examined to identify selection patterns arising from the combined effects of deck width, pier height, span, economics, and aesthetic requirements. To improve the objectivity of qualitative judgments, five governing factors were inferred from the case studies: structural suitability, construction conditions, construction economics, aesthetics, and ease of operation and maintenance. An AHP-based quantitative model was established, with weights of 0.191, 0.253, 0.351, 0.132 and 0.073. Finally, the complete calculation from individual criterion scores to overall scores and rankings was demonstrated for the low-pier zone of the Changtai Yangtze River Bridge. Precast segmental box girders achieved the highest score of 7.55, which is consistent with the adopted scheme, supporting the validity of the model and enabling quantitative and reproducible selection. The findings provide a theoretical and practical reference for superstructure selection in similar long approach viaducts.

The selection logic for superstructure forms of land-based approach viaducts under conventional conditions is shown in Figure 6.

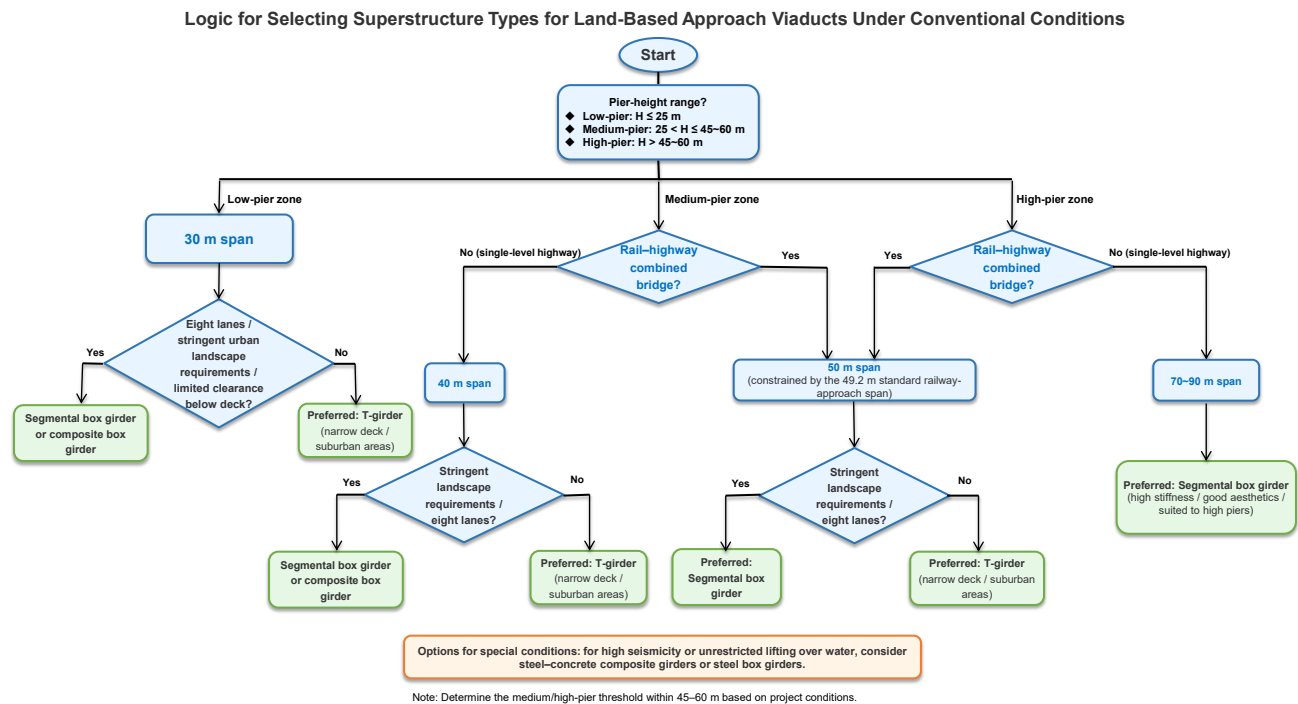


Figure 6 Selection logic for superstructure forms of land-based approach viaducts under conventional conditions

5 Conclusions

The approach viaducts of the Husutong, Wufengshan, Changtai, and Zhangjinggao Yangtze River bridges in Jiangsu Province were examined through the two key stages of span selection and structural comparison. Typical structural forms for long approach viaducts were systematically compared, and selection recommendations were developed. The main conclusions are as follows:

- (1) Long approach viaducts of major river crossings are characterized by tall piers, substantial longitudinal gradients in pier height, and large construction scales. Appropriate pier–span matching and superstructure selection are essential for controlling structural safety, project cost, construction difficulty, and visual quality.
- (2) On the basis of bridge aesthetics and economic checks, an optimal pier-height-to-span ratio of 0.618–1.0 was established, and suitable pier-height ranges were quantified for standard spans of 30–90 m. Comparisons of construction and installation costs for different pier-height and span combinations support three zones: a low-pier zone at ≤ 25 m, a medium-pier zone extending from 25 m to a project-dependent boundary of 45–60 m, and a tall-pier zone at or above that boundary. The resulting tiered span-selection framework recommends 30 m for low-pier zones, 50 m for medium- and tall-pier zones of combined road–rail bridges, and 40 and 70 m for medium- and tall-pier zones of single-level highway bridges, respectively.
- (3) Under conventional conditions, the preferred forms for long land-based approach viaducts are precast T-girders and precast segmental box girders. T-girders offer low cost, rapid construction, and convenient maintenance and are suited to short and intermediate spans in low- and medium-pier zones and suburban sections. Segmental box girders provide high stiffness and favorable aesthetics and are suited to urban settings, wide decks, and tall-pier zones.

Owing to construction constraints and relatively high construction and maintenance costs, steel–concrete composite girders and steel box girders are retained as alternatives only for special conditions, such as high seismic intensity or construction over water without lifting constraints.

- (4) An AHP-based quantitative evaluation model was established using five governing factors inferred from the case studies: structural suitability, construction conditions, construction economics, aesthetics, and ease of operation and maintenance. Their respective weights are 0.191, 0.253, 0.351, 0.132, and 0.073 ($\lambda_{\max} = 5.117$; $CR = 0.026 < 0.1$). In the low-pier zone of the Changtai Yangtze River Bridge, precast segmental box girders had the highest overall score of 7.55, which is consistent with the actual scheme. This agreement supports the model's validity and enables quantitative and reproducible selection outcomes.
- (5) Span- and girder-type selection is governed by the combined effects of structural behavior, construction conditions, economics, maintenance feasibility, visual harmony, and construction coordination. An optimal scheme cannot be determined from pier height or span alone; a comprehensive assessment of the project location, geology, and economic conditions is needed.

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AUTHOR BIOGRAPHIES

	Wei Zhao M.Eng. Senior Engineer. Working at China Design Group Co., Ltd. Research Direction: Bridge Design. Email: 106399227@qq.com
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