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DANJIANG BRIDGE, TAIWAN PART I.

LIST OF CONTENTS

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Dear Readers

The first special edition about the Danjiang Bridge in Taiwan describes it from the first steps, from concept to modelling, architecture and design of the bridge with emphasis on the pylon.

When complete, the bridge will stand not only as the world's longest single-tower asymmetric cable-stayed bridge but also as a testament to international collaboration, digital innovation, and architectural vision.

In December, we will publish the second edition, focusing on various aspects of its design and construction, including environmental considerations, seismic resistance and durability, and the design of the excavation and retaining system used for the cofferdam during foundation construction.

The December edition will also feature a comprehensive construction gallery, showcasing the bridge's progress from the start of construction to its current state.

Later on, in the February 2026 e-BrIM magazine, we will publish two more articles – one about 3D Digital Bridge Design, Integration, and Management, and an article about monitoring of the bridge.

I want to thank **all authors, and also people** *helping us prepare both special editions, especially* **Kilian Karius***, LAP, who has been assisting us with both editions, connecting us with relevant stakeholders, and helping with many other things. Further, I would like to thank* **Peter Walser** *of LAP for bringing up the idea of publication, as well as other people, especially* **Wen-Kai (A-Kai) Chen** *and* **Johnny Ro***.*

And I want to thank our Editorial Board, especially **Richard Cooke** *and* **David Collings***, for their assistance with this edition and review of the articles.*

We also thank **our partners** *for their continuous support.*

The next e-mosty will be published on 20th December.

The next e-BrIM will be released on 20th October. It will be the first edition to be published also in Spanish, www.e-brim.com/es.

We welcome your articles for both the e-BrIM and e-mosty magazines. You can contact me at magda@e-mosty.cz.

Magdaléna Sobotková

Chief Editor

e-mosty

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is an international, interactive,
peer-reviewed magazine about bridges.

It is published at www.e-mosty.cz and can be read
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It is published quarterly: 20 March, 20 June,
20 September and 20 December.
The magazines stay **available online**
on our website as pdf.

The magazine **brings original articles about bridges and bridge engineers** from around the world.
Its electronic form enables the publishing
of high-quality photos, videos, drawings, links, etc.

We aim to include **all important and technical information** and show the grace and beauty
of the structures.

We are happy to provide media support for important bridge conferences, educational activities, charitable projects, books, etc.

Our Editorial Board comprises bridge engineers
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The readers are mainly bridge engineers, designers, constructors and managers of construction companies, university lecturers and students,
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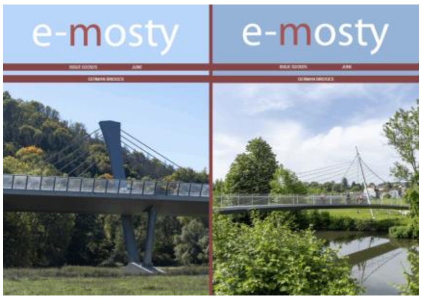

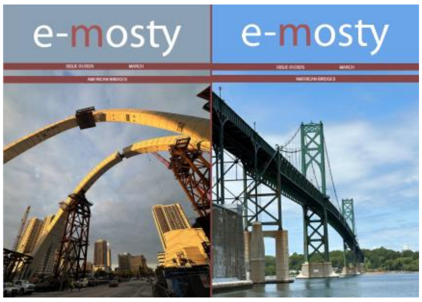

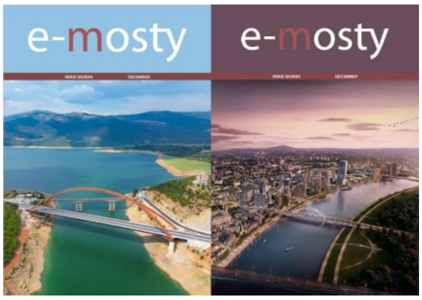

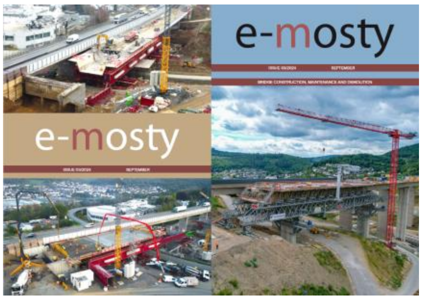

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It is typically published three times a year: 20 February, 20 May and 20 October.

The magazines stay **available online** on our website as pdf.

The magazine brings **original articles** about **bridge digital technology** from early planning till operation and maintenance, **theoretical and practical innovations, Case Studies** and much more from around the world.

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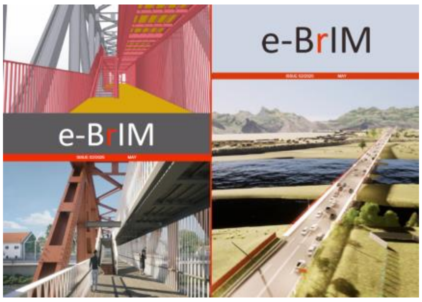

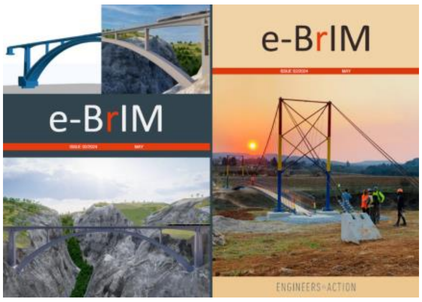

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DANJIANG BRIDGE, TAIWAN

View of the Bridge

Planned Opening of the bridge to traffic: 2026

Type of the bridge: Cable-Stayed with one pylon

Length and spans: 920 m (75 m + 75 m + 450 m + 175 m + 75 m + 70 m)

Height of the pylon: 200 m

Navigation: 200 m wide navigation channel with a 20 m clearance

Width: 44.7 m between railings, expanding to 55.3 m in the cable-stayed section

Lanes: Two lanes in each direction, 2.5 m lane for motorbikes and a 5 m wide walkway

Location: Tamsui and Bali in northern Taiwan

Owner: Directorate General of Highways, Taiwan, R.O.C.

Owner's Project Manager: TYLin Taiwan

Employer: Kung Sing Engineering Co. (KSECO)

Employer's Technical Advisor: Wiecon

Architect: Zaha Hadid Architects

Design Team: Sinotech Engineering Consultants and Leonhardt Andrä und Partner (LAP)

Visualisation: MOREAN

Wind Engineering: EZI-Ingenieure

Stay Cables: DYWIDAG

Exp. joints and bearings: mageba

Formwork: PERI

Danjiang Bridge Main Span Closure on 16th September 2025

DANJIANG BRIDGE ARCHITECTURAL DESIGN

Shao-wei Huang, Associate Director
Zaha Hadid Architects

Figure 1: Night view of the Bridge

INTRODUCTION

In the ever-changing urban landscape of Taiwan, infrastructure is more than just a means of transport. It reflects ambition, progress, and a vision for the future.

The Danjiang Bridge stands as a bold statement of Taiwan's infrastructural and cultural evolution. Situated at the estuary of the Tamsui River, where land, water, and sky converge in dramatic harmony, the bridge is not only a vital piece of transport infrastructure but also an iconic landmark for Taiwan.

The Sinotech Engineering Consultants and Leonhardt, Andrä & Partner joint venture with Zaha Hadid Architects won the international competition to design the new Danjiang Bridge in Taipei for the Directorate General of Highways, Taiwan, R.O.C., in 2015.

The success of the Danjiang Bridge competition entry reflects the power of international collaboration. Zaha Hadid Architects, renowned for their fluid architectural language and innovative use of technology, partnered with **Sinotech Engineering Consultants (Taiwan)** and **Leonhardt, Andrä & Partner (Germany)**.

This collaboration combined global design expertise with local engineering knowledge and regulatory understanding.

The international jury awarded the team **first place**, ahead of other distinguished competitors, including CECI with Nippon Engineering Consultants, Aecom Asia with Resources Engineering Services, and MAA Group with Cowi. The outcome demonstrated how architectural vision and engineering ingenuity could converge into a compelling, buildable proposal.

When completed, the Danjiang Bridge will claim an extraordinary feat of engineering: the **world's longest single-tower, asymmetric cable-stayed bridge.** Yet, its design goes beyond the technical superlative. By reducing traffic congestion, extending public transport connectivity, and integrating seamlessly into the ecological and cultural landscape of the Tamsui estuary, the project embodies a holistic approach to infrastructure in the twenty-first century.

CONTEXT AND URBAN SIGNIFICANCE

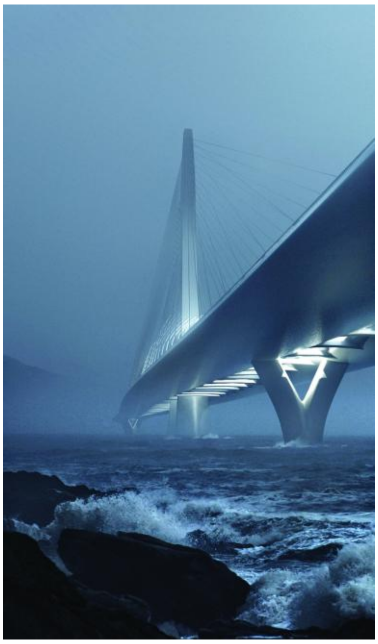
New Taipei City is a city shaped by its rivers. The Danshui River, also known as the Tamsui River, is particularly significant, having historically served as a trade artery and today forming a natural boundary between the dense urban settlements on its eastern banks and the growing communities on its western side.

The existing Guandu Bridge, located upriver, was built in the 1980s and has long struggled to cope with heavy traffic volumes. As Taipei's northern coast developed—spurred by the rapid expansion of the **Port of Taipei (Taipei Harbour)**, Taiwan's busiest shipping hub—the need for a new crossing became undeniable.

The Danjiang Bridge is designed to respond to this demand, linking **Highways 2 and 15** with the **West Coast Expressway** (Route 61) and **Bali-Xindian Expressway** (Route 64).

In addition to alleviating road congestion, the bridge introduces a new dimension of multimodal connectivity. By carrying an extension of the **Danhai Light Rail Transit (DHLRT)** across the river, the bridge ties the western town of Bali and the port directly into Taipei's metropolitan transit system.

This integration of road, rail, and pedestrian connections within a single structure exemplifies Taiwan's forward-thinking approach to urban mobility.



Figures 2 and 3: Renderings of the pylon

Figure 4: Connection of the Bridge to its surrounding environment

THE NATURAL SETTING: THE DANSHUI RIVER ESTUARY

Beyond its functional purpose, the Danjiang Bridge is deeply attuned to its site. The Danshui River estuary is a place of ecological richness and cultural resonance. On the eastern bank lies Tamsui, a historic town with colonial architecture, temples, and waterfront promenades. On the western bank lies Bali, renowned for its cultural sites and growing recreational hub.

Each evening, residents and visitors gather along the riverbanks to witness the **sunset over the Taiwan Strait**. This daily ritual has made the estuary one of northern Taiwan's most beloved scenic spots. The design of the Danjiang Bridge acknowledges this cultural practice, ensuring that the structure does not obstruct these views but instead frames them.

Equally important is the ecological integrity of the estuary. As a transitional zone between the river and the ocean, it supports a diverse ecosystem.

In line with Taiwan's increasing commitment to environmental protection, the bridge was designed to minimise its footprint within the riverbed, reducing potential disruption to aquatic habitats.

DESIGN CONCEPT: AN ELEGANT LANDMARK

At the heart of the design is **a single concrete tower** rising with quiet elegance from the eastern bank. From this tower, an array of steel cables fans out asymmetrically to support a **920m long deck**. This cable-stayed configuration is structurally efficient while visually restrained.

The tower itself has been engineered to be as slender as possible, its geometry refined to achieve both structural stability and architectural clarity. Positioned strategically, it avoids obstructing river navigation channels while preserving unobstructed sunset views. Its placement also minimises the need for in-water supports, protecting the estuary.

The **asymmetrical composition** sets the Danjiang Bridge apart from conventional cable-stayed bridges. Rather than relying on two balanced towers, the single tower creates a striking sculptural presence.

The deck, gracefully extending from one side, achieves both economy and drama, presenting a dynamic gesture across the river.

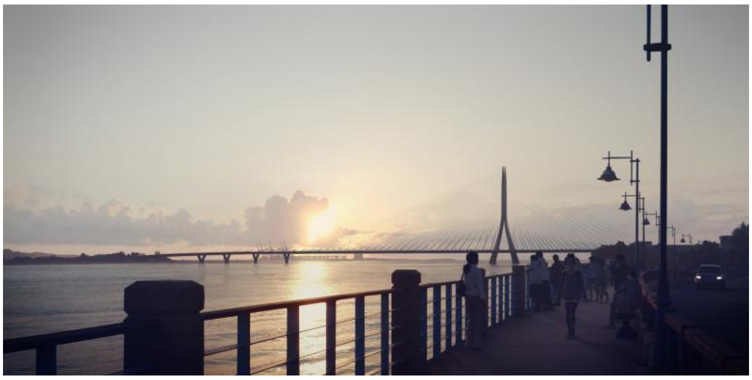
The bridge is designed not merely as infrastructure but as a civic landmark. From afar, its silhouette will define the horizon, a symbol of connection between Taipei and the world beyond. From within, whether crossing by car, train, or on foot, users will experience a unique journey over water, framed by cables and sky.

HARMONISING INFRASTRUCTURE, ECOLOGY, AND CULTURE

The Danjiang Bridge exemplifies a new paradigm of infrastructure design—one that is not isolated from its context but harmonised with it. Its single mast reduces ecological disruption, while its careful siting respects cultural practices of sunset viewing.

Its design embodies elegance and restraint, avoiding visual dominance over the river while asserting a clear architectural presence.

This sensitivity reflects Zaha Hadid Architects' broader design philosophy: that architecture should engage with landscape, culture, and community in ways that are transformative yet respectful.



Figures 5 and 6: Sunset over the Strait with a rendering of the bridge

Figure 7: The deck and pylon sections

ENGINEERING EXCELLENCE: WORLD'S LONGEST SINGLE-TOWER CABLE-STAYED BRIDGE

The designation of the Danjiang Bridge as the **world's longest single-tower, asymmetric cable-stayed bridge** is not simply a record-breaking boast. It is the outcome of an engineering solution optimised for site conditions, urban needs, and environmental sensitivities.

The single-tower solution dramatically reduces the number of foundations required in the river, lowering environmental impact and construction complexity. At the same time, it requires rigorous engineering precision to balance the asymmetrical forces across a nearly 1km long deck.

Working with structural specialists Leonhardt, Andrä & Partner, the design team employed advanced modelling and simulation to test wind loads, seismic resilience, and long-span dynamics. The mast's proportions were refined iteratively to ensure stability without unnecessary bulk. The result is a structure that is **both lighter and more economical** than multi-tower alternatives, while achieving an iconic profile.

DIGITAL INNOVATION: CLOUD-BASED 3D DESIGN

The complexity of the Danjiang Bridge demanded more than traditional design coordination. With teams distributed across Europe and Asia, and with the high precision requirements of long-span bridge engineering, the project adopted an **integrated cloud-based 3D design methodology**.

At the core was **CATIA V6 (3D Experience)**, a platform typically associated with aerospace and automotive industries. Its adoption for bridge design signalled a new era in infrastructure delivery. The system provided a **shared data environment** where architects, engineers, and consultants could author, review, and coordinate models in real-time, regardless of their geographical location.

Design information was authored directly in CATIA, ensuring consistency and accuracy. Specialist engineering analyses—such as structural optimisation, wind tunnel simulation, and seismic modelling—were integrated through cyclical data exchange, with custom scripts bridging external tools back into the master model.

The result was a **Digital Mockup** that served not just as a visualisation tool but as a **solid model representation of the design itself**.

BEYOND DESIGN: INTEGRATION INTO PROCUREMENT

One of the most innovative aspects of the Danjiang Bridge project lies in how its digital methodology influenced procurement.

Traditionally, government procurement in Taiwan has relied on 2D drawings for tender documentation. This approach often requires contractors to reconstruct 3D models at their own expense, introducing inefficiency and the potential for error.

Figure 8: Walkway for pedestrians and bicycles

For the Danjiang Bridge, the Employer's Requirements mandated a contractor-led **BIM (Building Information Modelling) process.** This created an unprecedented opportunity to use the **3D CATIA data as part of the contract documentation.** By elevating the digital model into contractual status, the project eliminated redundant 3D model reconstruction and established a **single source of truth** for design intent, construction detailing, and lifecycle management.

This approach positioned the Danjiang Bridge at the forefront of digital delivery in infrastructure, setting a precedent for future projects in Taiwan and beyond.

A BRIDGE FOR PEOPLE

While the Danjiang Bridge addresses pressing infrastructural needs, it also prioritises human experience. The bridge deck accommodates not only vehicles and trains but also **pedestrian pathways**, inviting people to walk across the Danshui River and engage with the landscape from a new perspective.

For locals, the bridge will significantly reduce travel times, linking Bali and Tamsui within minutes. For tourists, it offers a new vantage point over one of Taiwan's most picturesque estuaries. The integration of light rail encourages sustainable mobility, reducing reliance on private cars and contributing to Taiwan's low-carbon ambitions.

CONCLUSION: A SYMBOL OF CONNECTION

The Danjiang Bridge represents more than a transport crossing. It is a physical and symbolic connector—between east and west banks, between road and rail, between local communities and global networks. It embodies Taiwan's capacity to embrace innovation while honouring natural and cultural heritage.

When complete, it will stand not only as the world's longest single-tower asymmetric cable-stayed bridge but also as a testament to international collaboration, digital innovation, and architectural vision.

For Taiwan, it will become a new national landmark, framing timeless sunsets and futures alike.

For the world, it will be a case study in how infrastructure can inspire as much as it serves.

All renders in this article show

the Danjiang Bridge by Zaha Hadid Architects

Credits:

Figures 1, 4, 7, 8 Render by VisualArch

Figures 2, 3, 5, 6, 9 Render by MIR

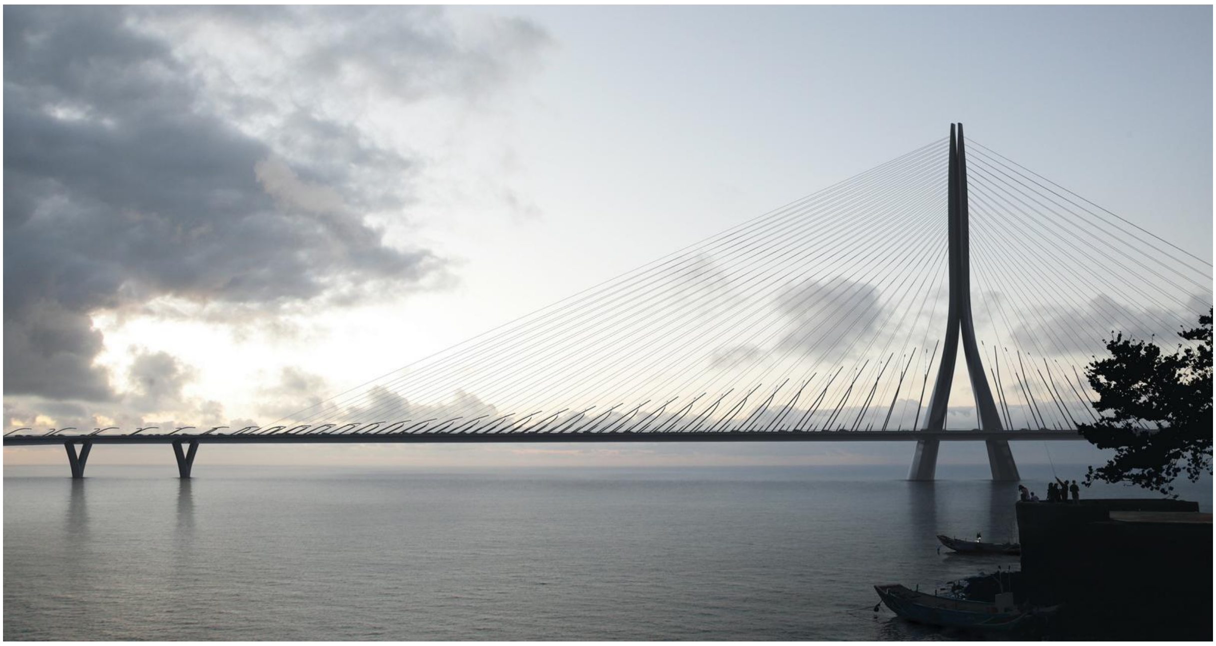


Figure 9: Rendering of the complete bridge

THE DANJIANG BRIDGE METHOD: STRATEGIC VISUALISATION THAT ENHANCES PUBLIC TRUST

Philipp Eckhoff, MOREAN

Figure 1: Visualisation of the complete bridge

THE CHALLENGE EVERY INFRASTRUCTURE LEADER FACES

When Zaha Hadid Architects designed the Danjiang Bridge, they faced a problem you know well: *How do you convince the competition jury of your design proposal and win the competition?*

The stakes were high, and it was necessary to consider that:

- Bold architecture often triggers scepticism;
- Complex engineering can breed doubt;
- Without public support, even brilliant infrastructure projects can stall, face costly delays, or worse… get cancelled.

That was where we stepped in... initially as visualisation producers, but what happened next transformed how we work with infrastructure clients today.

HOW ONE PROJECT CHANGED EVERYTHING (AND CREATED OUR METHOD)

We started this project the traditional way:

- Create a competition film
- Make it look impressive
- Meet the deadline

But the Danjiang Bridge demanded more. As mentioned above, the design was bold and the engineering complex. We realised **that pretty pictures would not be enough to build the trust this project needed.**

When we realised that, we evolved our approach in real-time:

Competition Film: Instead of just showcasing beauty, we focused on building trust in feasibility through clear construction sequences and real-world context. Every shot had to prove that the bridge was not just beautiful, but also buildable and safe.

VR Installation: The client requested that we create a showroom experience. We built a virtual reality experience that allows visitors to cross the bridge by car, bike, or on foot. Suddenly, abstract plans became a visceral understanding.

Strategic Breakthrough: We realised we were not just making visualisations... we were solving communication problems for different stakeholder groups. Each audience required different proof points, emotional connections, and levels of detail.

This project taught us that successful infrastructure visualisation is not about the images. It is about the strategy behind them.

Video 1: The Serene Dancer of the Night

Click on the image to play the video on Vimeo

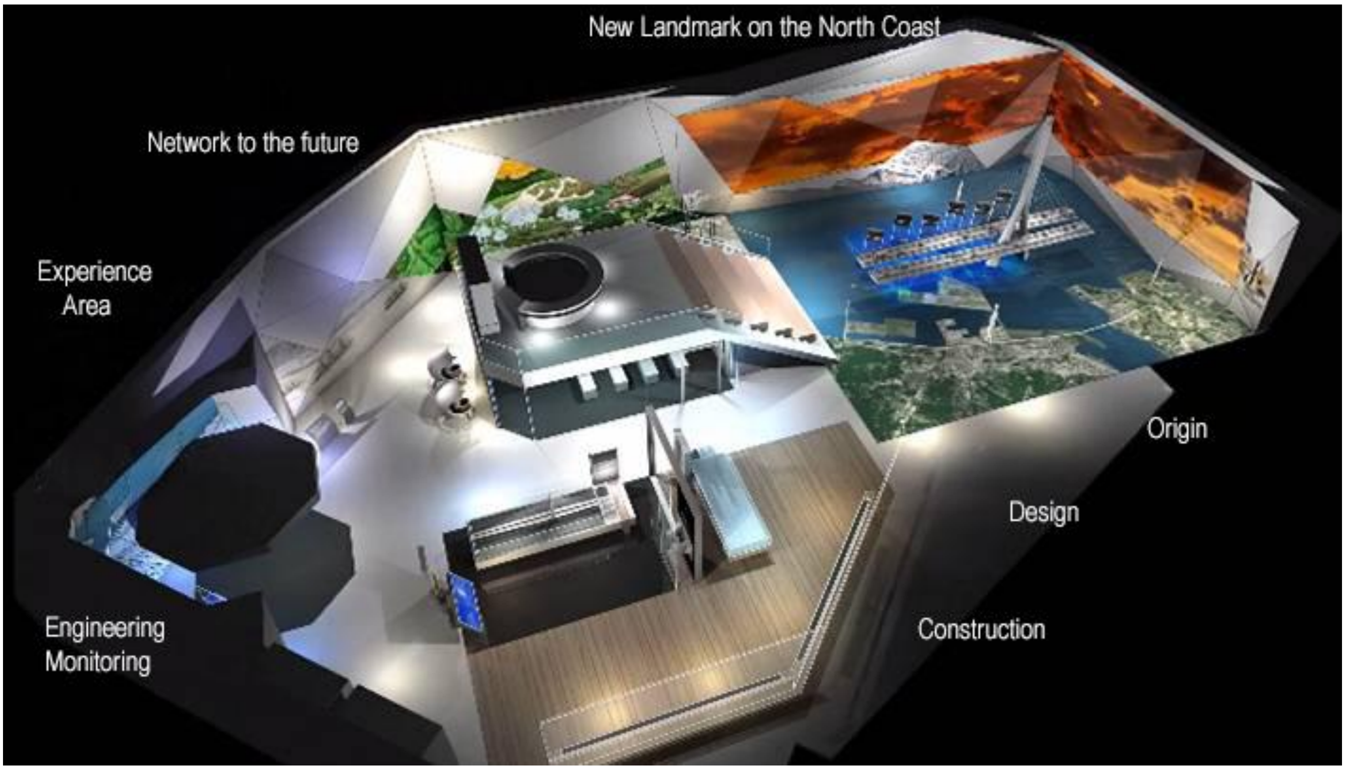


Figure 2: On-site showroom for the bridge project

Figure 3: Virtual reality experience of the bridge, presented in the showroom

FROM PRODUCERS TO STRATEGIC PARTNERS: WHAT WE LEARNED

Before Danjiang, we thought our job was to make technical designs look appealing.

After Danjiang, we understood that our real value was connecting design teams with their stakeholders; translating complex engineering into a confident understanding for everyone who needed to say "yes."

The lessons from this single project became the foundation of how MOREAN works today:

- **Evidence first**: Build trust by showing how things work, not just how they look
- **Audience mapping**: Engineers, decision-makers, residents, and media all need different messages
- **One master, many outputs**: Smart planning lets one project serve multiple communication needs
- **Early involvement**: The most significant impact happens when we shape strategy, not just execute visuals

Below is a table comparing two ways we work, with a focus on the differences we now make.

The old way (how we used to work)	The new way (what we learned)
Focus on beautiful images	Focus on communication outcomes
One film fits all audiences	Targeted content for each stakeholder group
Called in when the design is finished	Involved when strategy matters most
Deliver visuals and leave	Partner through the entire project lifecycle

THE METHOD THAT EMERGED

As the work on the Bridge continued with all the challenges, we evolved a method that can be described in five words: **Discover → Design → Build → Validate → Deliver**

Discover:

We learned to map stakeholders and their specific concerns first.

- Engineers want structural logic.
- Residents want safety assurance.
- Media wants a compelling story.
- Decision-makers want confident feasibility.

Design:

Based on those insights, we now create targeted content strategies. Each piece serves multiple purposes while speaking clearly to its primary audience.

Early involvement means:

- Visualisation strategy aligned with project goals from day one
- Content that grows with your project through all phases
- Fewer surprises, faster approvals, consistent quality
- Long-term partnerships that get better with every collaboration

Build:

Our data discipline emerged from necessity.

- One source of truth.
- No duplicate geometry.
- No guessing.
- Files are organised by date and discipline.

Validate:

We found that lightweight reviews with the right decision-makers are more effective than hour-long calls with 50 people.

Deliver:

Multiple outputs from one master project - competition submissions, public meetings, press conferences, and social media.

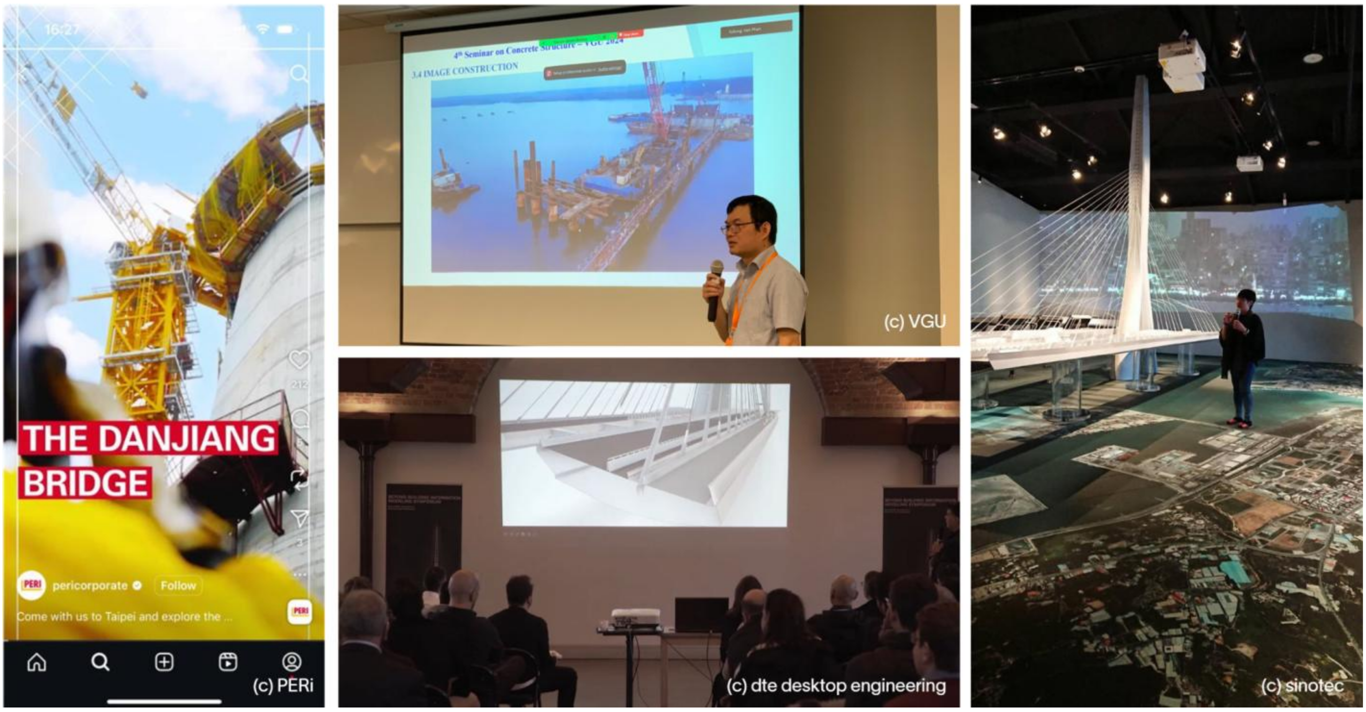


Figure 4: Jury Presentation, Public Presentation, Team meeting, Trade Show, Board Meeting and Social Media

Figure 5: Visualisation of the construction process

WHAT THIS EVOLUTION MEANS FOR THE FUTURE

The transformation we underwent with the Danjiang Bridge has enabled us to develop a strategic approach that our clients benefit from today.

For CEOs and Decision-Makers:

- Reduced the risk of public opposition derailing projects
- Faster approvals through clear, confident presentations
- One visualisation strategy that serves multiple business needs

For Project Managers:

- No more last-minute visualisation surprises
- Clear deliverables, owners, and deadlines from day one
- Reusable assets that multiply ROI across project phases

For Technical Teams:

- Visualisations that accurately represent your engineering
- Data workflows that integrate with your existing processes
- Clear communication of complex concepts to non-technical stakeholders

For Stakeholder Relations:

- Public content that builds trust rather than confusion
- Consistent messaging across all project communications
- Virtual experiences that let communities envision benefits

CONCLUSION

We learned through experience what we now know from the start: The best infrastructure visualisation strategies begin before the final design, when stakeholder concerns can still be addressed, when public input can still be integrated, and when communication can still shape outcomes. The strategic approach should be taken from day one.

MOREAN evolved from visualisation producers to strategic communication consultants through projects like the Danjiang Bridge.

DESIGN AND CONSTRUCTION OF THE DANJIANG SINGLE TOWER CABLE STAYED BRIDGE IN TAIWAN

Kilian Karius

Leonhardt, Andrä und Partner Beratende Ingenieure VBI AG, Germany

Figure 1: Rendering of the bridge Source: Zaha Hadid Architects ©negativ.com

PROJECT DESCRIPTION

A major infrastructure project is currently underway at the Tamsui Estuary, Figure 2, connecting the districts of Tamsui and Bali in northern Taiwan.

The Danjiang Bridge, upon completion, is poised to achieve several key objectives:

- Reduce travel time between Tamsui and Bali, thereby expanding the region's economic and social reach and fostering local development,
- Link key recreational areas to boost tourism,
- Provide critical access to Danhai New Town, enhancing traffic flow along the northern coast,
- Support the infrastructure of Taipei Harbour,
- Contribute to the improvement of the Taipei metropolitan expressway network in alignment with the city's urban development plan,
- Extend the Light Rail Transit (LRT) system to the Bali area.

Our team, comprising Sinotech Engineering Consultants, Leonhardt Andrä und Partner (LAP), Architects of Zaha Hadid (ZHA), and MOREAN, designed the iconic single-tower main bridge, which emerged as the winning proposal in an international design competition.

The bridge is envisioned not only as a functional transportation link but also as a cultural and environmental landmark that harmonises with the surrounding landscape and complements the famous Tamsui sunset.

Bathymetry

The Tamsui River's drainage area spans 2,726 km², with the Danjiang Bridge designed to account for flood levels with a 200-year return period.

Figure 3 below illustrates the riverbed topography 200 m upstream and downstream of the bridge site. The riverbed's slope is gentler on the Tamsui side and steeper on the Bali side, with bathymetry ranging from 0 m to -8 m, and a maximum depth of approximately 8.4 m.

Geology

The nearest geological faults - Hsingchuang, Chinshan, and Shanchiao - are located 7–8 km away, with the Shanchiao fault having last been active about 10,000 years ago.

At approximately -33 m on the Tamsui side, bedrock begins and gradually descends to -66 m on the Bali side. This gradient indicates that placing the Main Bridge foundation on the Tamsui side is the most cost-effective and structurally sound option.

Bridge layout

The 920 m Main Bridge features spans of 75 m + 75 m + 450 m (main span) + 175 m + 75 m + 70 m, as illustrated in Figure 4.

The main span crosses a 200 m-wide navigation channel with a 20 m clearance for fishing boats, tourist boats, and private yachts.

The bridge's typical total width is 44.7 m between railings, expanding to 55.3 m in the cable-stayed section.

Here, the deck separates to accommodate the 5 m wide pylon legs.

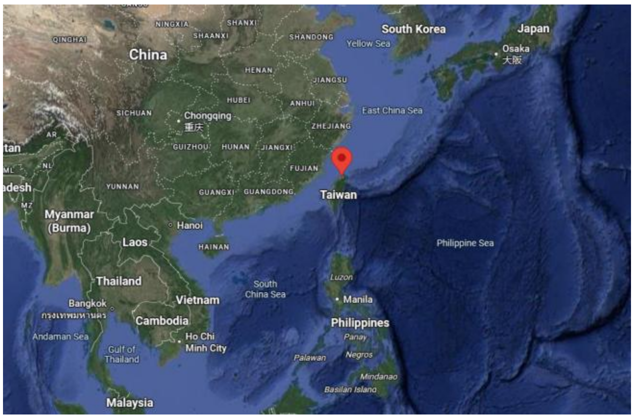


Figure 2: Location of the bridge. Click on the map
Source: Google Maps

The deck carries two lanes of traffic in each direction, a 2.5 m scooter lane for motorbikes and motorized scooters, and a 5 m wide walkway shared by pedestrians and bicycles.

During Phase 1, the deck also includes a high-occupancy vehicle (HOV) lane, which will be adapted for light rail (LRT) tracks in Phase 2.

STRUCTURAL DESIGN

Mass distribution and balance

The span lengths of Danjiang Bridge on either side of the pylon are 450 m and 175 m, creating unbalanced reactions under all loadings. The first design challenge was to optimise material distribution while minimising the structure's total weight (and seismic mass).

Our solutions to optimise the permanent load distribution and to reduce weight include using concrete-steel composite sections and orthotropic steel deck sections where appropriate to address the imbalance.

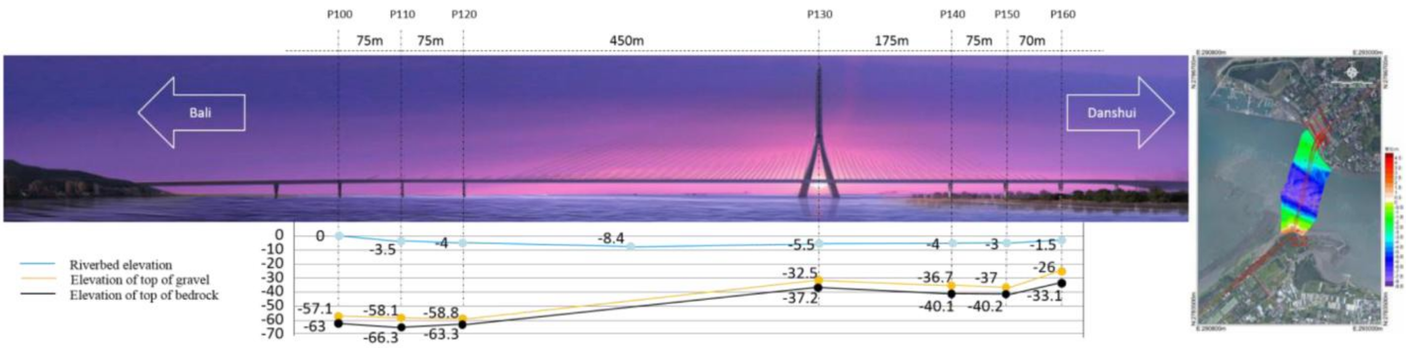
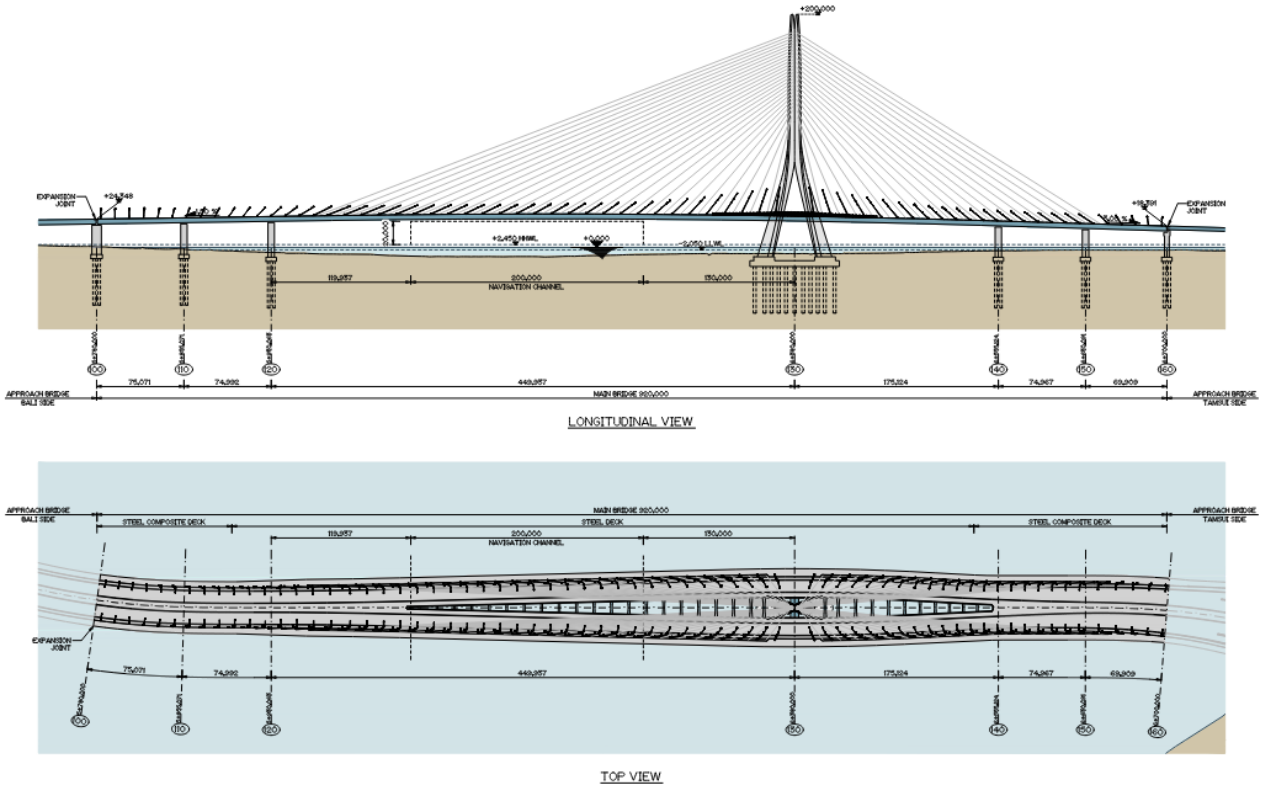
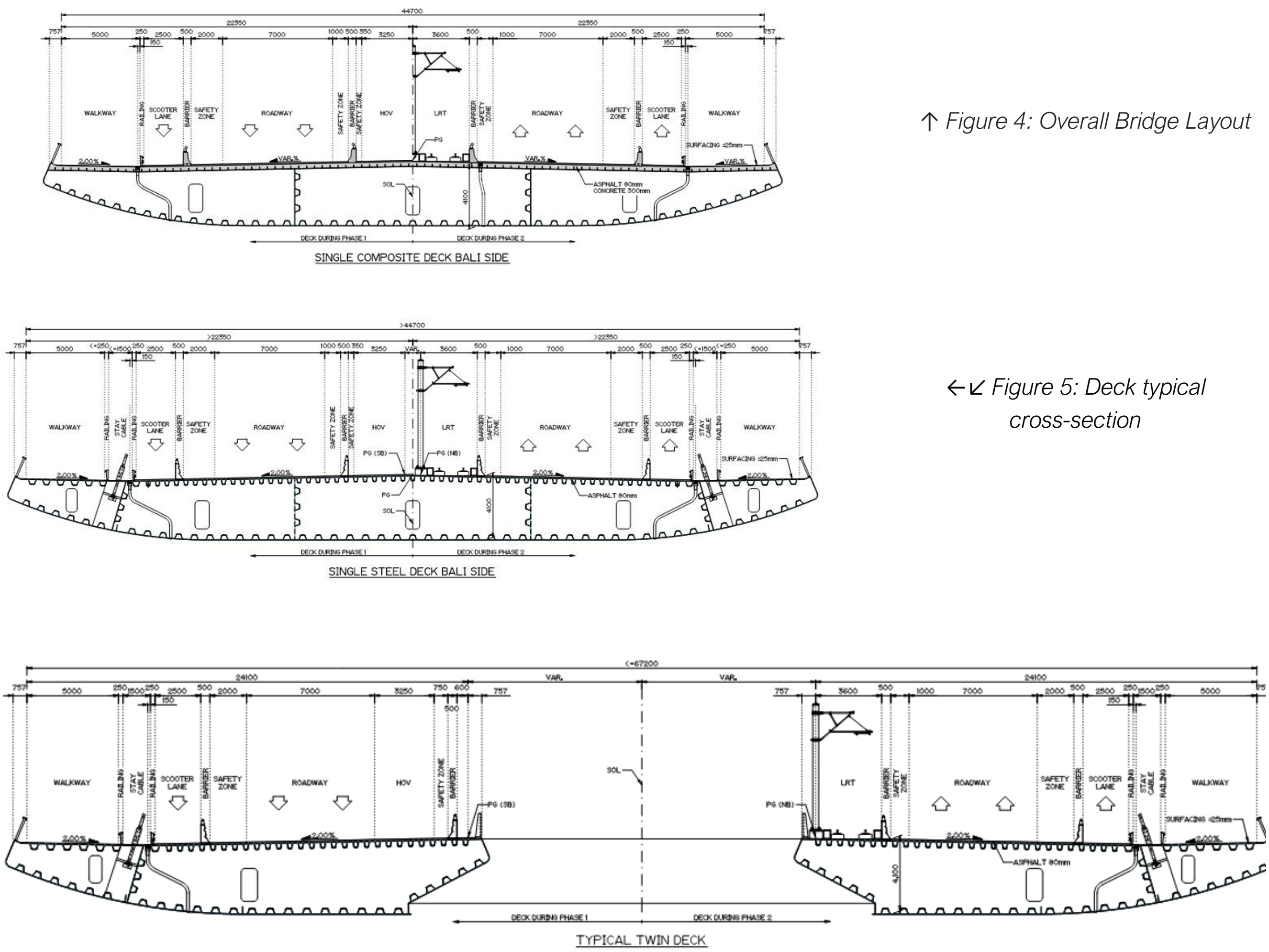


Figure 3: Bathymetry



↑ *Figure 4: Overall Bridge Layout*



←↙ *Figure 5: Deck typical cross-section*

Figure 6 shows the 115 m long composite section area with a 30 cm concrete slab connecting to the 660 m long orthotropic deck with additional concrete only over 22.5 m near P120.

To counterbalance, a 99 m composite section with a 65 cm slab is placed near Piers P140 and P150, plus a 46 m section with 30 cm concrete near P160 on the Tamsui side.

Keeping the structure's weight low was crucial for the stay cable system, anti-seismic design, and foundation, as well as enabling longer segments for faster cantilever erection.

Using hollow steel pipes for the upper pylon and hollow sections for the piers. This design saved 550 m³ (14%) of concrete in the upper pylon and 1200 m³ (20%) in the intermediate piers.

Employing higher-strength materials to minimise dimensions:

Pylon and Pier P140: f'_c = 56 MPa self-compacting concrete

Other piers: f'_c = 49 MPa

Reinforcement: f_y = 420 and 490 MPa

Structural steel as per ASTM A709: Grade 50W, f_y = 350 MPa and Grade HPS70W, f_y = 490 MPa

Other weight-reduction measures included using steel crash barriers instead of concrete and steel sleepers for the LRT rails.

Pylon

The bridge's identity is largely defined by the pylon geometry. Therefore, it was crucial to translate the architectural concept's free-flowing shapes into a geometry that is both constructible and aligned with the vision.

This process began at the competition stage, as shown in Figure 7, resulting in a 200m high reinforced concrete pylon with two legs converging 45 m above the deck, topped by two architectural extensions ("bunny ears").

During the preliminary design phase, the geometry was further optimised in collaboration with formwork manufacturers.

A key optimisation was transforming the double-curved surfaces into single-direction radii, enabling the use of climbing formwork.

This goal was achieved in all areas except for the merging section (where the two legs converge) and the upper three segments ("bunny ears"), which still required conventional formwork.

To facilitate this process, the shapes were mathematically formulated, which was also necessary for the construction tender.

Figure 8 illustrates the transition from workshop concepts to final design formulations. The final design outer geometry is shown in Figure 9.

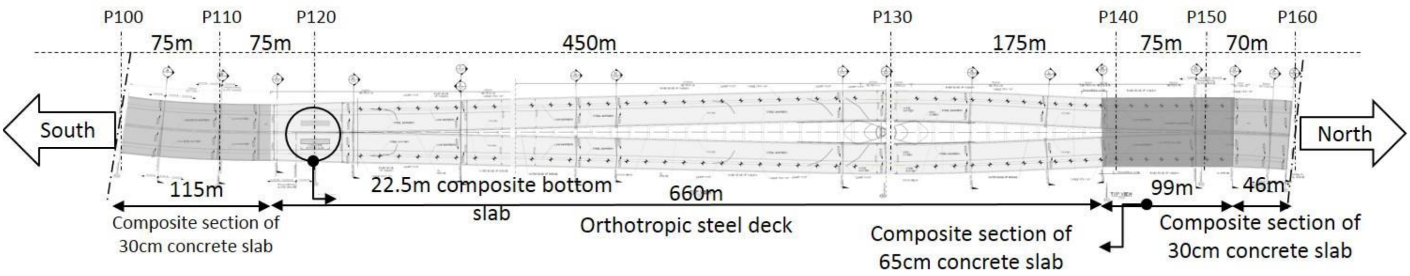


Figure 6: Choice of bridge deck materials

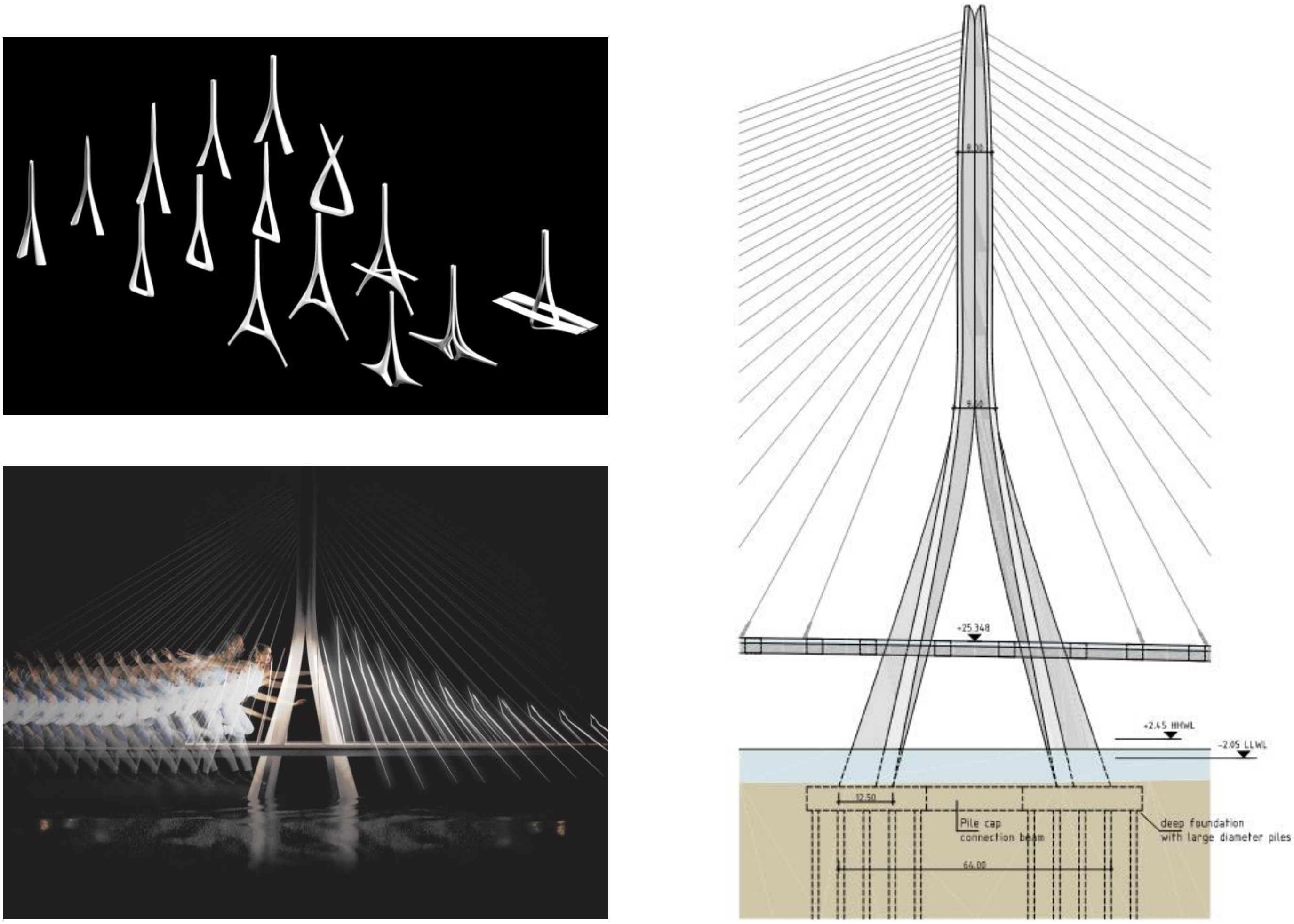


Figure 7: Evolution of pylon shape at competition

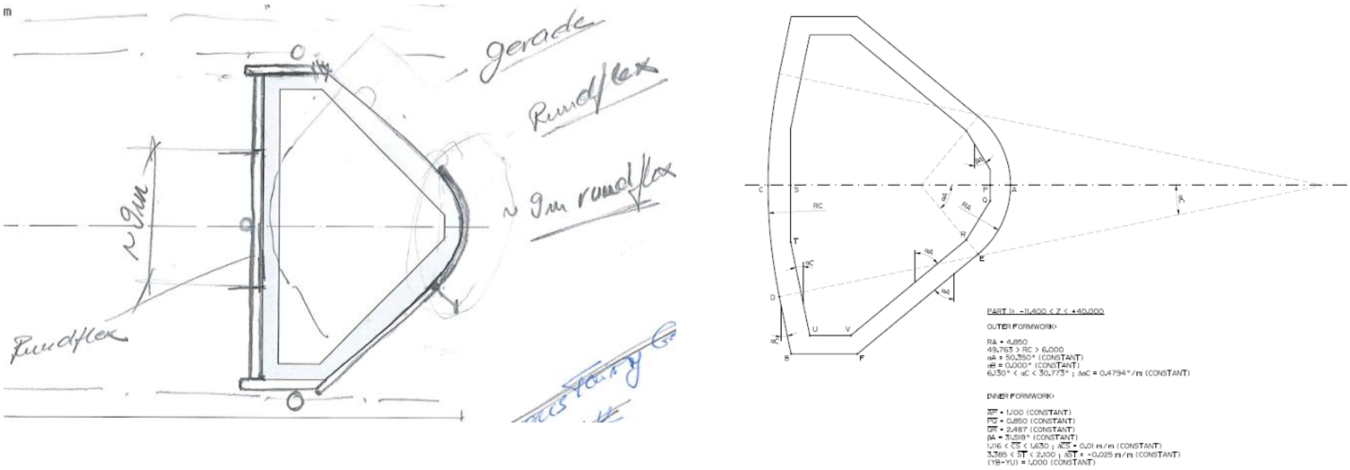


Figure 8: Evolution of pylon shape at tender design

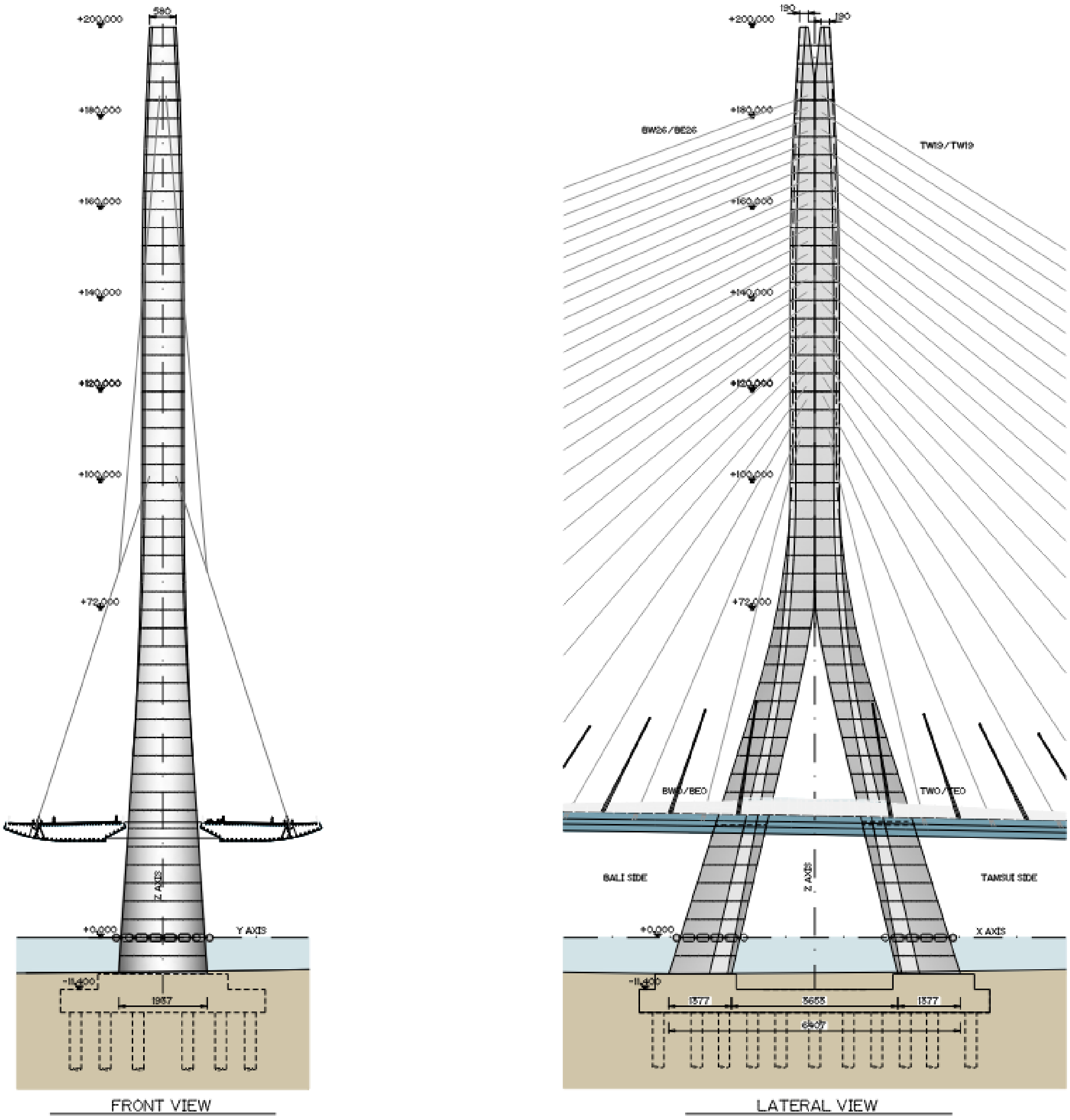


Figure 9: Pylon final geometry

Stay cable system

Stay cables are specified as a parallel strand system made of individual high-density polyethene (HDPE) coated seven-wire steel strands with galvanic coating inside an HDPE stay cable outer pipe. The stays are arranged in an unsymmetrical fan shape pattern as shown in Figure 10.

The main span consists of 27 stay cable pairs, the side span of only 20 pairs, which are spaced at 15 m intervals in the orthotropic deck and at 12 m intervals in the composite deck on the Tamsui side.

The stay cable forces under permanent loads at traffic opening and at time infinite (t∞) differ from each other not only due to long-term effects, but

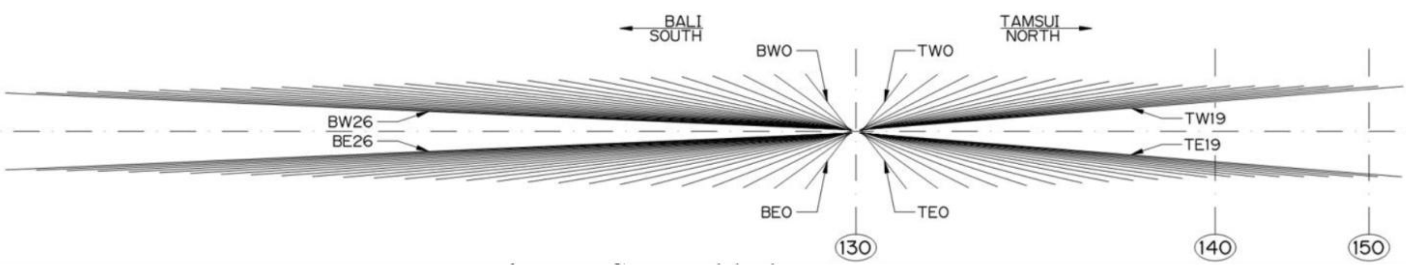


Figure 10: Stay Cable Layout

also from replacing the HOV lane by LRT tracks during the 120-year service life of the bridge. Restressing is, however, not planned, as the stay forces are configured to fulfil the following criteria at all times: (1) Minimise the pylon shear force at the merging point, (2) Ensure permanent compression in the bearings, (3) Limit the deck bending moments.

Architectural lamp posts

The Danjiang Bridge features a unique lighting design, with conical and curved lamp posts positioned between the cable stays. These posts reach a maximum length of approximately 30 m and are inclined at angles matching those of the adjacent stay cables. This makes them a distinctive feature of the bridge's identity.

Extensive dynamic analyses were performed to assess the lamp posts' performance under various conditions, including (a) buffeting caused by wind acting on the poles, (b) vortex-induced vibrations (VIV) from wind interaction, (c) dynamic excitation due to VIV of the bridge deck, and (d) dynamic excitation from the seismic response of the bridge deck.

To ensure optimal performance under conditions (b) and (d), artificial damping is required. Therefore, the lamp posts will be equipped with tuned mass dampers and optional mass-detuning.

Articulation

Selecting and fine-tuning the seismic isolation devices has been a critical challenge throughout the design. Seismic isolation is required in both horizontal directions to reduce support reactions. While movements are necessary for energy dissipation and frequency extension during a seismic event, seismic displacements must be limited due to expansion joint size, space constraints at the piers and pylon, and forces transferred to the pylon head through the stays.

The challenge was to develop a system that meets all requirements while preventing movement under regular service and typhoon loads. This ultimately led to a system that changes its properties at a specific force level.

In the longitudinal direction, hydraulic fuse restrainers (HFR) were selected as the optimal solution.

Figure 11: Architectural Lamp Posts

Seven HFR devices connect the deck to the Tamsui pylon leg, acting as nearly rigid supports under non-seismic loads. Upon reaching the threshold force, an orifice opens and the HFRs function as viscous dampers.

Additional redundancy and safety against unseating under extreme conditions are provided by standard viscous dampers on transition piers and rigid pipe stoppers on both pylon legs.

After a seismic event, the orifice closes, and the structure may require recentring after multiple smaller or extensive events.

All substructures contribute lateral support. The pylon and the transition piers have sufficient capacity to cater for rigid lateral support.

The intermediate piers, which are more slender, would be overloaded during a seismic event, so unidirectional friction pendulum bearings (FPB) were selected.

Their properties were tuned to provide adequate breakaway force under normal loads, limit seismic displacements, and ensure re-centring after a seismic event. Only two property sets were specified to reduce testing and fabrication costs.

The deck is vertically supported at the piers and by the stay cables.

At the pylon, it is free-floating. At Piers P120 and P140, tie-down cables are installed in the piers to eliminate any uplifting forces in the FPB.

Figure 12 shows the overall articulation scheme.

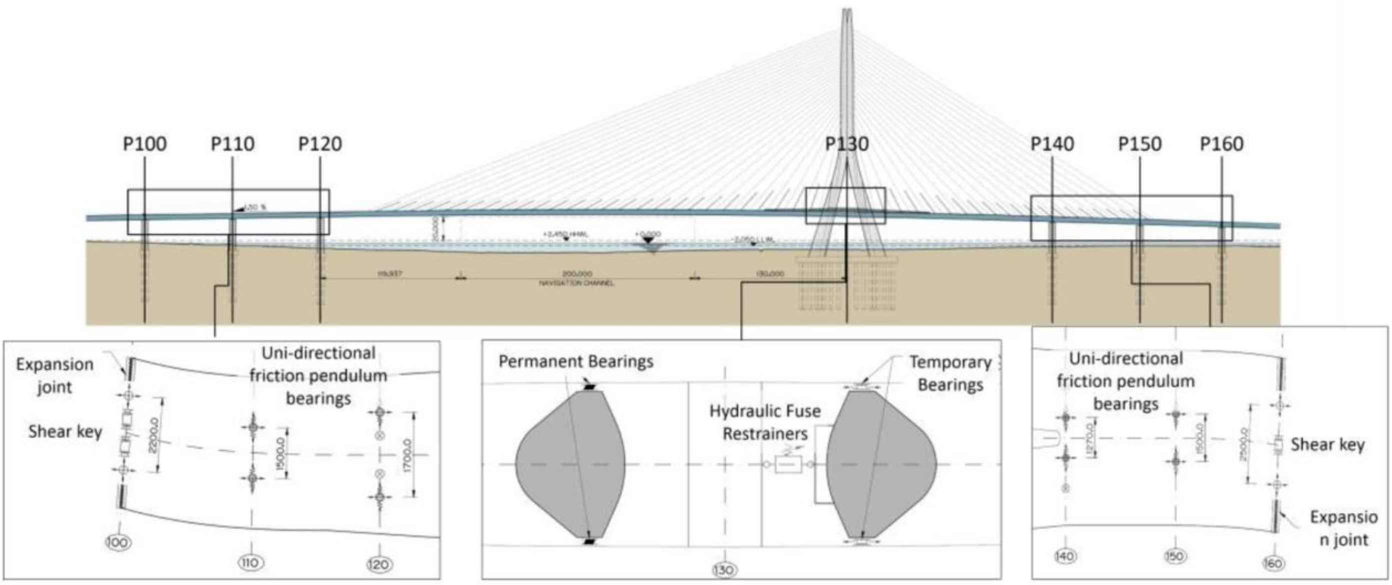


Figure 12: Articulation Scheme

Analysis Models

For the global analysis, a three-dimensional model was created using the SOFiSTiK software. The structure is modelled using beam, cable, truss, and spring elements.

The superstructure is initially modelled as a single spine beam, continuing until the deck separates into twin decks.

In this span, the superstructure is represented by two parallel spine beams, rigidly coupled to the single spine beam.

The same procedure is applied at both the start and end of the twin decks. Between the two parallel spine beams, crossbeams are included, modelled as single beam elements.

The pylon is modelled with a single spine beam at the top and separate spines for the legs, which are rigidly coupled at the merging point. The V-shaped piers are modelled using the same approach as the pylon. The tie-down cables are represented as cable elements.

Figure 13 illustrates the global model.

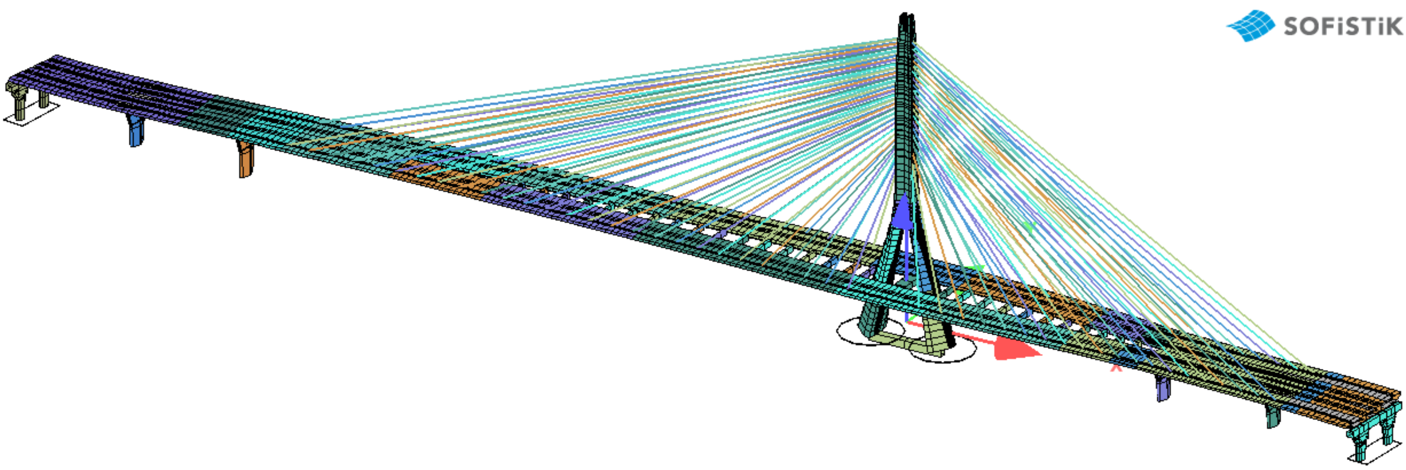


Figure 13: 3D SOFiSTiK Model for Global Analysis

In addition to the global beam model, several local shell models have been developed to further analyse the following:

- The local and transverse load-bearing behaviour of the superstructure,
- The verification of the cross-beams,
- The merging point of the pylon.

Separate models were also created to analyse the lamp posts.

Performance-Based Seismic Design

Taiwan is one of the world's most earthquake-prone regions. The site lies in Taipei Zone II according to the MOTC Highway Bridge seismic design specification, with peak ground accelerations (PGA) of 0.32 g at Maximum Considered Earthquake (MCE) and 0.24 g at Design Basis Earthquake (DBE) levels. Performance-Based Seismic Design (PBSD) is adopted as the framework to achieve a target post-event operational level (e.g., damage level) for varying ground motion intensities.

The goal is to comply with the performance criteria of Table 1 by achieving the following objectives:

- Frequent small earthquakes (SEE): The structure behaves elastically, with no damage to components and immediate traffic access. Residual displacements from several small events may require minor interventions for re-centring or realignment.
- Occasional earthquakes (DBE): The structure incurs minimal damage and limited residual displacements, requiring interventions for re-centring or realignment.
- Rare large earthquakes (MCE): The bridge avoids collapse, ensuring safe evacuation. It is considered a lifeline infrastructure, with repairable components. Plastic hinges should not form. The bridge remains operational for emergency traffic after the event.

Non-linear time history analysis was conducted using seven ground motion records compatible with the MOTC response spectra, considering wave propagation effects and the significant nonlinear dynamic response of the structure, driven by the friction pendulum bearings and hydraulic fuse restraints.

A project-specific seismic hazard study was also performed to evaluate local site effects, accounting for the site's unique geotechnical characteristics (seismic "signature"). Three historical ground acceleration time-histories from the Chi-Chi Earthquake, Hualien Earthquake, and 331 events were scaled to match the hazard curve as per Figure 14.

For the non-linear time history analysis, the energy dissipation offered by the components of the isolation system, either as hysteretic damping through friction or as viscous via hydraulic dampers, is directly included in the nonlinear analysis via suitable elements located at the bearing positions.

The set of HFR is modelled as a nonlinear viscous damper with a force limit. Each FPB is modelled with nonlinear hysteretic friction elements connecting the deck and the pier nodes at the actual location of the corresponding bearing.

In the longitudinal direction, the isolator element behaves like a frictionless flat sliding bearing.

In contrast, in the transverse direction, the hysteretic relation of the bearing through the friction coefficient and the curvature of the sliding surface (hardening branch) is assigned via the definition of the characteristic backbone curve.

Figure 15 shows the validation of the modelling.

↓ *Table 1: Main performance levels*

Seismic Intensity	Hazard Level (Return Period)	Service Performance Level	Damage Performance Level	Behaviour Factor R	Structural Behaviour
SEE (Safety Evaluation Earthquake)	80%/50y (30 y)	Fully Operational	None	1.0	Elastic
DBE (Design-Based Earthquake)	10%/50y (475 y)	Operational	Minimal	1.0	Essentially Elastic
MCE (Maximum Considered Earthquake)	2%/50y (2500 y)	Limited service (Emergency vehicle only)	Repairable	1.0~1.5	Limited Ductility

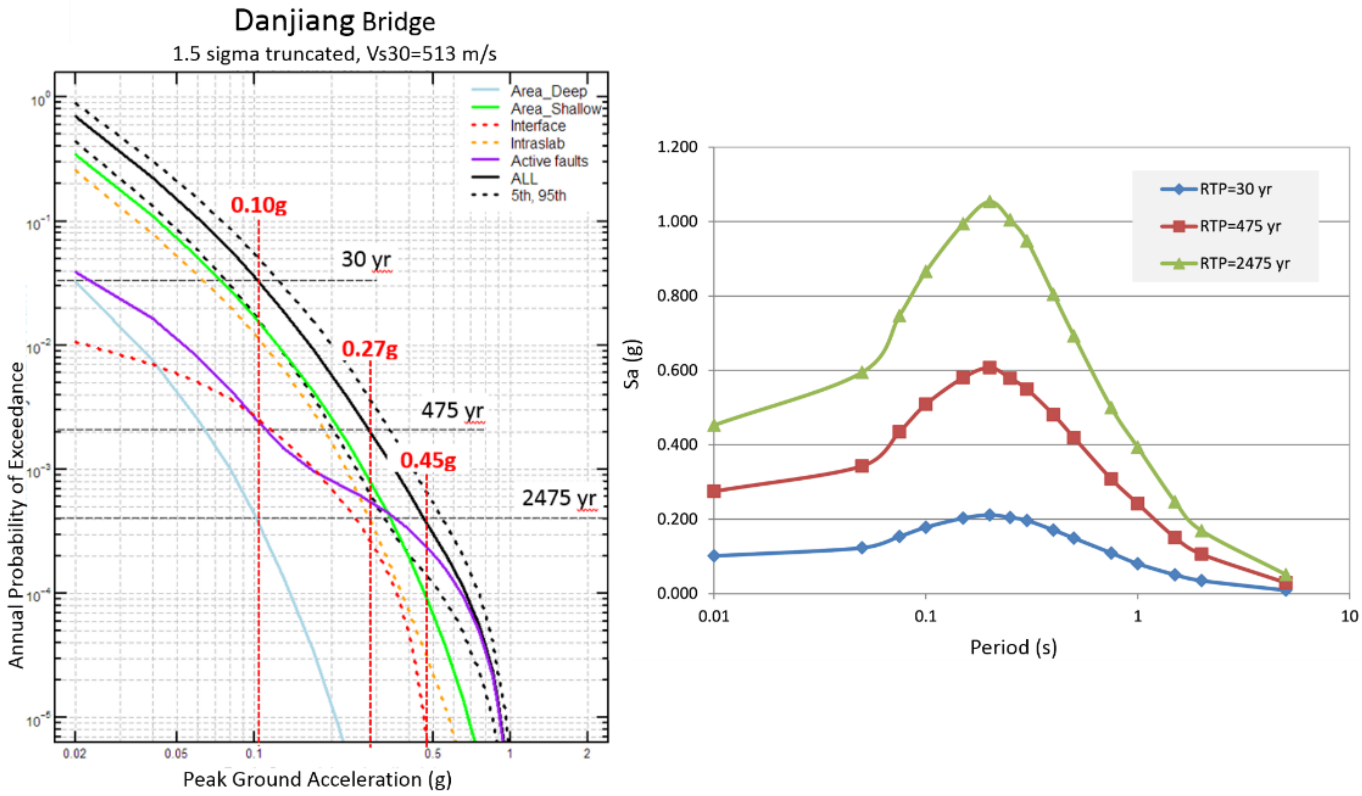


Figure 14: Hazard curves for MCE, DBE, SEE

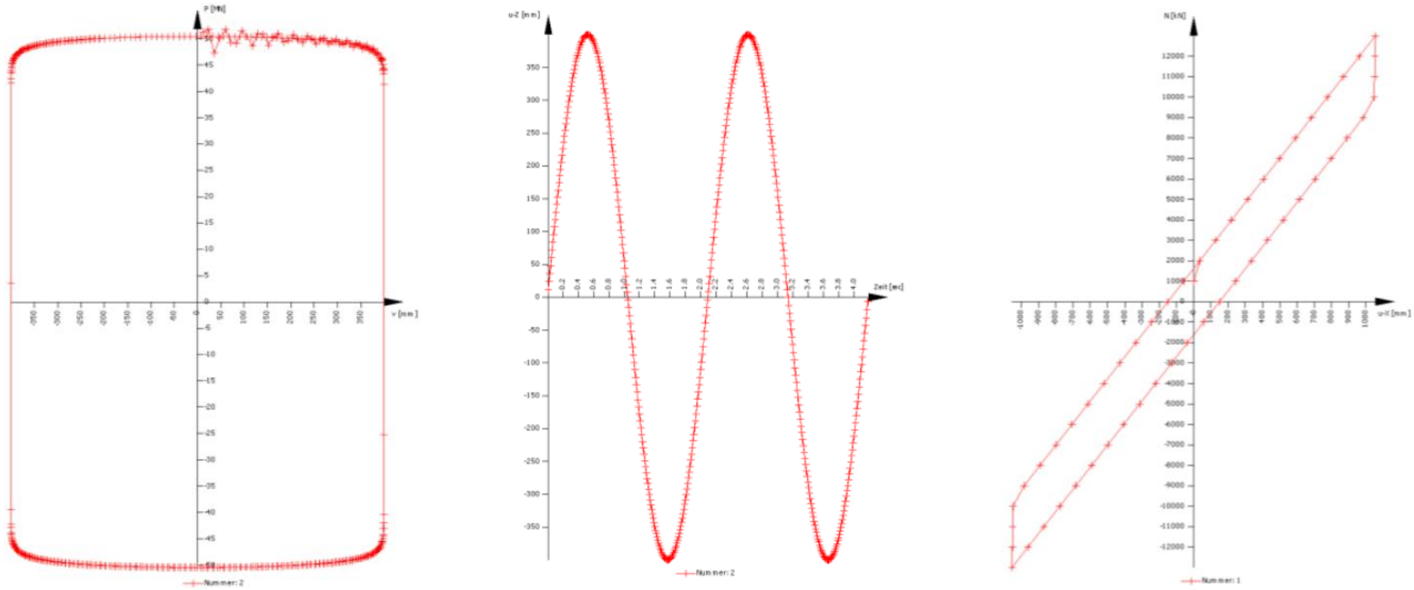


Figure 15: Validation of the seismic isolators

a) HFR hysteretic loop b) displacement TH c) FPB hysteretic loop

Wind effects

Taiwan is prone not only to earthquakes but also to tropical cyclones (typhoons), making the climate severe at the Danjiang Bridge location. Prevailing wind speeds were carefully studied by extreme value analysis based on long-term wind records.

The results, confirmed by literature, indicate a basic wind speed (10-minute mean) of 46.0 m/s at a 100-year return period for the bridge at the final stage. For construction, the design wind speed is 38.1 m/s at a 25-year return period, and the operational wind speed with traffic loads is 30.3 m/s.

Wind Tunnel Tests on Deck Cross Sections (Scale 1:120)

Various configurations were tested to evaluate aerodynamic and aeroelastic parameters, considering twin deck gap, wind characteristics, and deck configurations at different stages.

The results confirmed that the deck cross sections are stable against Flutter, Galloping, and Divergence up to approximately 100 m/s wind velocities.

Wind Tunnel Test on Free-Standing Pylon (Scale 1:200)

Pressure measurements and foundation reactions were analysed for the free-standing pylon. Galloping was not detected, but vortex-induced vibrations are possible.

The maximum vibration amplitudes at the pylon top range from 140 mm (perpendicular) to 200 mm (longitudinal), with accelerations of 0.84 m/s² and 0.34 m/s², respectively.

Partial Model Tests for Traffic Vehicle Stability (Scale 1:175)

Wind effects on passing vehicles were tested with the full pylon model and part of the twin deck in three configurations: without wind screens, with wind screens, and with both wind screens and noise barriers.

Wind velocities in sheltered zones with windbreaks were lower, reducing the risk of wind-induced hazards compared to open deck areas.

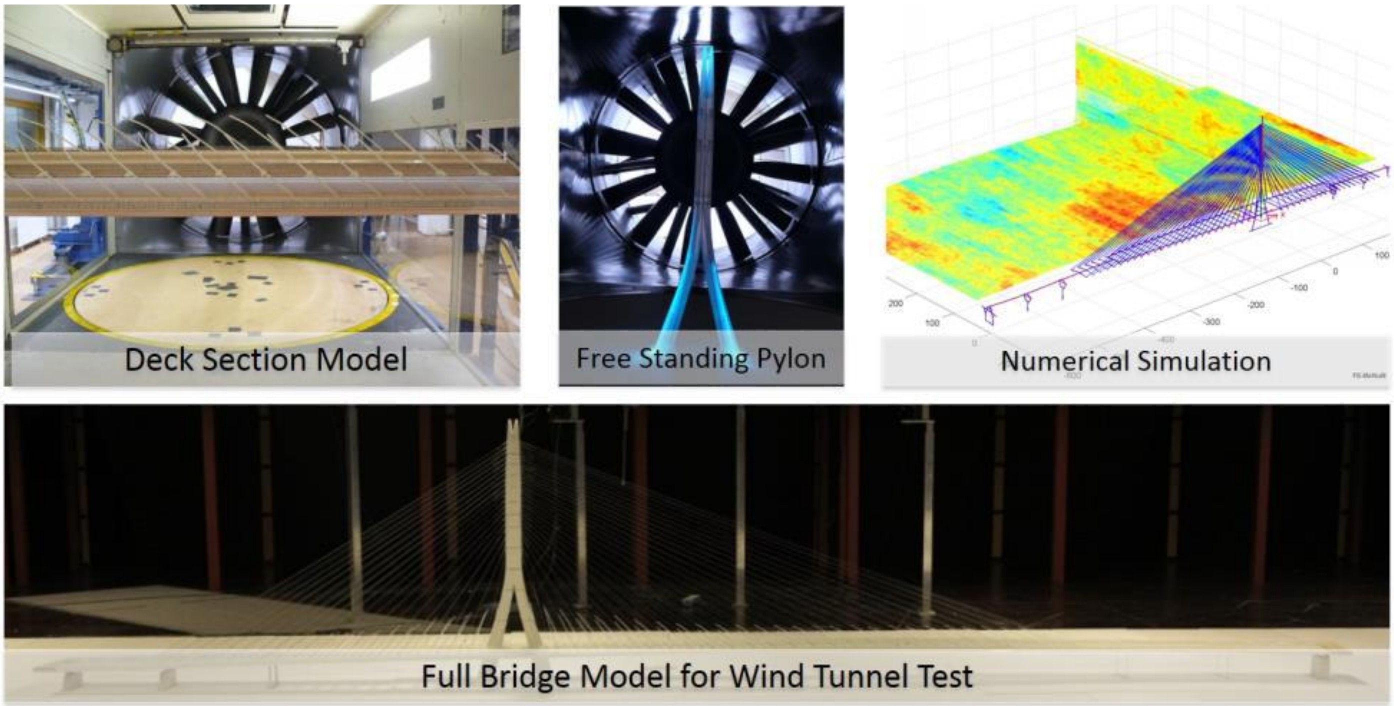


Figure 16: Wind Tunnel Test Models

Numerical Simulations for Buffeting Response and Aerodynamic Instabilities

A 3D aeroelastic model was used to simulate wind effects based on wind tunnel data. No instability was found in the final bridge state or construction stages up to 100 m/s wind speeds.

The bridge is stable against Flutter, Galloping, and Divergence. Vortex shedding and buffeting amplitudes remained below pedestrian threshold levels, with a recommendation to close the bridge for winds exceeding 22 m/s at deck height.

The model also provided wind load cases for structural analysis.

Full Model Wind Tunnel Tests (Scale 1:175)

Full model tests validated earlier numerical simulations and confirmed the bridge's structural suitability.

The three tested configurations - bridge in service, erection stage 1, and erection stage 2 - demonstrated aerodynamic stability against Flutter, Galloping, and Divergence for wind speeds up to at least 90 m/s.

CONSTRUCTION

The construction method for the Danjiang Bridge follows well-established procedures for this type of bridge.

To ensure both economy and risk mitigation, the design details and suggested erection sequence are tailored to utilise well-established construction methods, both in the industry and locally in Taiwan.

Steelwork fabrication

Steelwork is fabricated locally on Taiwan's East Coast, then transported by truck to storage areas at the site and Taipei port. Partial steel segments are assembled on-site before erection.

Figure 17 shows segment assembly and storage, while Figure 18 illustrates the metal workshop.

Figure 17: Deck segment assembly on site

Figure 18: Metal workshop

Pylon erection

Pylon erection is completed in 4 m segments, utilising various formwork types. Self-compacting concrete, commonly used in Taiwan, was chosen to match the local workforce's experience. Longitudinal bars are spliced using rebar couplers.

The PERI SCS climbing system was selected for constructing the pylon's lower inclined legs and top.

Figure 19 illustrates the erection scheme for the lower inclined legs, which includes temporary struts to ensure correct geometry and section forces. Concrete for the lower section is pumped from the jetty, while above the elevation of +56 m, it is delivered by bucket.

The pylon's central, straight section is built using the PERI ACS self-climbing system, which ascends the structure on rails.

Figure 21 shows the ACS system at the stay cable section. No inner formwork is needed, as concrete is cast against the stay cable anchor boxes.

Figure 22 shows the construction of the characteristic "bunny ears" by conventional methods and formwork.

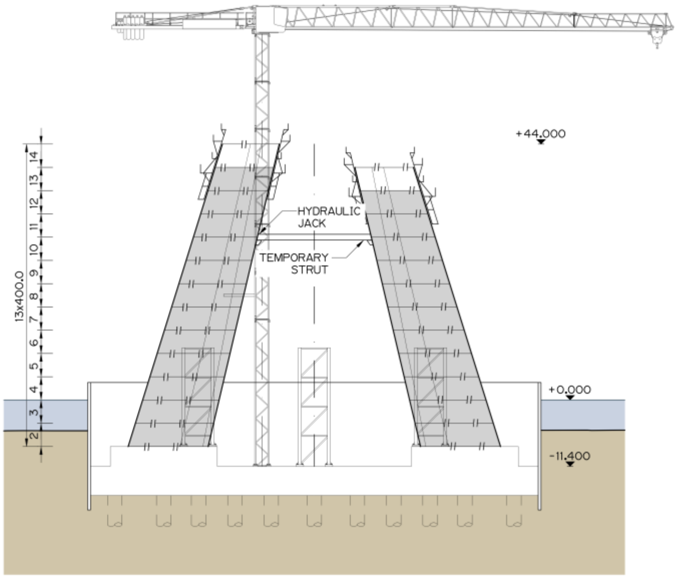


Figure 19: Construction scheme of lower pylon legs

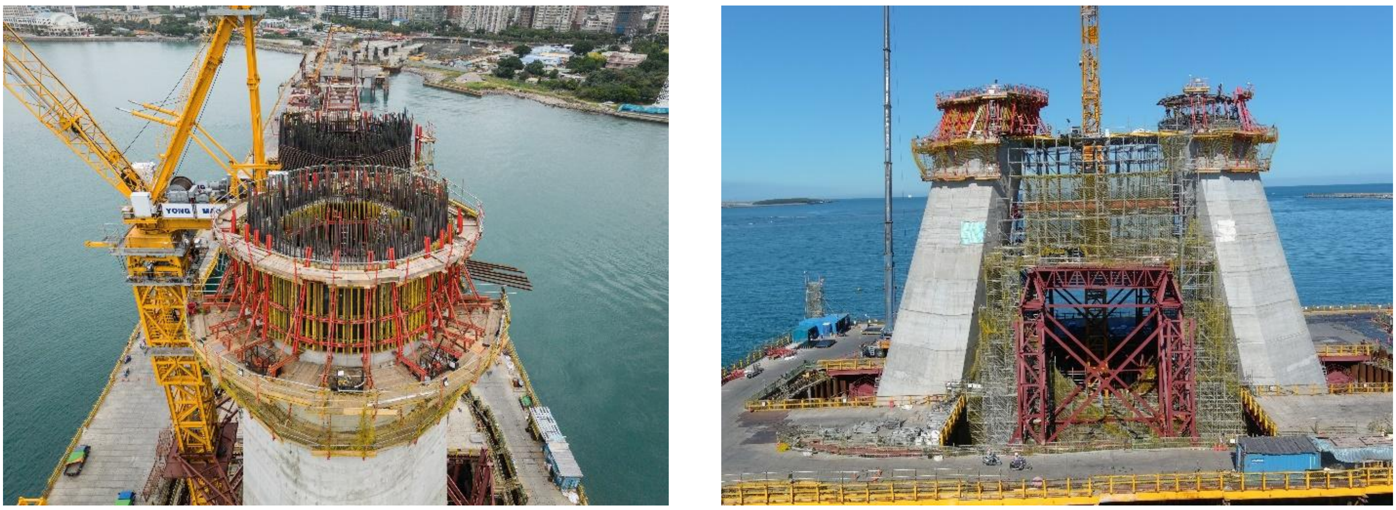


Figure 20: PERI SCS climbing form at pylon legs

Figure 21: PERI ACS self-climbing system

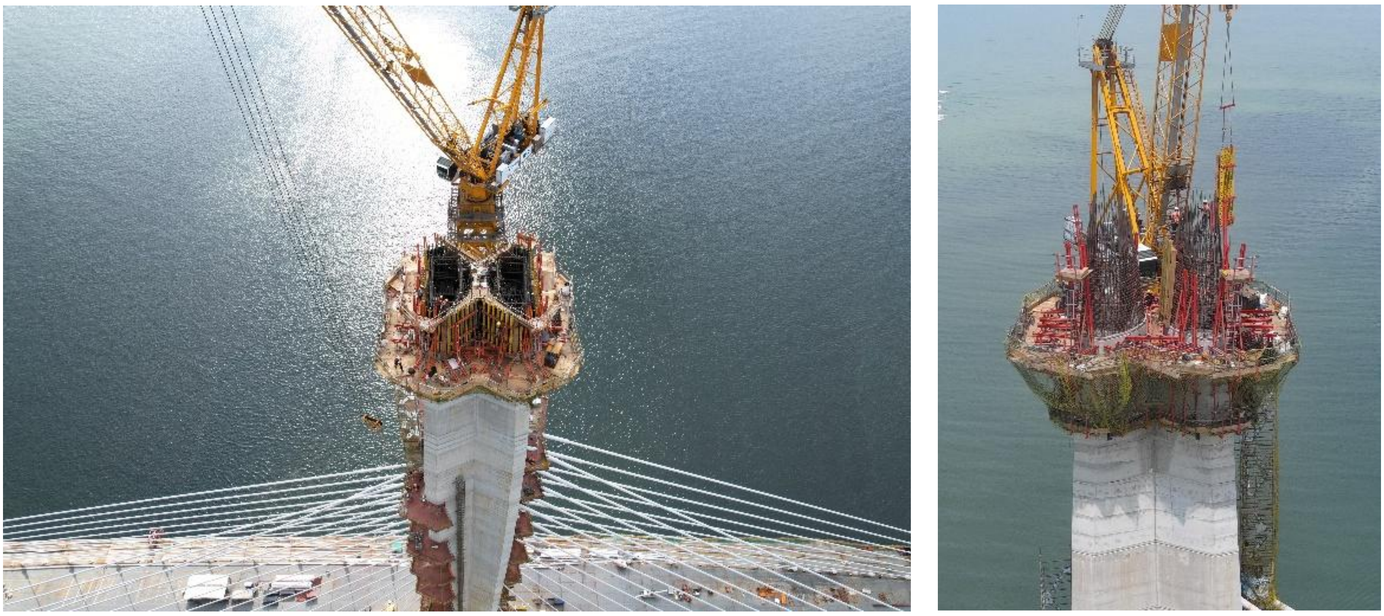


Figure 22: Construction of the "bunny ears" at the top of the pylon

Figure 23: Bali side span installation

Deck Erection

Figure 27 shows and describes the overall deck erection sequence. Initially, the approach spans and the pier table at the pylon are erected on temporary supports.

The original erection sequence anticipated that the approach span segments would be delivered by barge and installed by sliding them toward land on a skidding beam.

However, due to permit issues and barge sourcing, the contractor decided to lift the segments by crane from the landside and push them into position, as shown in Figure 23.

A change was also made to the composite deck slab design. The final design specified partial precast deck panels, identified as the most economical option at the time. However, the contractor implemented a cast-in-place solution, which is common in building construction in Taiwan.

Figure 24 shows the lost steel formwork panels used in this method.

In parallel with the erection of the approach spans, construction of the cable-stayed deck began with the construction of the pier table segments on a temporary shoring structure.

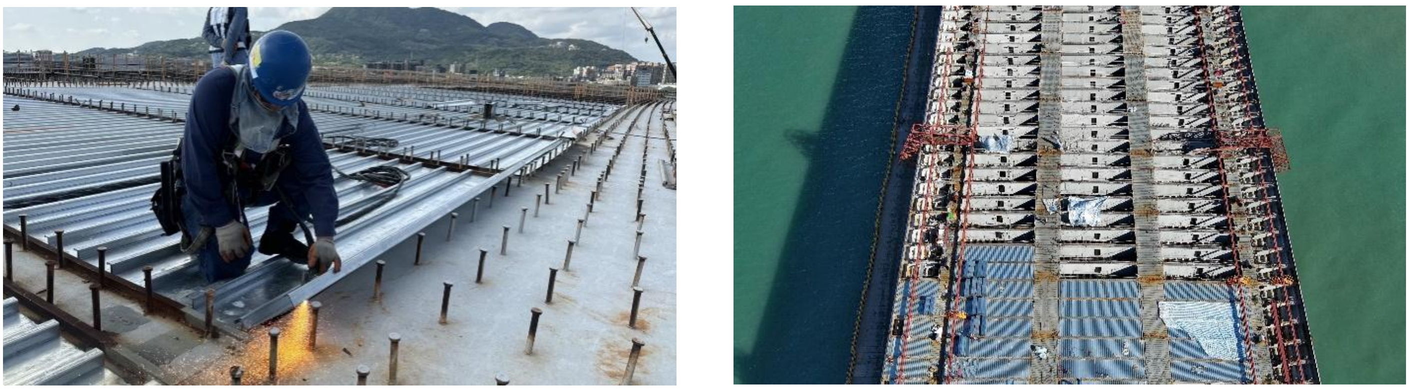


Figure 24: Formwork panels of composite slab

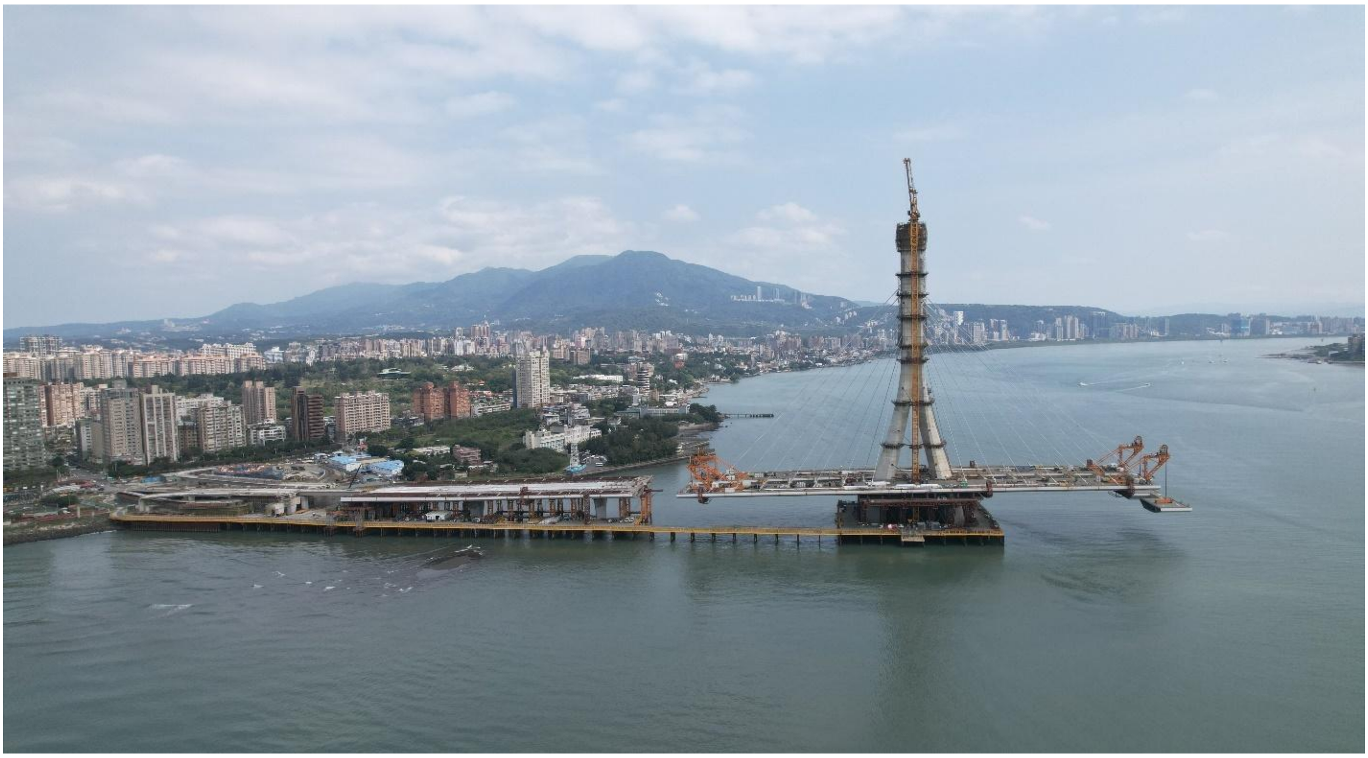


Figure 25: Balanced cantilever deck erection

Figure 26: Free cantilever deck erection

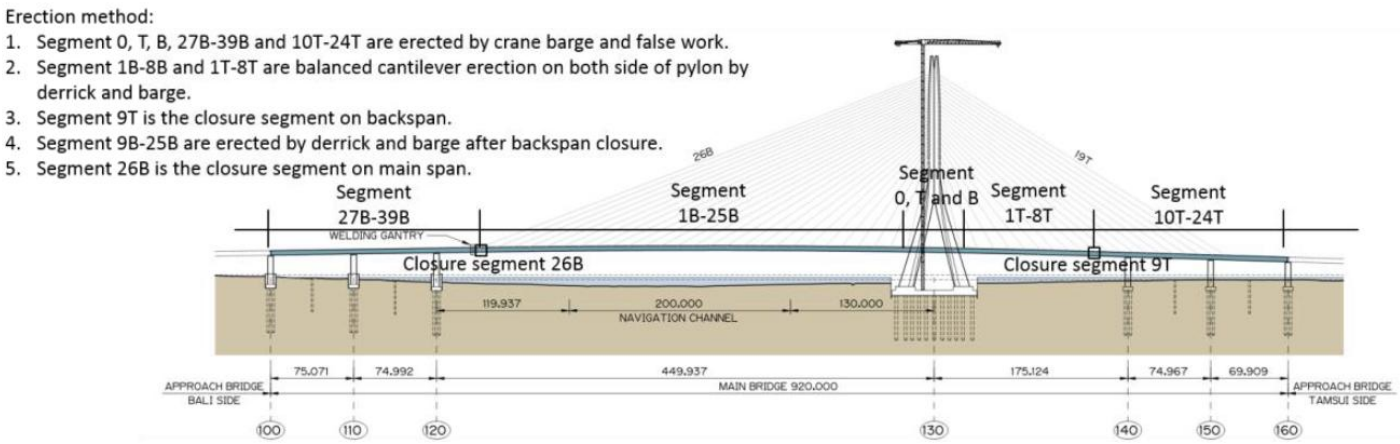


Figure 27: Deck erection sequence

Once the pier table segments were connected by means of site welding, derrick cranes were assembled on top of the pier table. These cranes are used to lift deck segments from the barge during the cantilevered construction process, as shown in Figure 25.

Stay cables from DYWIDAG are installed before the next deck segment is lifted. This sequence continued until the side span was closed.

From that point onward, only the main span is being erected using the free cantilever method, as shown in Figure 26.

At the side span, the corresponding stay cables are installed as part of the typical erection cycle to balance the forces introduced to the pylon.

CONCLUSION

The development of the Danjiang Bridge presented significant challenges. The site's location itself posed a complex environment for any bridge, with risks from both earthquakes and typhoons.

Designing an iconic architectural structure that met the expectations of the Owner and the public, while also staying within budget, posed additional challenges to the project.

However, the current progress and quality of the work demonstrate that it is indeed possible to overcome these formidable challenges.

This success highlights the power of collaboration, with all project participants working together toward a common goal and prioritising the best interests of the project.

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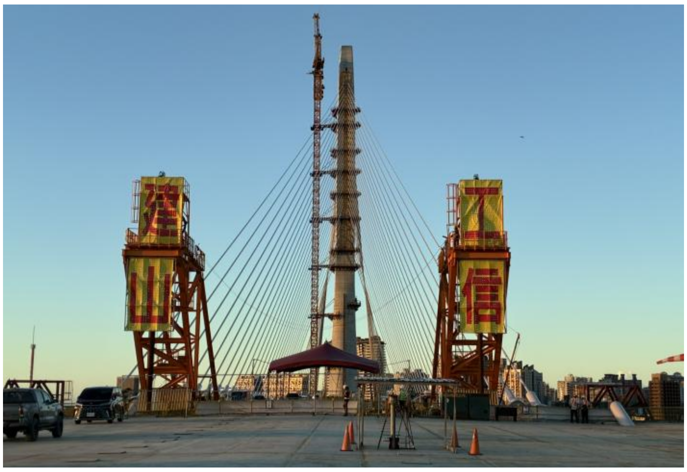

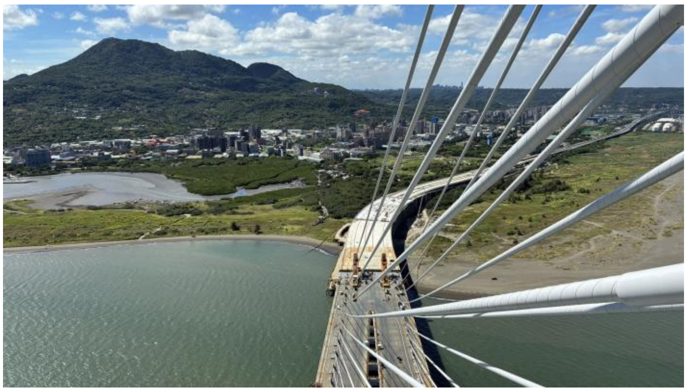

Figures 28 – 35: Main Span Closure in September 2025

DANJIANG BRIDGE – GEOMETRY DEFINITION OF THE PYLON

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INTRODUCTION

The design alternative that won the competition has a strong identity defined by the pylon shape, as shown in Figure 1.

It features warped surfaces with continuously varying angles and radii, creating a distinctive aesthetic that had to be maintained in the subsequent design stages.

At the same time, construction feasibility conditions had to be met. The difficulty of designing the formwork had to be minimised, while always respecting the desired result.

The steps followed to define all the dimensions of the pylon are described below.

THE START OF THE DESIGN PHASE

The designers met with companies that supply complex formwork to learn about existing systems for curved and warped surfaces and their limitations. Compañía de Proyectos de Ingeniería S.R.L. (Copiga) accompanied the design team and provided its expert services in CAD rationalisation.

One such existing system for curved surfaces is PERI RUNDFLEX Circular Wall Formwork®, which allows different radii to be adjusted at various heights, allowing for variable radii, see Figure 2.

Warped surfaces, though, would have to be custom-manufactured in the workshop, Figure 3, so for reuse and efficiency, the variation in the horizontal generatrix had to be fine-tuned to have a constant angle change with height variation.

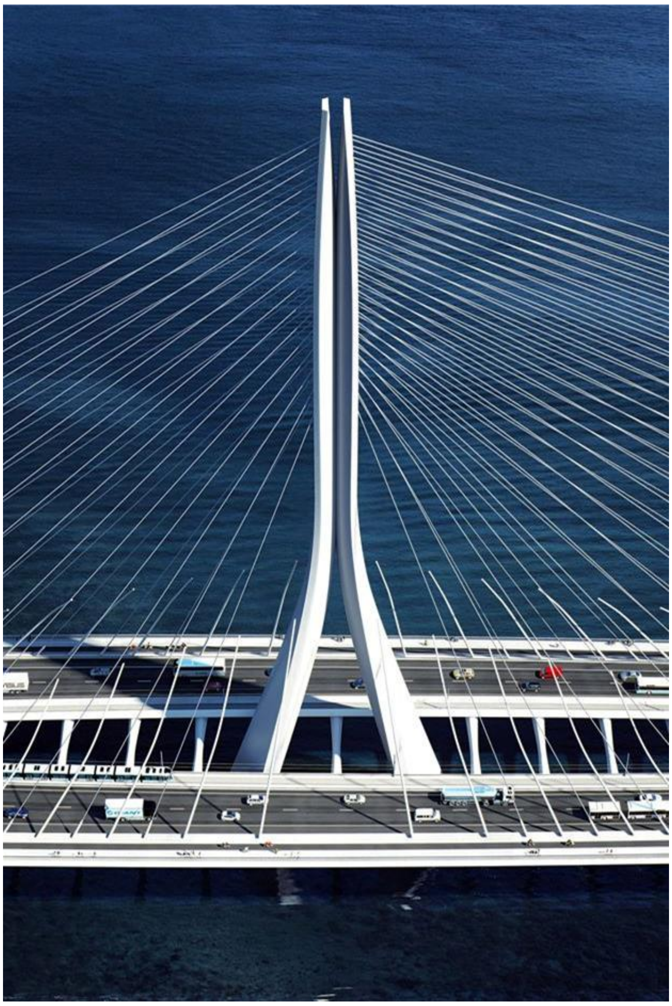


Figure 1: Render view presented in competition

Credit: Zaha Hadid Architects, render by MIR

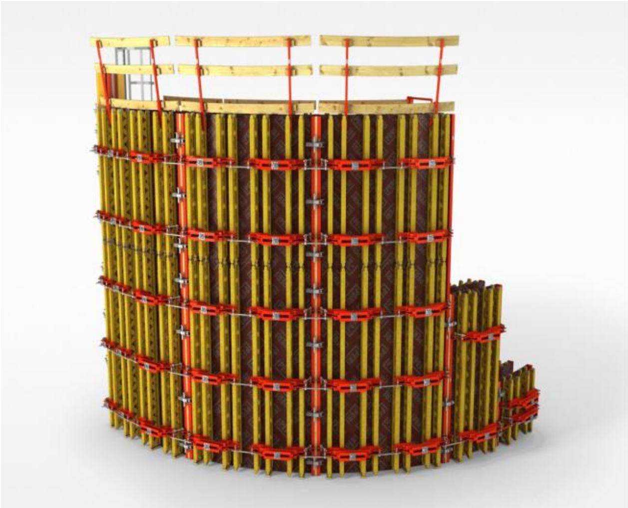


Figure 2: Curved formwork, with radial adjustment at different elevations Source: PERI

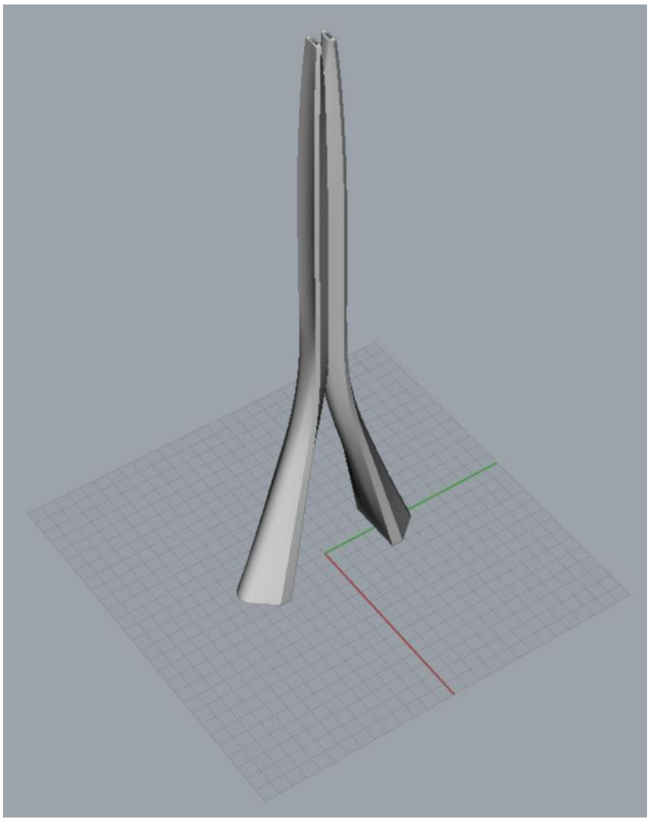
Figure 3: Warped formwork panel prepared at workshop

ANALYZING THE 3D MODEL

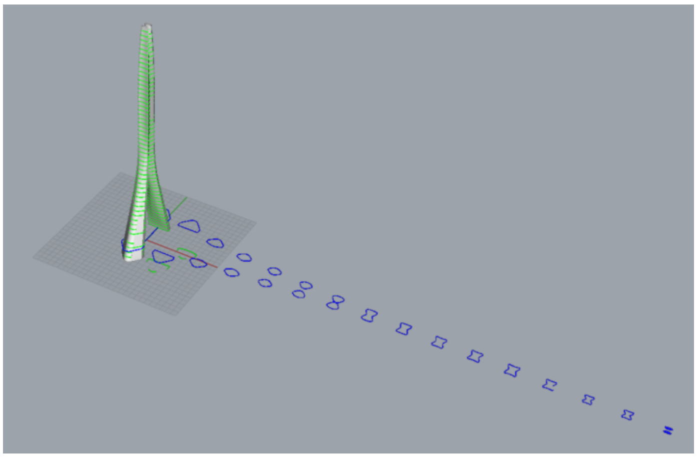
The existing base information to work off was a 3D model of the pylon, designed by the architects, Figure 4.

To analyse how the sections change along elevation, we obtained equidistant sections, Figure 5.

We exported these sections to CAD software so we could compare them, superimposing them on three different parts: legs (Figure 6), vertical shaft, and 'bunny ears'.



↑ Figure 4: Initial 3D model



← Figure 5: Sections obtained from the 3D model

The typical cross-section has an exterior face formed by a curve at the bridge axis that continues into one straight segment on each side, a similar interior face (a curve at the bridge axis + a straight segment on each side), and two straight side faces.

The figure shows that the radii are practically constant in the lower part of the exterior face, although they are not strictly the same. For this reason, the dimensions and shapes were also rationalised in the geometric definition of the pylon.

To this end, the typical points of the sections were designated with the letters A to G, Figure 7.

In addition, the vertical layout of some of these points (A, B, C, and F) was defined. This vertical layout has a straight lower part, a curve with a constant radius, a vertical segment, and a curved upper part with a constant radius.

In this task, we also had to consider the segments in which the pylon would be built. We considered 4m high segments, and we sought to ensure that the changes between straight and curved segments in the vertical layout coincided with a joint between the segments.

To meet all requirements simultaneously, a spreadsheet was created that would allow us to calculate all the points defining a cross-section based on the coordinates of points A, B, and C and the angles of the straight segments on the exterior, interior, and lateral faces.

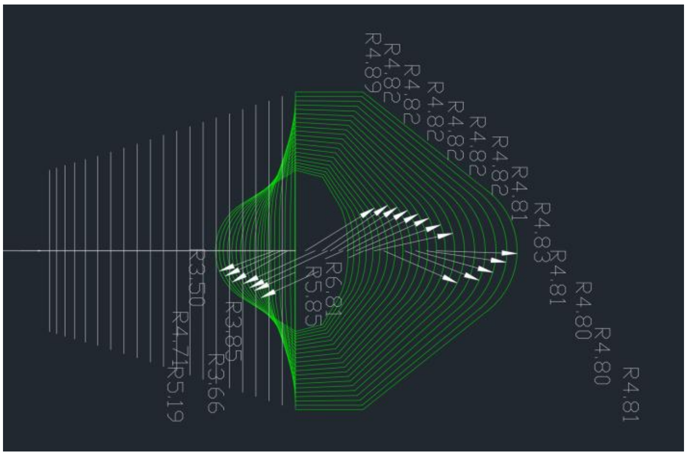
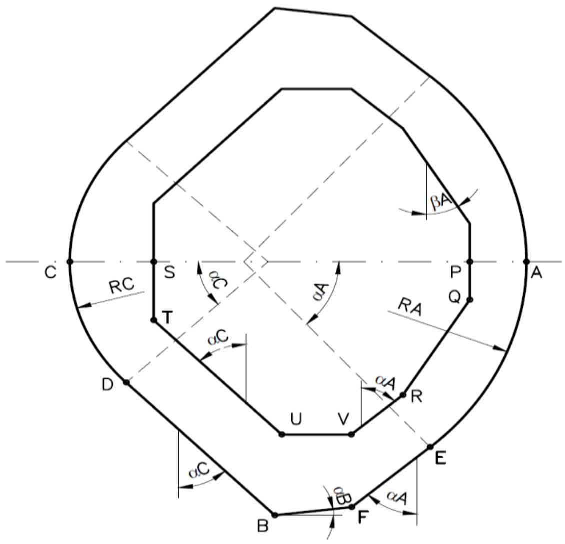
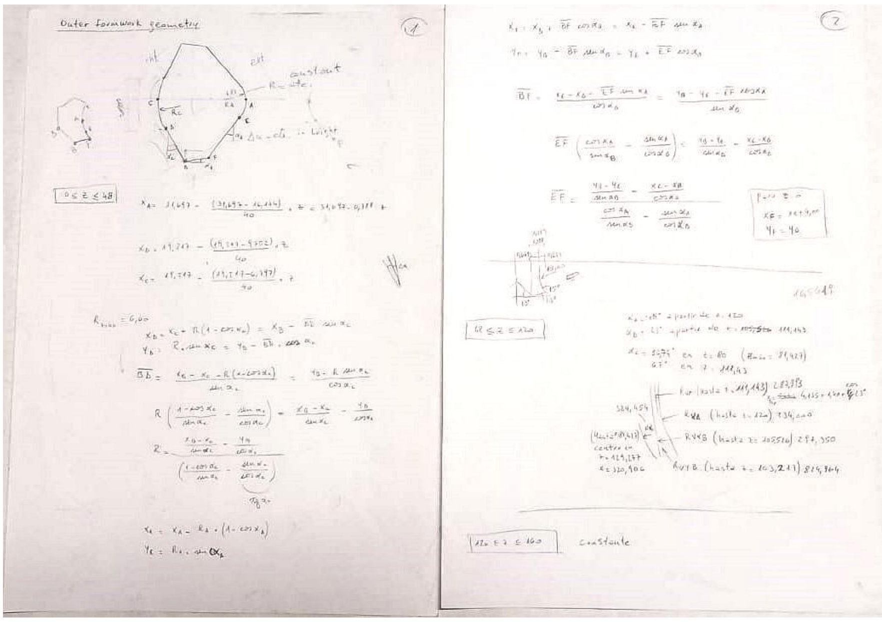


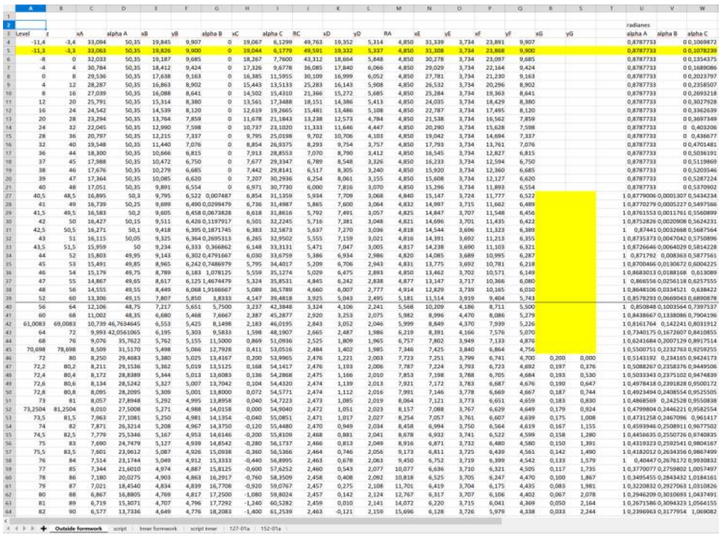
Figure 6: Superimposed sections of pylon legs

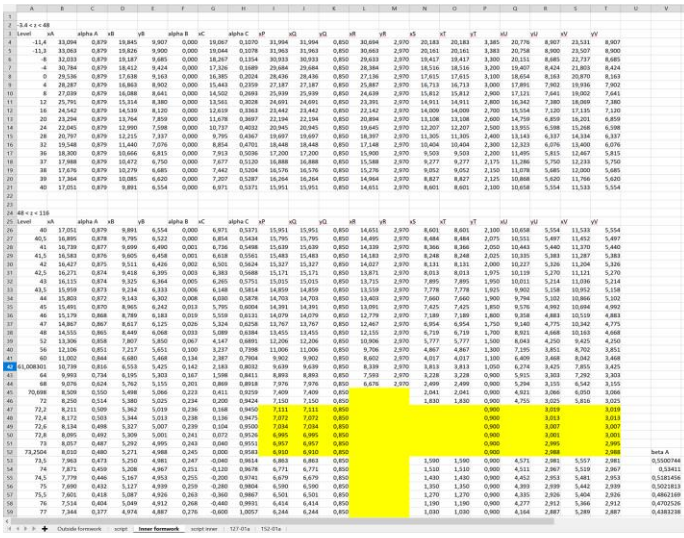




↑ *Figure 7: Points and angles considered for geometry definition*

← *Figure 8: Some of the formulas used in the spreadsheet*





Figures 9 and 10: Excerpts from Geometry Spreadsheet – Outside formwork (left) and Inner formwork (right)

The solver tool was used to ensure certain transitions occurred at the desired points.

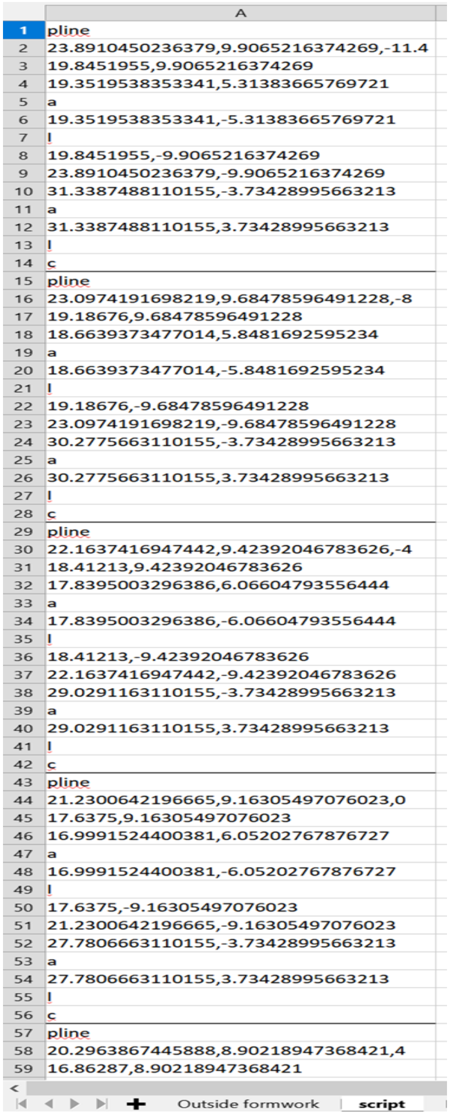
A spreadsheet was also created for the inner formwork, Figure 10. It was developed considering polygonal shapes and, where possible, keeping the internal faces parallel to the straight segments of the exterior formwork.

NEW RATIONALIZED 3D MODEL

With all this data available in the spreadsheets, scripts were generated for the automatic drawing of these sections in a CAD program, Figure 11, avoiding mistakes and spending less time.

These sections were used to generate a 3D model that allowed the architects to verify whether the obtained solution met the required standards, Figures 12 to 16.

The complete mathematical geometry definition was then condensed to four design drawings, Figures 17 to 20.



	A
1	pline
2	23.8910450236379,9.9065216374269,-11.4
3	19.8451955,9.9065216374269
4	19.3519538353341,5.31383665769721
5	a
6	19.3519538353341,-5.31383665769721
7	l
8	19.8451955,-9.9065216374269
9	23.8910450236379,-9.9065216374269
10	31.3387488110155,-3.73428995663213
11	a
12	31.3387488110155,3.73428995663213
13	l
14	c
15	pline
16	23.0974191698219,9.68478596491228,-8
17	19.18676,9.68478596491228
18	18.6639373477014,5.8481692595234
19	a
20	18.6639373477014,-5.8481692595234
21	l
22	19.18676,-9.68478596491228
23	23.0974191698219,-9.68478596491228
24	30.2775663110155,-3.73428995663213
25	a
26	30.2775663110155,3.73428995663213
27	l
28	c
29	pline
30	22.1637416947442,9.42392046783626,-4
31	18.41213,9.42392046783626
32	17.8395003296386,6.06604793556444
33	a
34	17.8395003296386,-6.06604793556444
35	l
36	18.41213,-9.42392046783626
37	22.1637416947442,-9.42392046783626
38	29.0291163110155,-3.73428995663213
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41	l
42	c
43	pline
44	21.2300642196665,9.16305497076023,0
45	17.6375,9.16305497076023
46	16.9991524400381,6.05202767876727
47	a
48	16.9991524400381,-6.05202767876727
49	l
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53	a
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55	l
56	c
57	pline
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59	16.86287,8.90218947368421

Outside formwork | script

→ Figure 11: Excerpt from Geometry Spreadsheet – Script

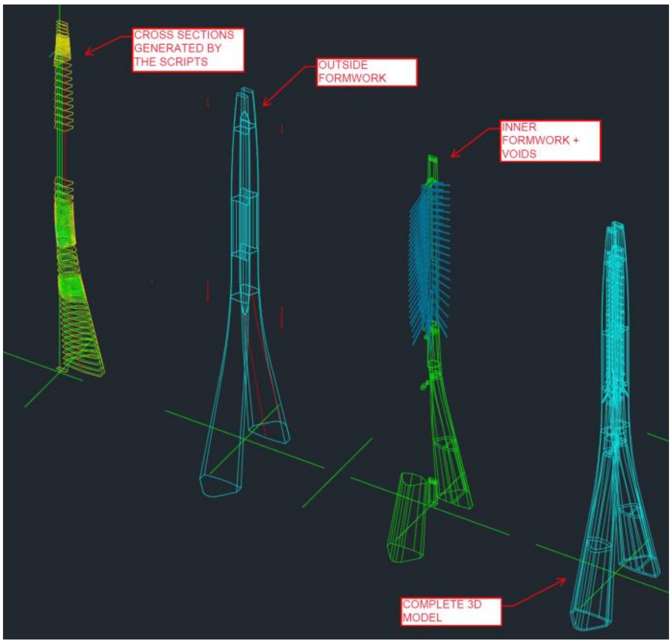


Figure 12: CAD 3D model based on the spreadsheet

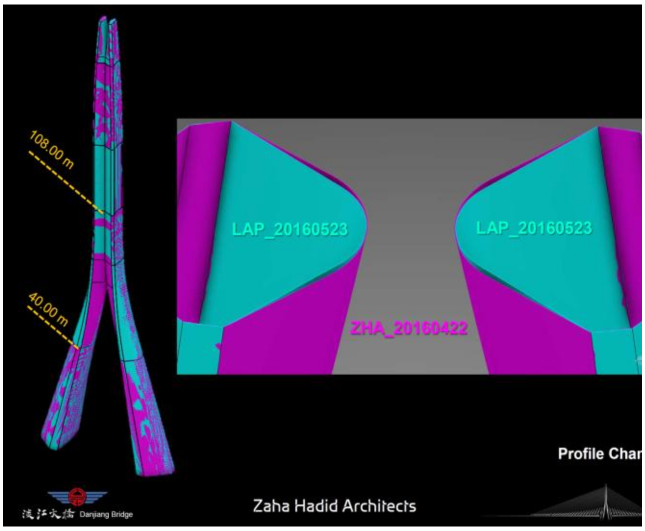
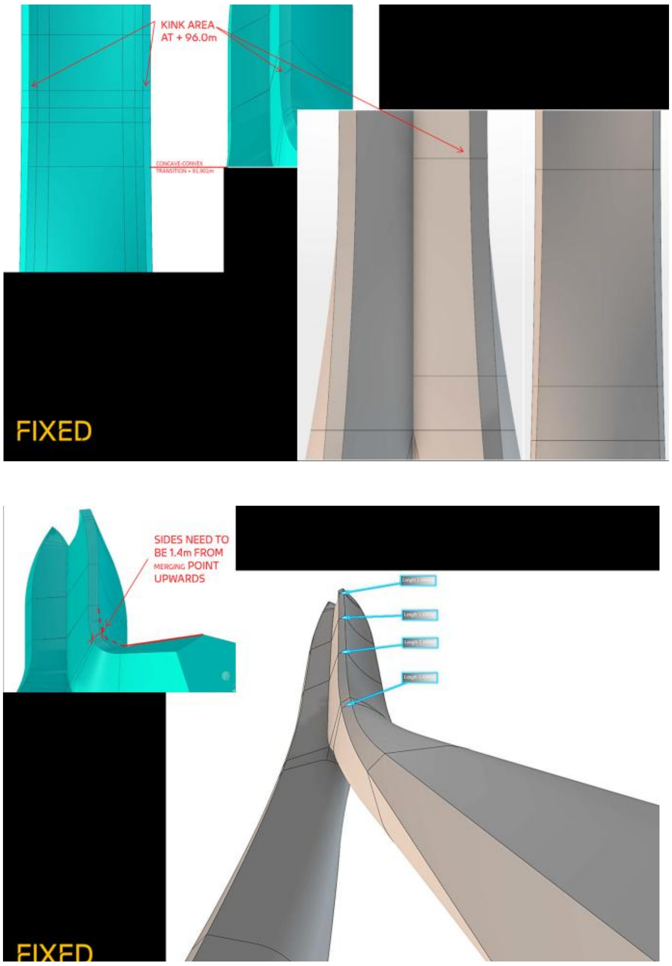


Figure 13: 3D models comparison



Figures 14 and 15: Example of architects checking

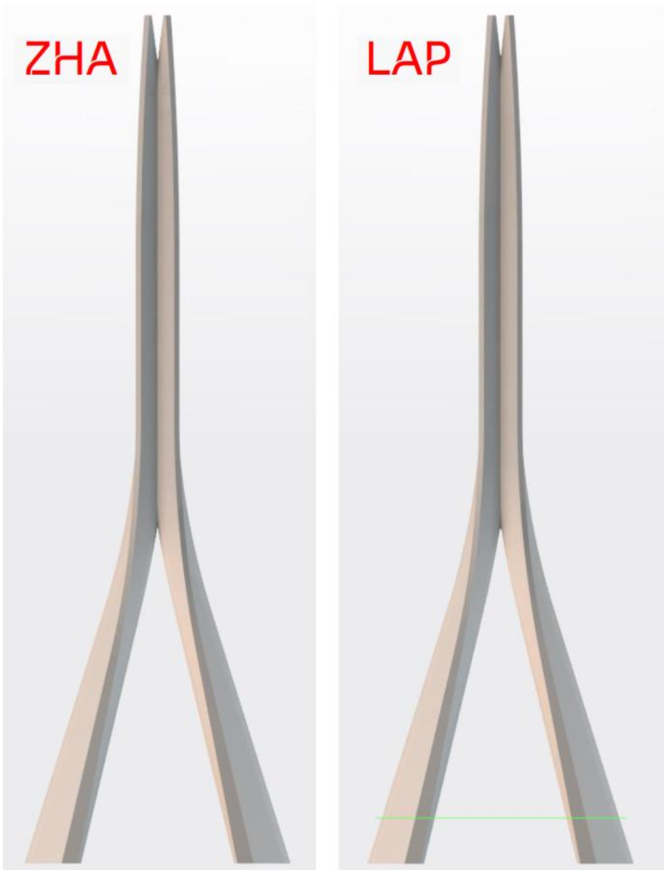
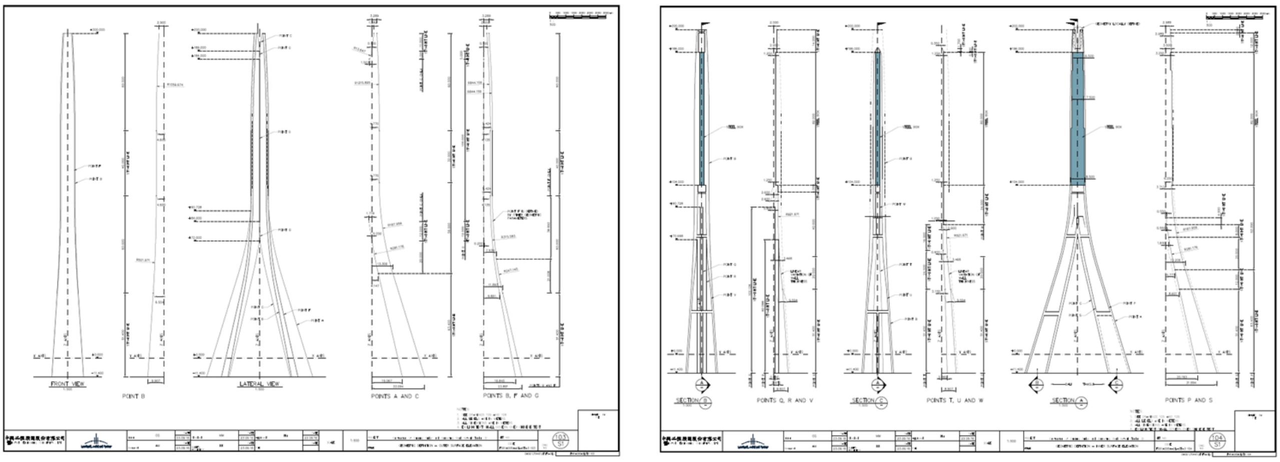
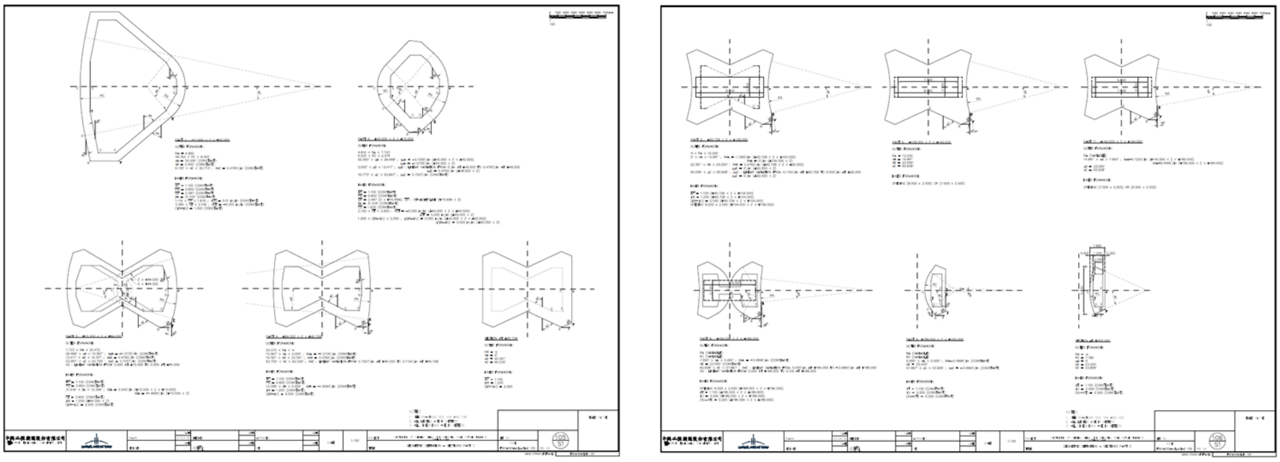
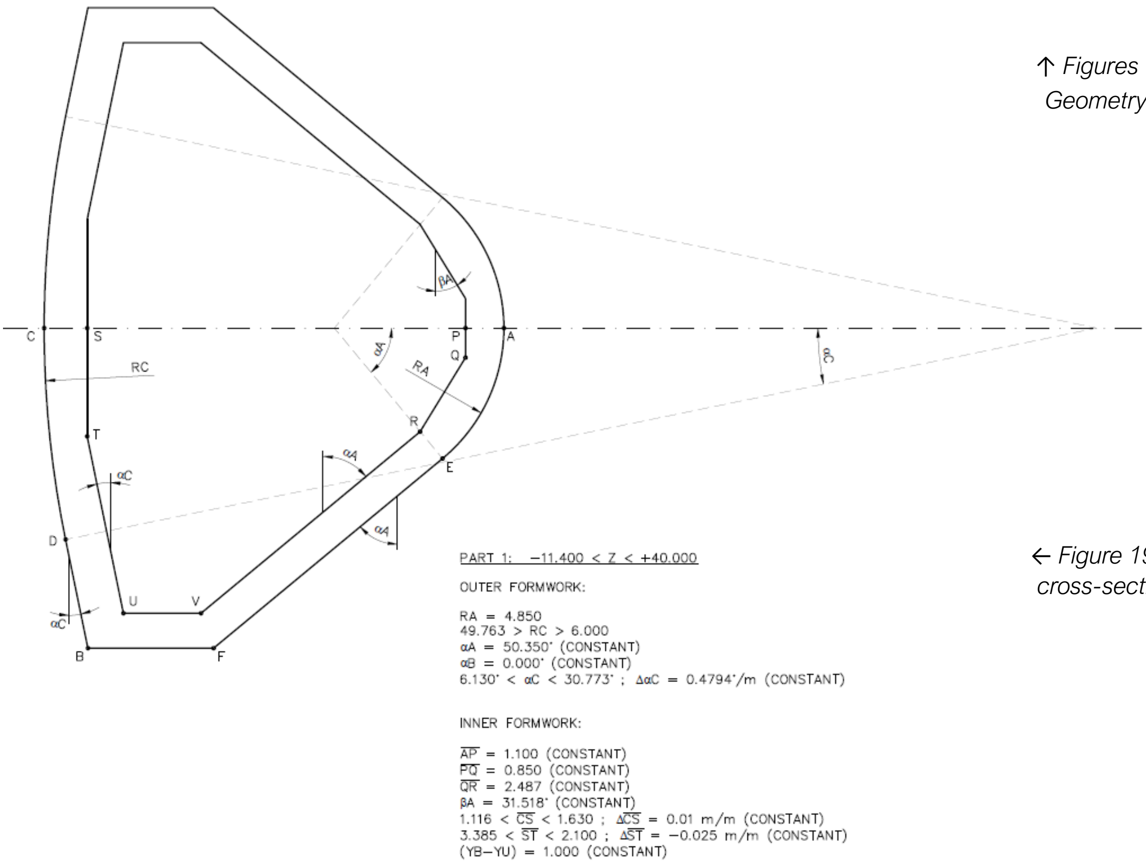


Figure 16: Final result





↑ *Figures 17 and 18: Geometry drawings*



← *Figure 19: Example of cross-section definition*

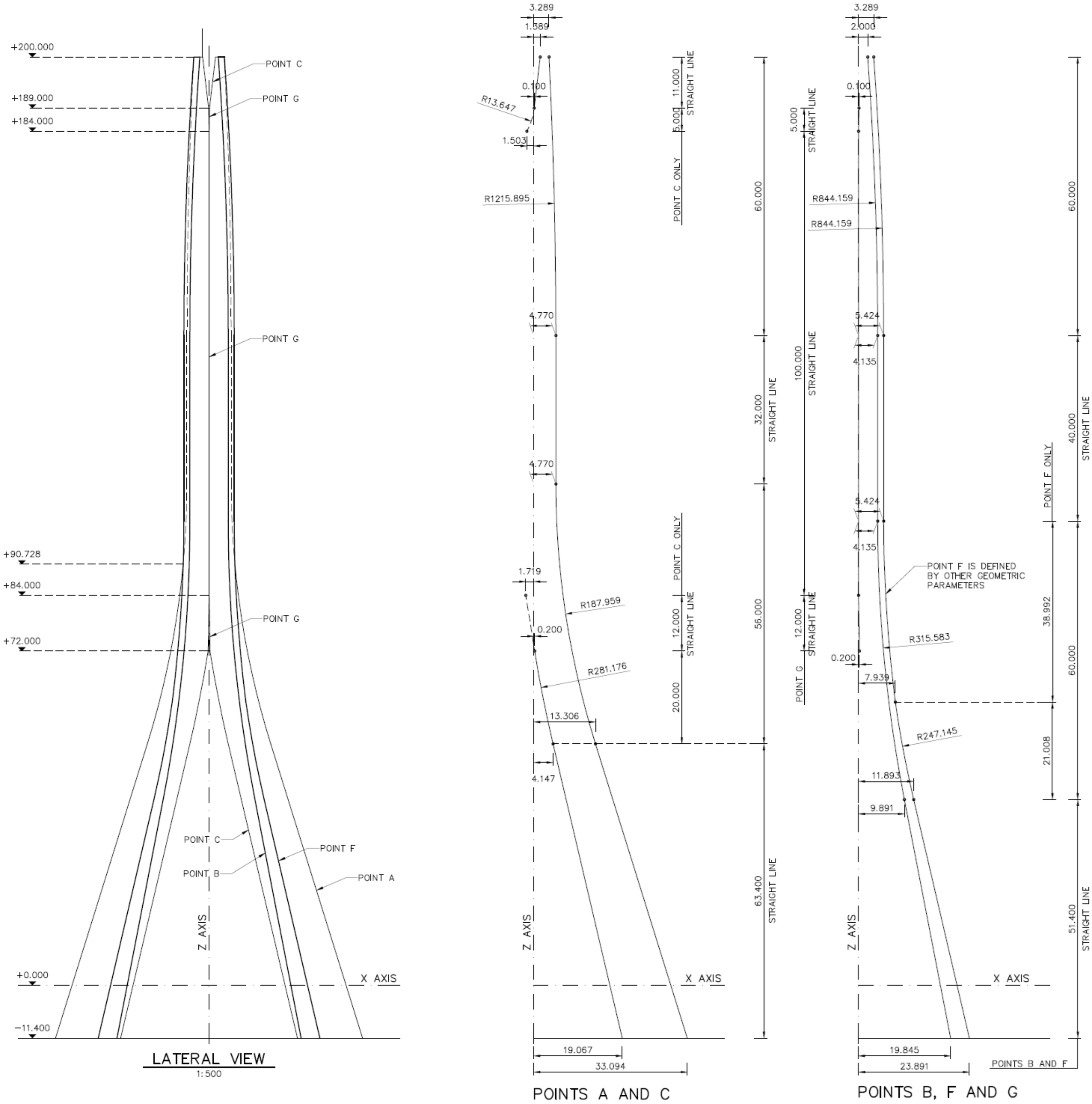


Figure 20: Example of vertical definition

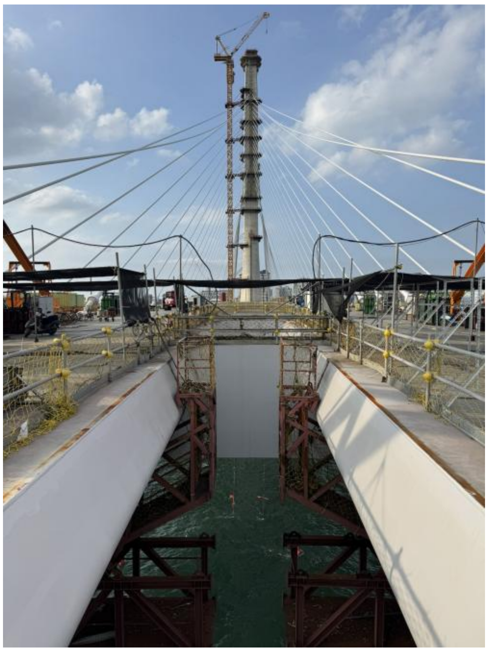
Figure 21: Original rendering and similar view of pylon under construction

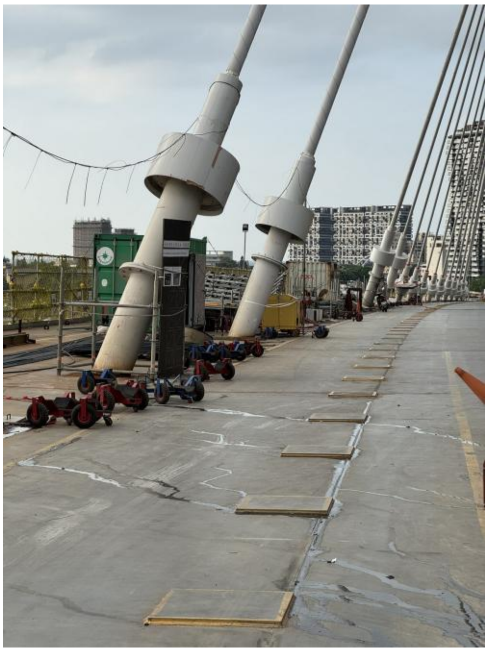
CONCLUSION

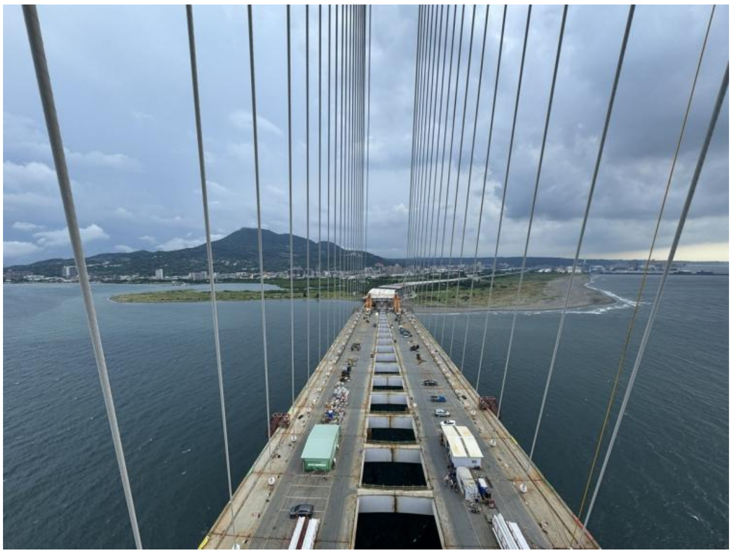
After the challenge of precisely defining the pylon's geometry, there is the even more complex challenge of its construction, which is currently underway, with the results shown in Figure 21.

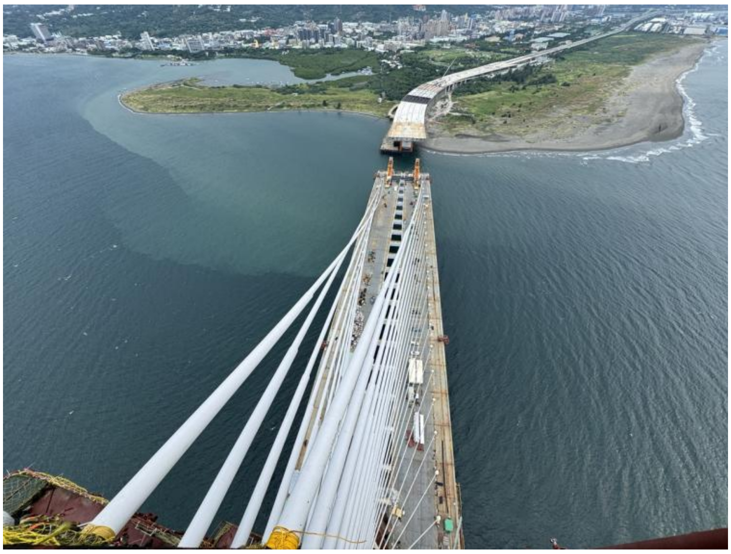
Based on what has been achieved so far, the results are more than satisfactory, and this bridge will become one of Taiwan's most recognisable symbols worldwide.

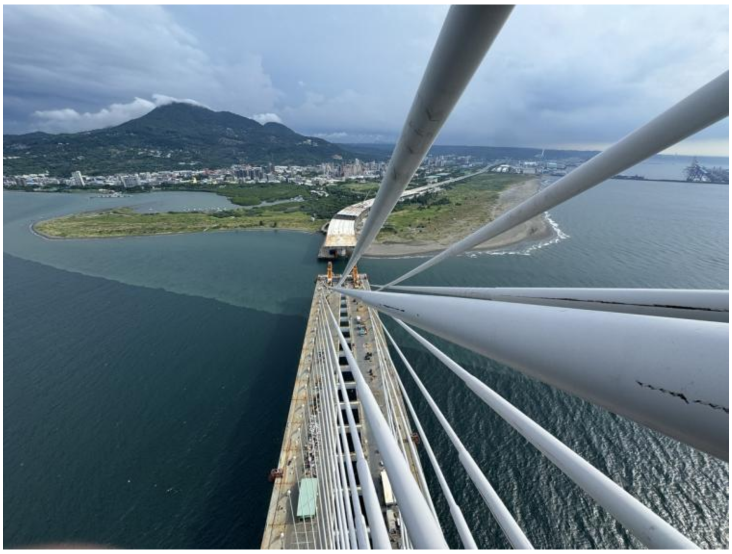
CONSTRUCTION GALLERY

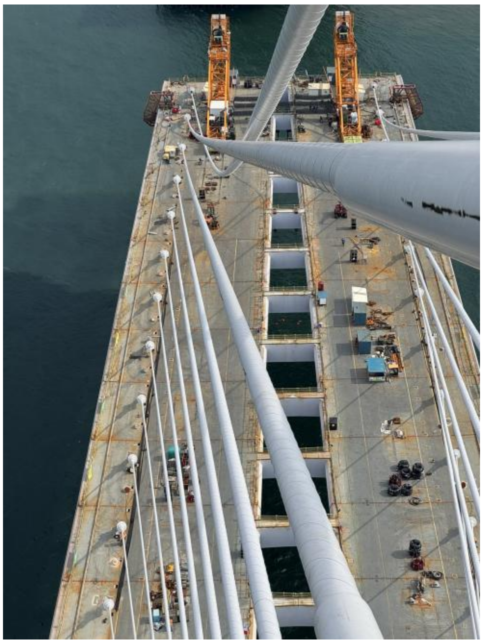


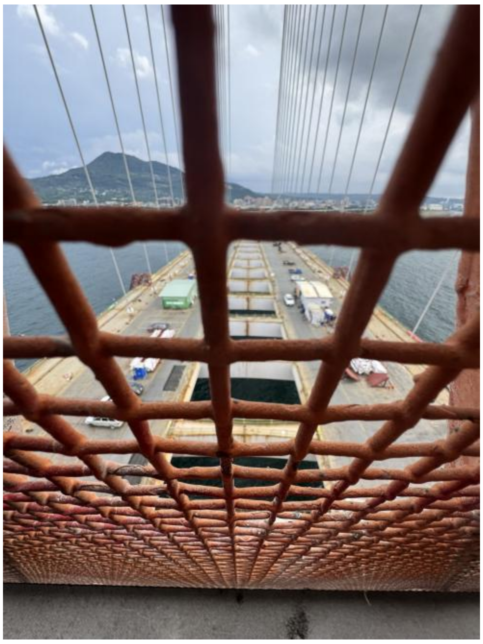


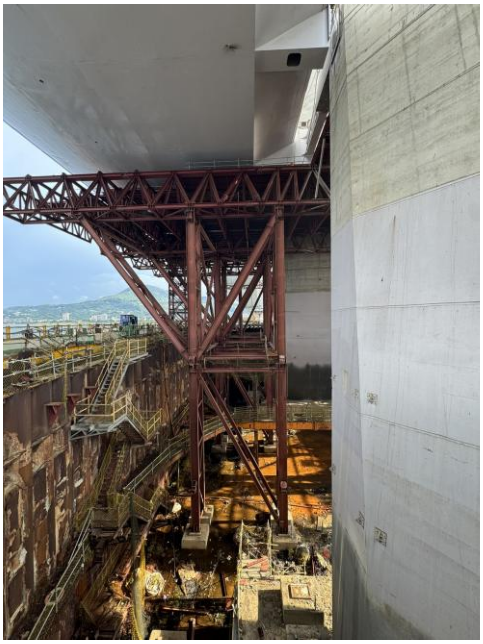


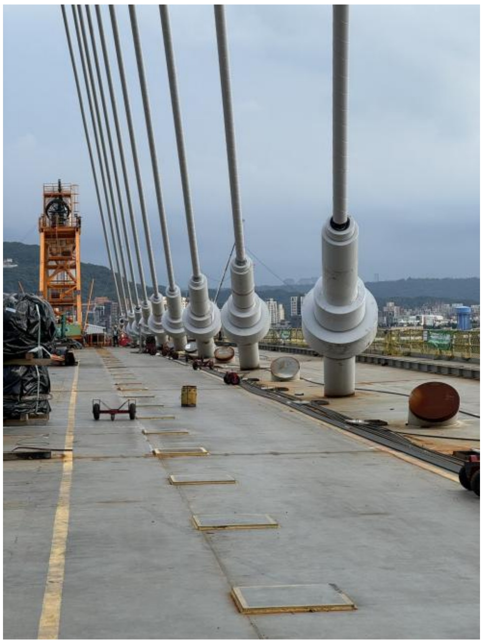


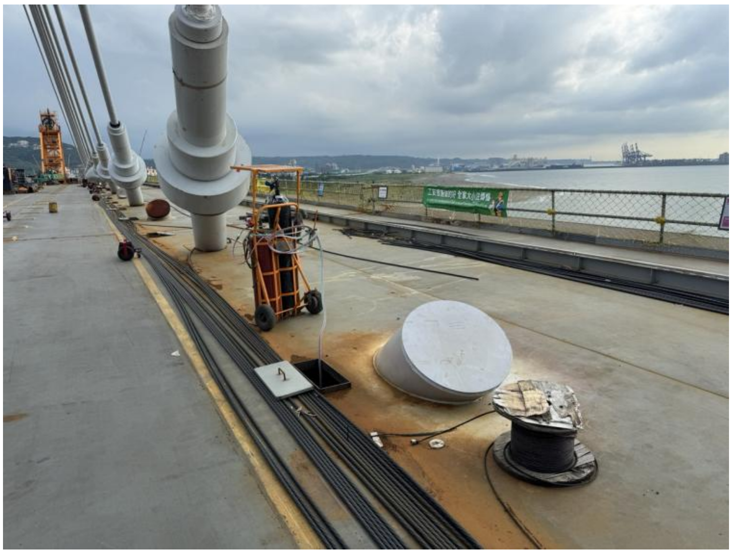












All photos Credit: Zaha Hadid Architects

DANJIANG BRIDGE – STAY CABLE SYSTEM TESTING, DESIGN AND ERECTION

Jannik Gawlista, Viviana Costa
DYWIDAG Systems International GmbH, Germany

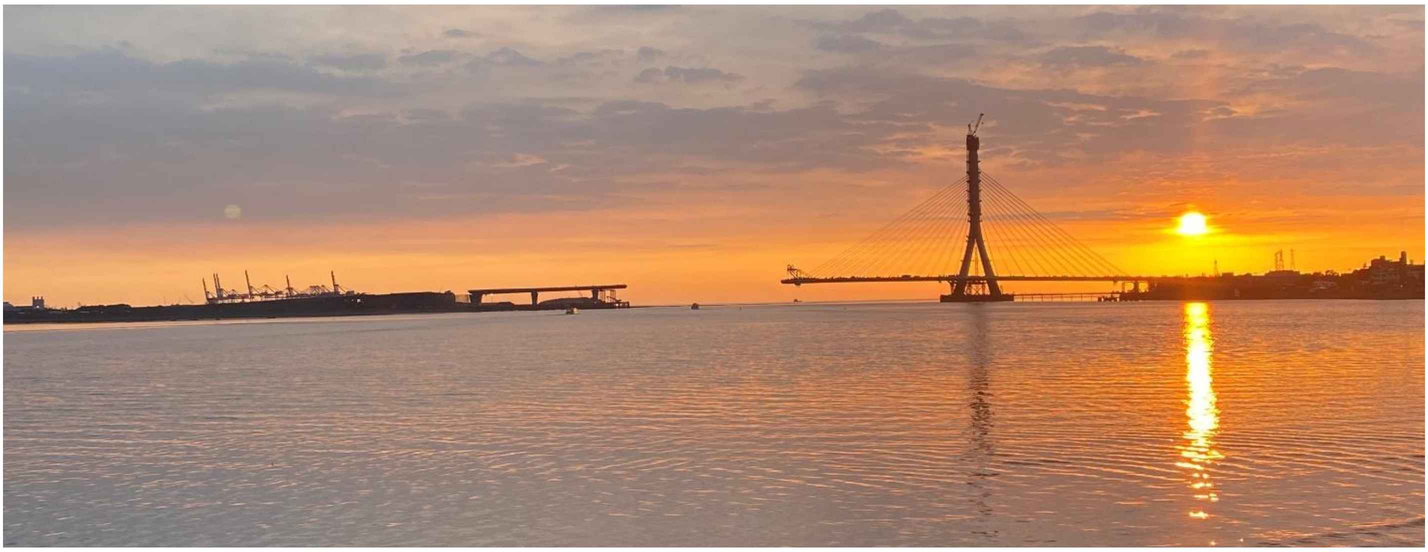


Figure 1: Sunset at Danjiang Bridge with ~50% of cables installed (May 2025)

INTRODUCTION

The Danjiang Bridge is currently being constructed in the north of Taiwan and is set to connect Bali and Tamsui once completed in 2025. The iconic bridge was designed by Sinotech Engineering Consultants, Leonhardt Andrä und Partner (LAP) and the Architects of Zaha Hadid.

The single-side main span reaches an astonishing 450 m, making it the largest asymmetric cable-stayed bridge with a single tower in the world once completed. The tower reaches approximately 200 m in height, and within steel anchor boxes, stay cables of up to 442 m are anchored.

DYWIDAG designed and installs the stay cable system for this remarkable project and will deliver a total of around 2300 tons of stay cable strands.

The bridge employs a state-of-the-art galvanized, waxed, and PE-sheathed parallel strand system, fulfilling typical international PTI and fib guidelines.

A total of 94 Stay Cables is anchored using DYNA Grip sizes DG-P55, 61, 73, 91 and 109.

Twelve Tie-Down cables of sizes DG-P43 and DG-P127 are placed in piers P120 and P140 at the main span and back span to control uplift forces resulting from the stay cables.

Some special cable features include internal friction dampers, a bending stopper at the deck and tower, anti-vandalism protection pipes and fire protection mats.

Rigorous full-size testing, design verifications and iterations were performed specifically for the project and will be described in more detail in this article.

TESTING

Wind Tunnel Tests

Due to their critical impact on the structural design of the bridge, the stay cable specification required experimental verification that drag force coefficients at a testing wind speed of 50 m/s do not exceed 0.65 for HDPE pipe diameters smaller than or equal to 225 mm and 0.60 for HDPE pipe diameters above 225 mm.

To address this requirement, DYWIDAG conducted project-specific testing of drag (C_D) and lift (C_L) values of the HDPE pipes with double helix of 200, 250 and 315 mm supplied for the project at the Jules Verne wind tunnel of CSTB in Nantes, France.

The test setup can be seen in Figure 2. Considering blockage ratios of up to 6.3% at the largest pipe diameter of 315 mm, the corrective Maskell III process was applied by the wind engineers.

The resulting drag coefficients of all test samples met the project requirements.

Considering the stay cables reach lengths of up to 442 m, susceptibility against cable vibrations was a critical design consideration. To minimise the effects of rain and wind-induced vibrations (RWIV), DYWIDAG supplied all HDPE pipes with a double helical fillet.

Figure 2: Wind tunnel testing of 200 mm HDPE pipe drag coefficient C_D at CSTB, France

The effectiveness of the helix was proven by two wind tunnel tests, which were performed for different pipe diameters at the Wind tunnel at FORCE Technology, Denmark. Considering the relatively low inherent damping of cables, elaborate additional damping evaluations were needed, which are presented in more detail in the next chapter.

Full-size Tests

Acceptance testing of at least three representative stay cable specimens was specified in the project specification. DYWIDAG has successfully conducted over 50 full-scale tests in alignment with the recommendations of either PTI, fib or SETRA over the last 25 years.

Nevertheless, and despite the relevant PTI recommendation generally allowing acceptance of prior tests, it was decided that four new full-size tests shall be conducted for the Danjiang project.

Anchorage size	Test	Condition	Reference
DG-P61	Fatigue & Tensile	45% GUTS, 200 MPa	Fib bulletin 89
DG-P55	Fatigue & Leak	45% GUTS, 159 MPa	PTI DC45.1-12
DG-P109	Fatigue & Tensile	55% GUTS, 121 MPa	PTI DC45.1-12
DG-P127	Fatigue & Tensile	45% GUTS, 200 MPa	Fib bulletin 89

Table 1: Full-scale cable system testing

The specified testing criteria require testing only at an upper load of 45% GUTS with 159 MPa, as well as 55% GUTS with 121 MPa stress range, which is in alignment with PTI DC45.1-12 [1].

DYWIDAG increased the testing criteria at two of the tests to comply with the even stricter testing requirements given in fib89 [2].

Cable sizes were selected to be representative of both the stay cable and tie-down system in alignment with section 4.2 of PTI DC45.1-12.

A summary of all conducted tests, their conditions and cable sizes are given in Table 1.

All full-size tests were conducted by the TÜV Austria GmbH at the laboratory of the Institute for Structural Engineering in Vienna, Austria. All four tests were successfully completed and surpassed the requirements. There was not one wire fracture observed in any of the performed fatigue tests.

All tensile tests fulfilled the given criteria and reached more than 92% AUTS, 95% GUTS and 1.5% elongation at max. load, and there was no red dye observed after the leak tests.

The results for one representative test are given in Table 2, and a picture of the largest full-scale test size 127, which reached a tensile strength of more than 33 MN, is presented in Figure 3.

TIE-DOWN SYSTEM

Bending

Under different load combinations and temperature variations, large displacements in longitudinal and transverse directions are expected at Bridge Piers P120 and P140, which contain tie-down cables for uplift control up to +/- 550mm transversally and +/- 300 longitudinally at one Pier (P120).

Displacements are also superimposed by a significant earthquake contribution with 50% of the thermal action, which is crucial for the bridge location. Consequently, tie-down cables are subject to substantial rotations at the Ultimate and Extreme Limit State.

In the occurrence of large angular deviations, DYWIDAG's internal good practice is to limit cable rotations at the anchorage to 25 mrad.

This design value is a conservative and empirical criterion for the filtering apparatus according to PTI DC45.1-12 (2.5% transversal load criterion, see section 5.3.4.1).

To cope with these requirements, HDPE deviators were placed at the ends of guide pipes at the deck and pier levels. It was thereby recommended that the application of HDPE deviators be made at the end of both.

Figure 3: Representative full-scale test setup (DG-P127)

Anchorage size	Efficiency AUTS	Efficiency GUTS	Elongation at max. load	Fatigue failures
DG-P61	94.9% AUTS ≥ 92% AUTS	96% GUTS ≥ 95% GUTS	2.72% ≥ 1.5%	0

Table 2: Representative full-scale test result (DG-P61)

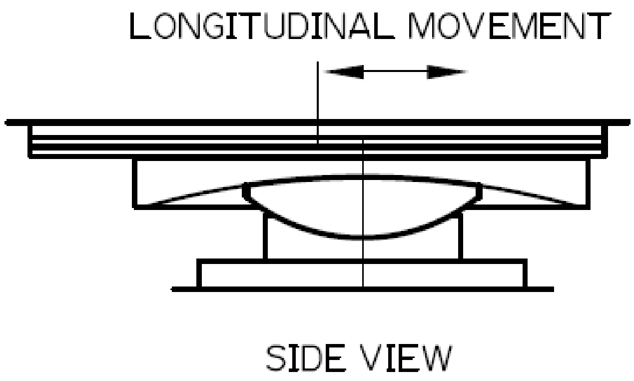


Figure 4: Bearing scheme

HDPE Deviators have a specific double functionality as they serve as a bundling system and contain cable rotations due to large movements at the deck bearings.

The relative shortness of cables, and therefore closeness of the HDPE Deviator to the anchorage, has required a detailed study of the PE component dimensions to make sure that:

a) In a straight configuration, the maximum bundling deviation of the outer strands is below the PTI full-size fatigue and tensile test criteria, see Figure 5, left.

b) The expected ULS rotations can be accommodated, see Figure 5, right.

Finally, HDPE deviators are designed in full compliance with equation 5.2 of PTI. The cable is deviated along the inner radius of the deviator, and therefore, the cable radius of curvature is dictated by the radius of curvature of the deviator.

This radius is specifically chosen to fulfill the bending stress limits that are valid for the project.

STAY CABLE SYSTEM

Bending

According to project specifications, stricter bending stress limits at ULS under maximum angular deviations compared to PTI (bending stresses lower than 241.7 MPa acc. to PTI vs 186 MPa according to project specifications) and special requirement of no planned deviation or blocking at SLS at deck, have made the design of the angular deviations filtering apparatus at Stay Cable challenging.

Specifically designed, patented HDPE stoppers are provided at the end of the deck guide pipes. These stoppers allow free cable movements under SLS rotations and provide a controlled deviation point for the cable bundle under ULS and Extreme rotations.

Similar to the deviators placed at the tie downs, see one chapter above, this design controls the resulting bending stresses at the cable anchorages and minimises resulting damper stroke demands and consequently damper housing diameter.

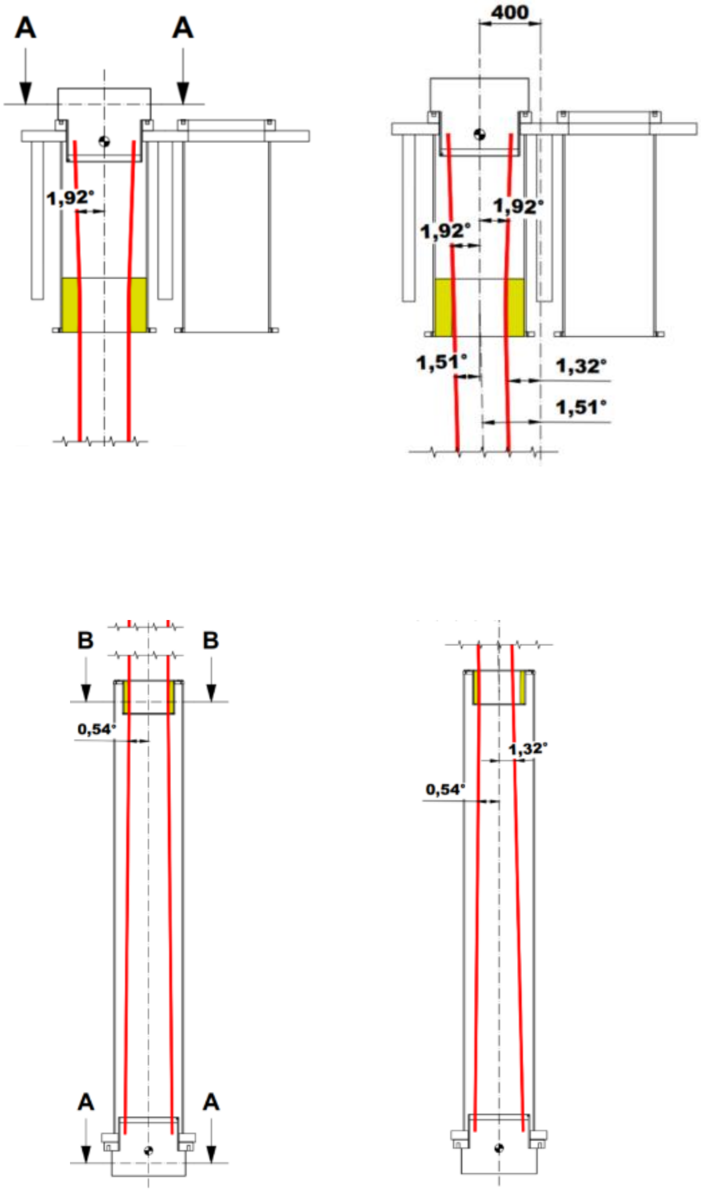


Figure 5: Bundle deviation static (left), ULS rotations (right)

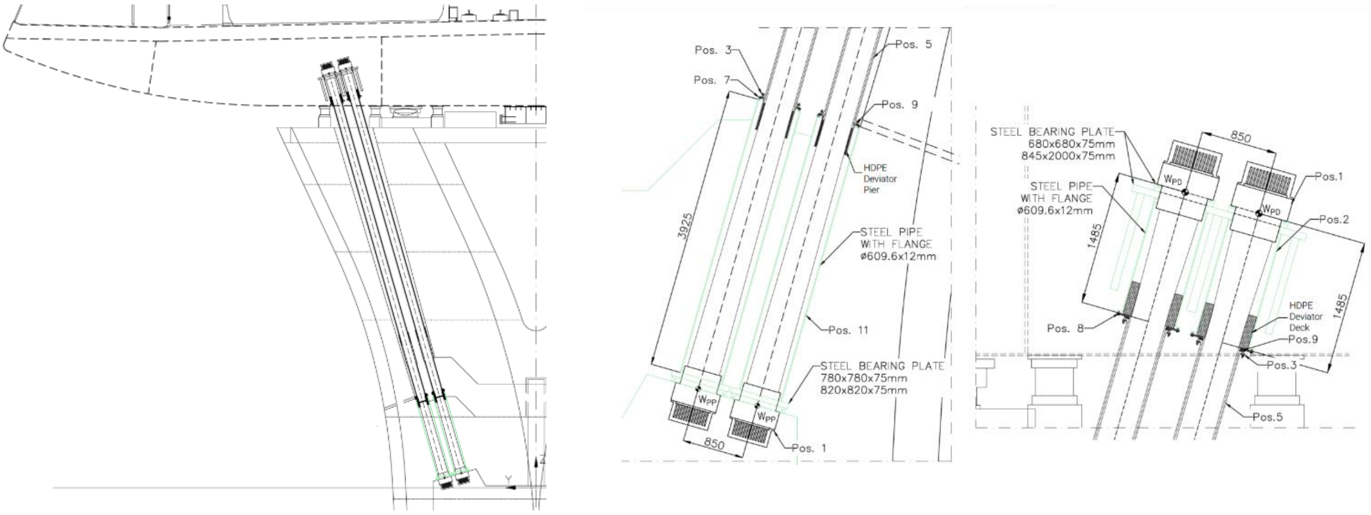


Figure 6: Tie Downs System Drawing

Such stoppers are also provided within the guide pipe towers to control bending stresses within the anchorage, avoid clashing of the strands and HDPE sleeves with any steel edges given the maximum provided rotational angles, under Extreme or ULS load case combination whichever is higher, that reach up to 60 mrad (either transversally or longitudinally) at the longest cable.

Stoppers take only a fraction of the total deviation of the cable. This fraction depends on the distance between the bundle and the stopper.

The resulting deviation at the stopper position is then the total deviation minus the rotational angle blockage portion imposed by the stopper as per design.

Damping

At the Danjiang Bridge project, a minimum damping ratio of 0.67% (4.2 % logarithmic decrement) must be achieved for modes 1 and 2 in any direction perpendicular to the stay axis. This is to address the rare susceptibility of the cables to parametric excitation and more common wind phenomena such as Rain-Wind Vibrations (RWIV).

The detailed wind engineering study also defines the maximum tolerable dynamic amplitude as “1.5 times the diameter of the HDPE pipe”.

To verify these requirements, the so-called performance chart method was applied to design all friction dampers.

The friction damper performance chart is a design tool that allows for the assessment of achieved damping relative to the maximum cable amplitude, based on the equivalence principle ([3], [4]).

As illustrated in the performance chart example in Figure 7, friction dampers exhibit nonlinear damping behaviour. For friction damper design, parameters such as (bm1) and (bm2) can be used to define the friction force level (also known as capacity). Based on this capacity, the design amplitude range, within which the provided damping exceeds the requirements, can be calculated.

The previously described method of performance charts has been validated through direct calculations and numerous in-house verifications, specifically for the dampers used at the Danjiang Bridge in Taiwan. For each validation, a cable was numerically simulated using a finite element method (FEM) approach.

Some simulation results are depicted in Figure 8.

The simulated measurements indicated that the performance chart method underestimates the actual damping by 10 to 30%, which aligns with large-scale testing results [5]. Therefore, relying on a maximum damping value (as per the equivalence principle), the performance chart approach is considered a conservative design method.

As a result, the damping requirements for each cable with a friction damper were met through careful design choices.

Based on the friction damper design, the required friction force level (referred to as capacity) for each cable was determined. Consequently, a range of damper capacities is necessary for the Dan Jiang Bridge project.

Protection Systems

In accordance with the Stay Cable project specifications, the stay cables are equipped with an anti-vandalism pipe and fire protection necessary to meet the requirements of the Bridge Protection Plan.

The anti-vandalism steel tube shall accommodate cable sag and potential misalignment between the cable and the exit pipe, also at ULS for the bridge in service condition.

The high expected rotations and steep cable angle of the first cables require a large diameter of the AV-Pipe and special attention to prevent any clash with the bundle.

For this specific case, AV-Pipe are connected in a hinged connection on top of the Exit Pipe through a supporting plate, replacing the damper housing as otherwise incorporated.

Protection systems shall be designed such that in a hydrocarbon fire event of 1100 °C, for a specified period of time, the temperature measured at the outer layer of the main tension element does not reach 300 °C in the protected area.

The DYWIDAG cable fire protection at the free length of the cable consists of a highly resistant insulation mat which is wrapped around the stressed strand bundle with longitudinal and transverse overlapping. It is fixed with stainless steel bands.

The outer cover is an HDPE pipe with an increased diameter so that the mats fit into the HDPE pipe.

The direct fixation on the strand bundle assures a safe and reliable fire protection of the cable.

The mats have a hydrophobic behaviour to prevent the absorption of rainwater during installation or condensation during the service life of the cable.

The system has been tested in several tests and fulfils the requirements for fire protection according to PTI DC 45.1-12 as well as according to project specifications.

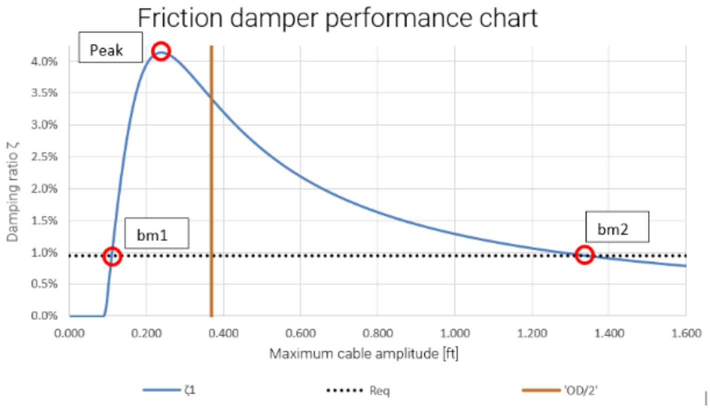


Figure 7: Example of friction damper performance chart

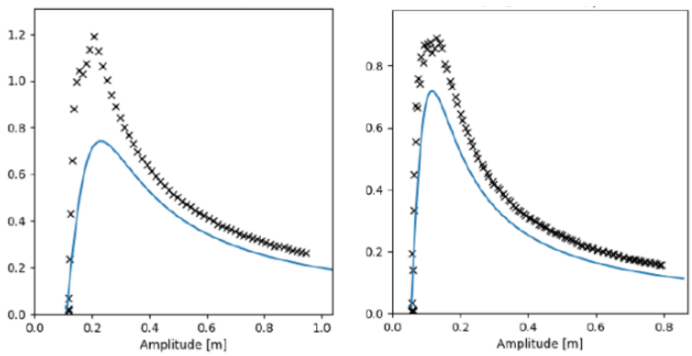


Figure 8: Amplitude-dependent damping: Measured by direct calculation (black crosses) and performance chart method (blue line)

Assembly

The Guide Pipe design takes into consideration the rotational demand of the cable. The resistance of the steel pipes is verified to a transverse load (in agreement with the project's requirement).

Exit Pipe is rigidly connected to the Guide Pipe flange and designed to allow free cable displacement under service conditions and load cases. An accurate numerical and analytical analysis has moreover been conducted to verify the bolted flange connection, including bolts and welding.

The adjustable anchorage is placed at the pylon side, where a ring nut is screwed onto the round anchor block with an external trapezoidal thread and is supported by the bearing plate fixed to the pylon steel structure.

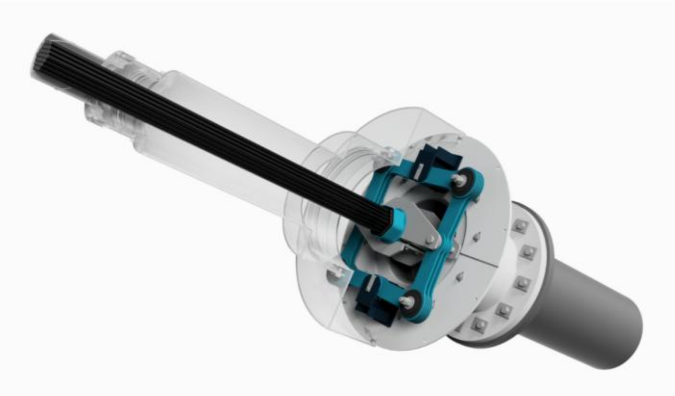


Figure 9: Friction Damper System

Figure 10: Fire protection system

The length of the anchorage external thread is determined for each cable to provide an adjustment possibility of the cable length in compliance with the project specification requirements. At least 2.5% of cable force adjustment should be ultimately guaranteed.

The designed Rotational friction damper consists of several types of steel plates pre-stressed together by steel bolts to form a V-shaped damper. Four V-shaped dampers are combined to create the internal stay cable damper. Circular friction pad discs, made of special composite high-tech friction materials, are placed between the steel plates.

To maintain a constant pre-stressing force in the bolts, several disc springs are used on both sides. Hardened washers are placed between the disc springs and the two external steel plates to ensure uniformly distributed pressure. The device's energy-absorbing performance can be adjusted at any stage by modifying bolt torque or by adding/ removing layers of steel plates and friction pads.

For the friction cable damper, four friction joints are used to provide symmetry with four connectors. The friction damper is installed between the exit pipe flange and the compaction clamp and protected by an outer housing, see Figure 12.

While the exit pipe flange is rigidly connected (welded) to the exit pipe, the compaction clamp is installed at the strand bundle. This fixation is subjected to various rotation and movement demands and was specially designed to cope with the following:

- Expected axial cable elongation variations resulting from load and temperature changes of the up to 445m long cables.
- Free cable movements under Service Limit State (SLS) Rotations of up to 30 mrad.
- Ultimate Limit State (ULS) and Extreme Rotations of up to 62 mrad.
- Additional consideration of fabrication and Installation Tolerances.
- Maximum damper housing diameter allowance due to the adjacent scooter lane.

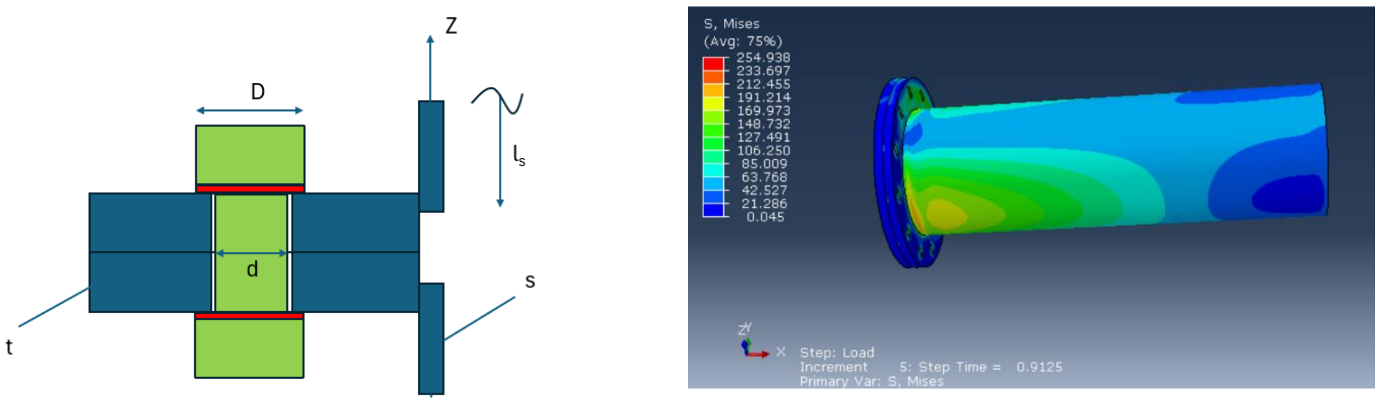


Figure 11: Analytical model of exit pipe joint (left) and numerical analysis (right)

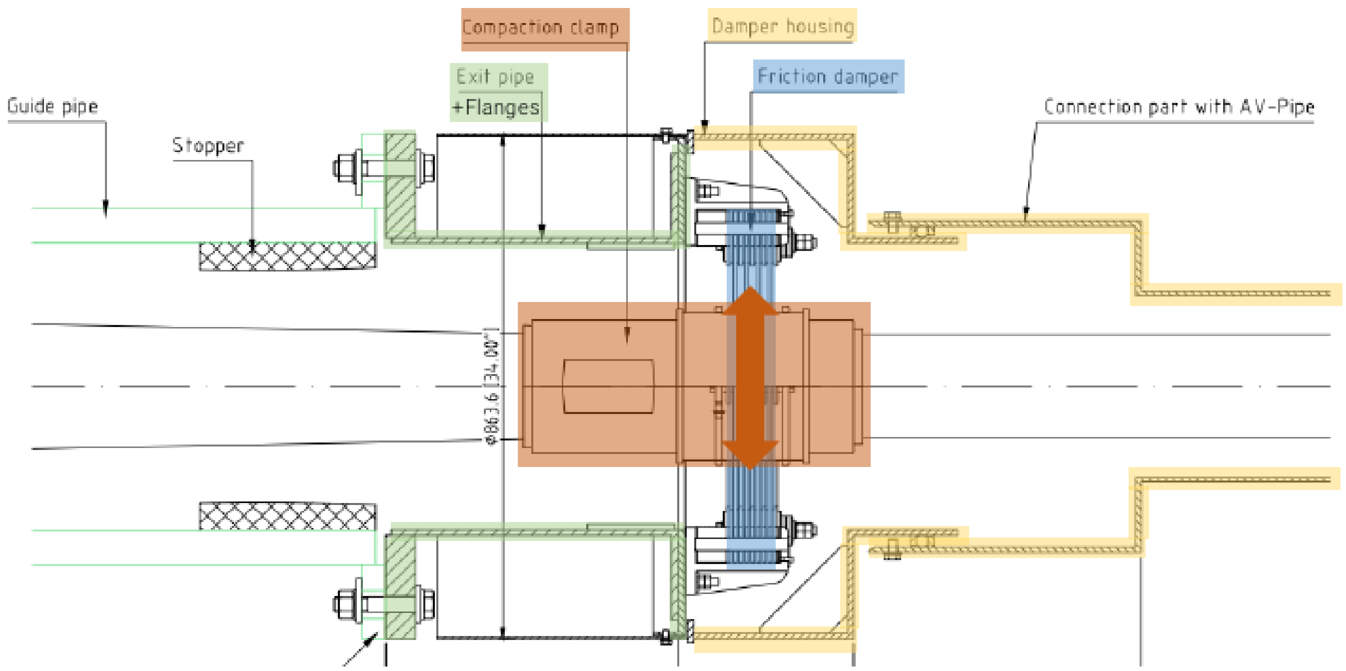


Figure 12: Friction damper assembly

ERECTION

Tie-Down Erection

Tie-down cables at Pier P140 are planned by design to be installed and stressed 80% of the design value after back span closure, and the remaining 20% after the main span closure. Tie downs at P120 will be fully stressed after the main span closure.

Stay Cable Erection

The first pair of lowermost stays on the Bali and Tamsui sides (resp. BE0-BW0 and TE0 and TW0) were erected at the end of September 2024, and since then, installation of the stay cables has been underway. Two strands at a time are lifted through a hybrid centre wire coupler (combination of buttonhead and wedge).

There are at least two stressing stages per cable, one installation and one restressing stage. In both stages, strands are stressed by force using the ConTen system with reference strands, which ensures equivalent strand forces at the end of stressing. Cycle time is around 2 days per cable.

CONCLUSION

A general overview of the stay cable system related testing, design and assembly for the Danjiang Bridge project have been presented with special focus on the innovative applications and special design tailored to the project requirements that boast the record of being the first largest asymmetric cable-stayed bridge with a single tower in the world.

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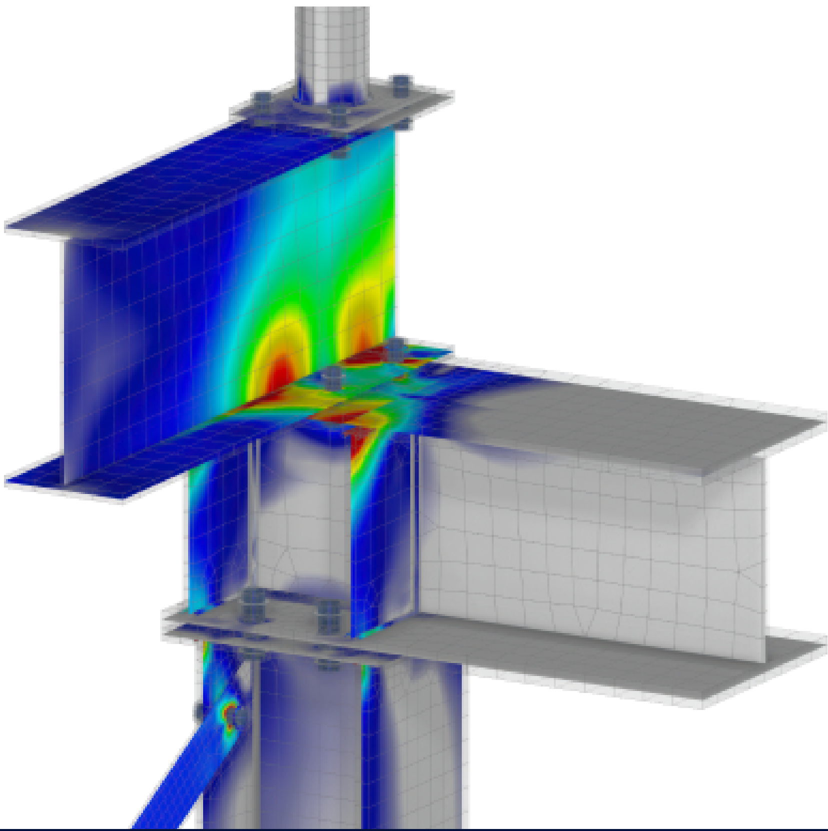

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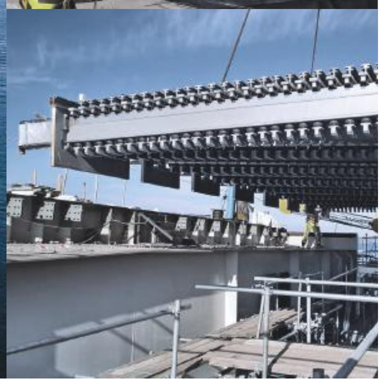

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- Service velocity up to 20 mm/sec (10 times higher than for a regular bridge)
- Watertight across the bridge width
- Maintenance free

References:
- Bahia de Cadiz, Spain
- Hochmoselübergang, Germany
- Osman Gazi Bridge, Izmit, Turkey
- Mainbrücke Randersacker, Germany
- Millau Viaduct, France
- Rheinbrücke Schierstein, Germany
- Rion Antirion, Greece
- Russky Island Bridge, Vladivostok, Russia
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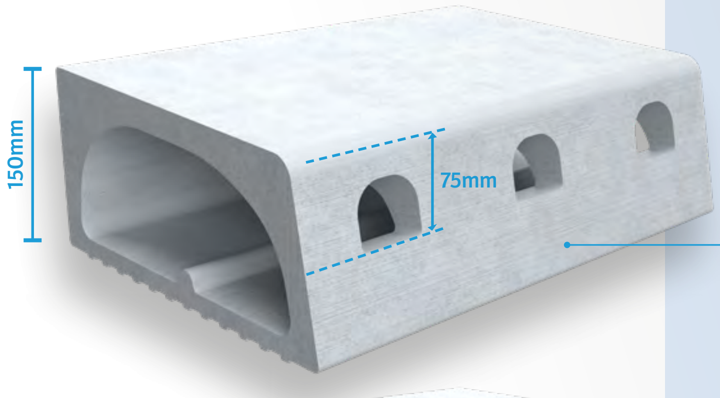

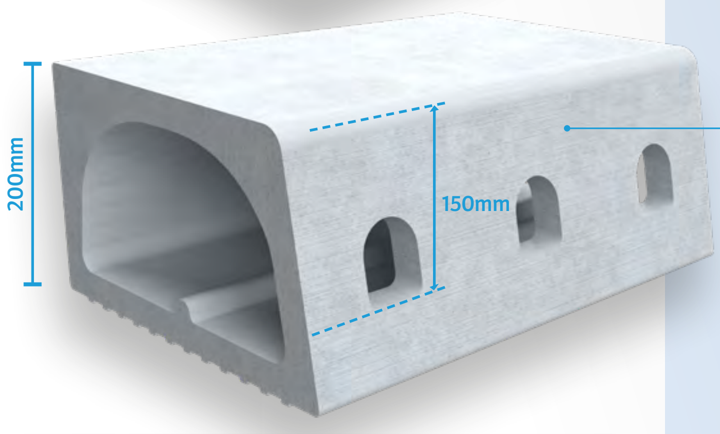

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The height of the inlet openings is milled to project-specific dimensions.

BD350x150 = 150mm high element
Top slope 4%
(according to BAST guideline Kap12)

BD350x200 = 200mm high element
Top slope 2%
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