e-mosty

ISSUE 04/2025 DECEMBER

DANJIANG BRIDGE, TAIWAN PART II.

LIST OF CONTENTS

INTERNATIONAL ONLINE PEER-REVIEWED MAGAZINE ABOUT BRIDGES

It is published at www.e-mosty.cz. Open Access.

Released quarterly:

20 March, 20 June, 20 September and 20 December

Number: 04/2025, December **Year:** XI.

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The Publisher: BRIDGES ONLINE, s. r. o. (Ltd.)
Velká Hraštice 112, 262 03 Czech Republic
VAT Id. Number: CZ02577933

E-MOSTY ISSN 2336-8179

Dear Readers

The second special edition about the Danjiang Bridge in Taiwan focuses on ***various aspects of its design and construction****.*

The first article presents the innovative planning and design of the excavation and retaining system used for the cofferdam during the construction of the main cable-stayed bridge's foundations, followed by an article on the innovative 3D formwork and climbing solutions developed, manufactured, and supplied by PERI. The third article focuses on seismic isolation design. High-performance structural protection components are described in an article by mageba. The last article is about modular steel safety barriers, which will be installed on the bridge. High containment level and a lightweight structure were key factors for their selection.

This edition also features a comprehensive construction gallery, showcasing the bridge's progress from the start of construction to its current state, as well as drawings.

We do not publish repetitive information that was already covered in the September e-mosty, such as the evolution of the concept, composition of the bridge, project information, design, etc.

Later in the February 2026 e-BrIM magazine, we will publish three more articles: one on 3D Digital Bridge Design, Integration, and Management; one on the sustainable integration of the Danjiang Bridge with the environment; and one on bridge monitoring.

I want to thank ***all authors and the people helping us prepare both special editions, especially Kilian Karius at*** *LAP, who has been assisting us with both editions, connecting us with relevant stakeholders, and helping with many other things. Furthermore, I would like to thank Edinson Guanchez for his assistance with the article on the foundations, as well as Sinotech, KSECO, and Wen-Kai (A-Kai) Chen.*

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 March. The June Edition will focus on Australian and New Zealand Bridges.

The next e-BrIM will be released on 20th February, in both English and Spanish.

On behalf of the organisers, we would like to invite you to the 2026 World Bridge Engineering Conference, which will take place in Miami, Florida, USA, from 1st to 2nd December 2026. More information is on page 8.

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

Thank you all for your cooperation in 2025, and I look forward to working with you in 2026.

Happy New Year.

Magdaléna Sobotková

Chief Editor

INTERNATIONAL ONLINE PEER-REVIEWED MAGAZINE ABOUT BRIDGES

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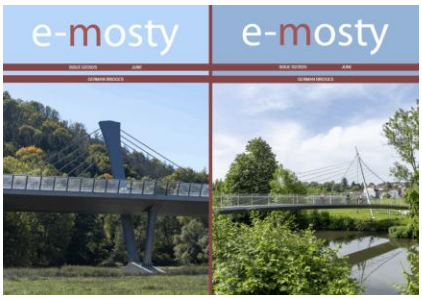

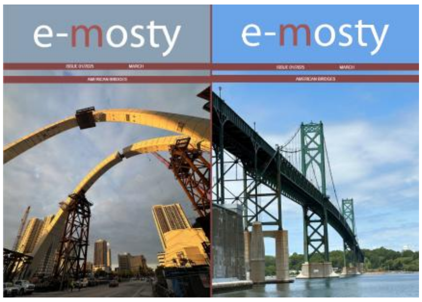

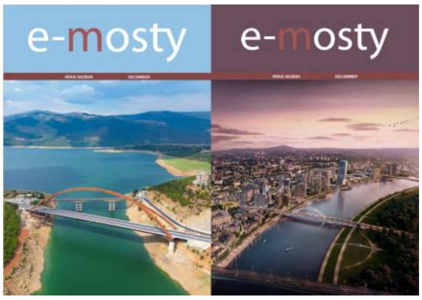

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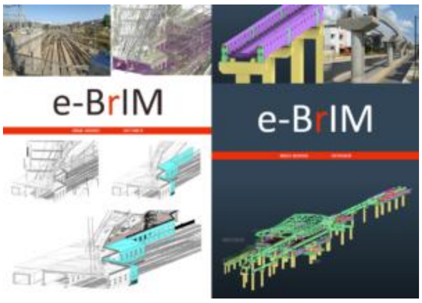

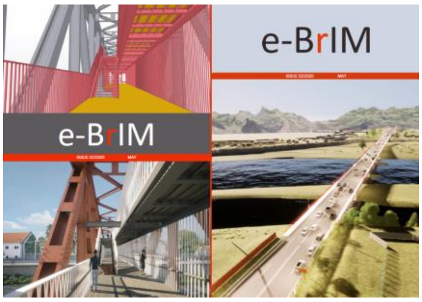

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COFFERDAM SUPPORTING METHOD FOR PYLON FOUNDATION EXCAVATION OF THE DANJIANG BRIDGE

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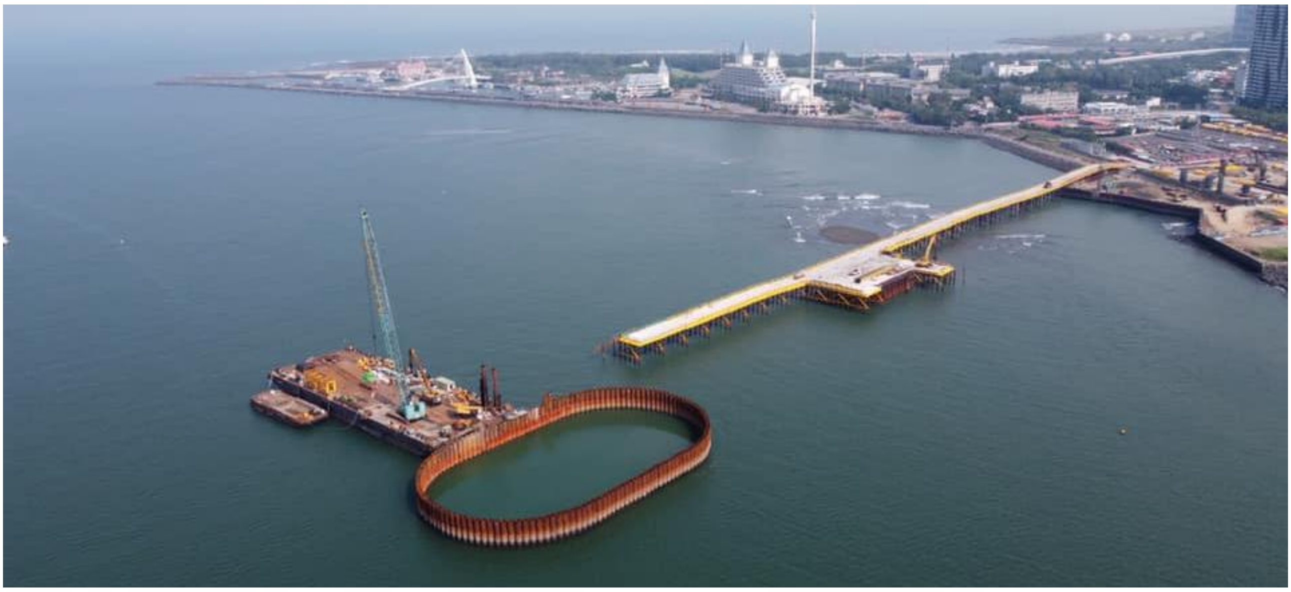


Figure 1: View of the cofferdam during construction

I. INTRODUCTION

The Danjiang Bridge (also known as the Tamkang Bridge) is a major transportation infrastructure project in Northern Taiwan. The bridge spans the Danshui River estuary, connecting the Bali and Danshui districts of New Taipei City.

The project encompasses the approach bridge and ramp on the Bali (south) side, the main bridge crossing the river, and the approach bridge and ramp on the Danshui (north) side.

This article presents the innovative planning and design of the excavation and retaining system used for the cofferdam during the construction of the main cable-stayed bridge's foundations.

It also describes the construction plan and the production and installation processes, which were developed following a thorough evaluation and decision-making process.

Furthermore, the article shares valuable insights into the significant advantages of this construction method in terms of both quantity and quality. These insights are intended to serve as a practical reference for geotechnical engineering professionals.

The outcomes of this project also align with international engineering standards, showcasing the capabilities and advancements of geotechnical engineering in Taiwan.

For the construction of the P130 foundation—the base of the single-pylon, asymmetrical cable-stayed main bridge—the construction team developed a custom in-water excavation and retaining system. This approach was developed to protect the integrity of the foundation during construction.

The design alternatives for the internal support system of the cofferdam—developed through innovative planning, structural analysis, and design—along with the selection of an optimal construction method tailored to site-specific conditions and supporting procedures, have yielded numerous tangible engineering benefits.

Additionally, several intangible ancillary advantages were realised. These outcomes were confirmed upon the successful completion of on-site construction.

II. SITE DESCRIPTION

Location

The bridge pylon P130 is located north of the main channel of the Danshui River at the estuary and is positioned towards the Danshui District of New Taipei City. The surrounding water depth is about 5m, where the riverbed is relatively flat without significant scouring or siltation.

The construction site is a publicly accessible area and an important route for local fishermen. It is adjacent to the Fisherman's Wharf tourist attraction and alongside New Taipei City's Blue Highway recreational waterway, see Figures 3 and 4.

Design and construction conditions of the cofferdam

The design of the ring support system considers the structural behaviour of the cofferdam, the selected construction method, and the physical constraints imposed by the riverbed and site conditions.

Further factors such as variations in riverbed elevation, maximum external water level fluctuations, dynamic hydraulic forces, seismic activity, wind loads, subsequent excavation and construction procedures were incorporated into the analysis, design and verification. The ring support system was prefabricated off-site and transported to the construction site via jetty on the Danshui side.

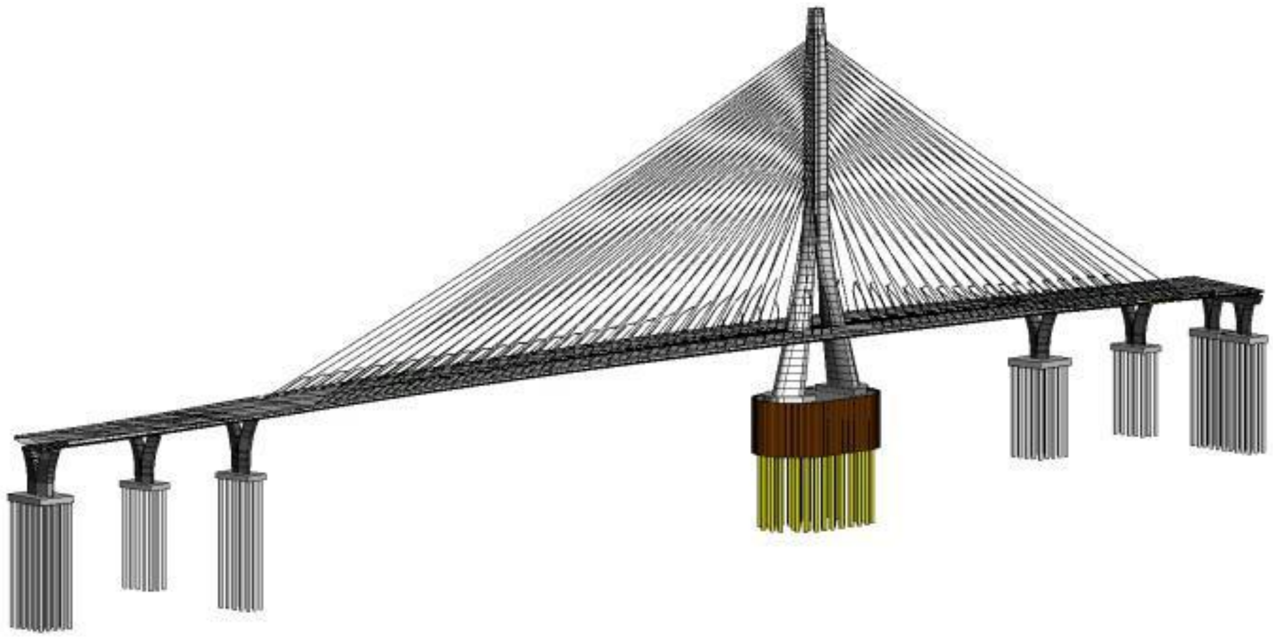


Figure 2: Danjiang Bridge Model *Courtesy of Splendid Technology Corporation*

Figures 3 and 4: Public areas around the bridge and the construction site

III. SYSTEM PLANNING CONCEPT AND CONSTRUCTION DECISION MAKING

Support System Planning Concept

To accommodate the requirements of two pylon legs (inverted Y-type pylon), the primary consideration was to maximise construction working space within the cofferdam. The construction team proposed two alternative solutions as illustrated in Figures 5 and 6.

Option A: an elongated outer ring with three internal strut rows and diagonal bracing. Compared to option B below, it has more horizontal bracing and vertical supporting members.

The structural steel box members around the internal surface of the cofferdam are heavier. As a result, the construction (compared to option B) may be more difficult.

Option B: two overlapped rings with a central strut and subsidiary minor struts over the ring joint area (utilising the advantages of ring force in terms of Barlow's Formula).

Construction Decision

The construction team carried out an independent evaluation, placing the highest priority on maximising an interference-free construction space.

After carefully considering construction difficulty, required execution time, and overall project cost, Option B was selected as the most suitable solution for the excavation support system.

At that time, the contractor estimated (based on their experience) that option B could save at least 30% of construction time and benefit the entire construction schedule in the initial period.

Final site report recorded that it took around 70 working days to finish the double-layer ring bracing system simultaneously with foundation (i.e., for the construction of a huge pile cap and 58 cast-in-place piles; 2.5m in diameter, 65 m long each) and excavation work to an elevation of -11.3 m (10 cm above the top of the pile cap).

IV. CREATIVITY AND IMPLEMENTATION OF WORKMANSHIP PLANNING AND DESIGN

Simplifying Structural Systems Using Fundamental Mechanics Theory

A uniformly distributed external pressure is acting on the cofferdam structure. These forces, initially acting orthogonally on the cofferdam steel pipes, are converted into compressive stresses along the ring support axis, similar to the behaviour of an arch, due to the arch's structural characteristics.

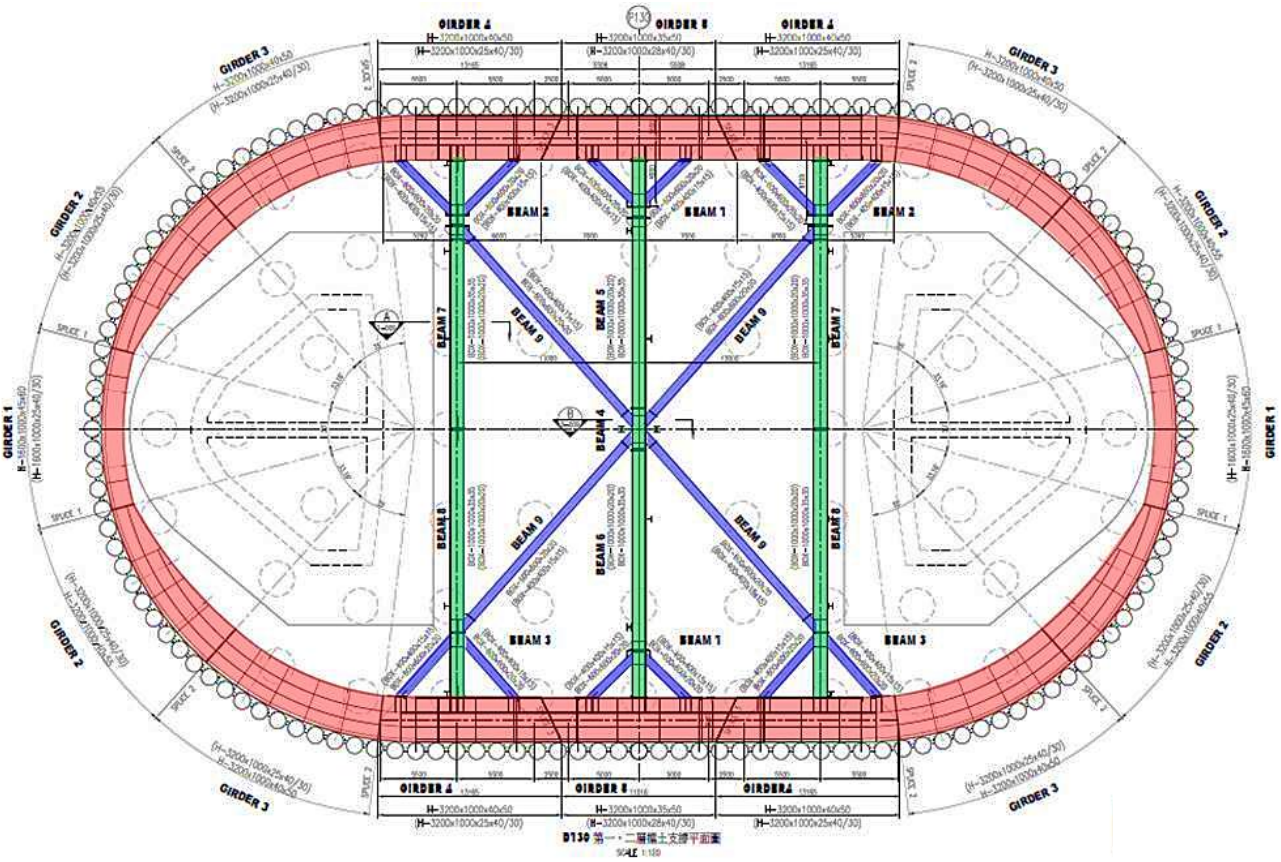
This annular system is designed to form in-plane stress loops with a self-balancing mechanism.

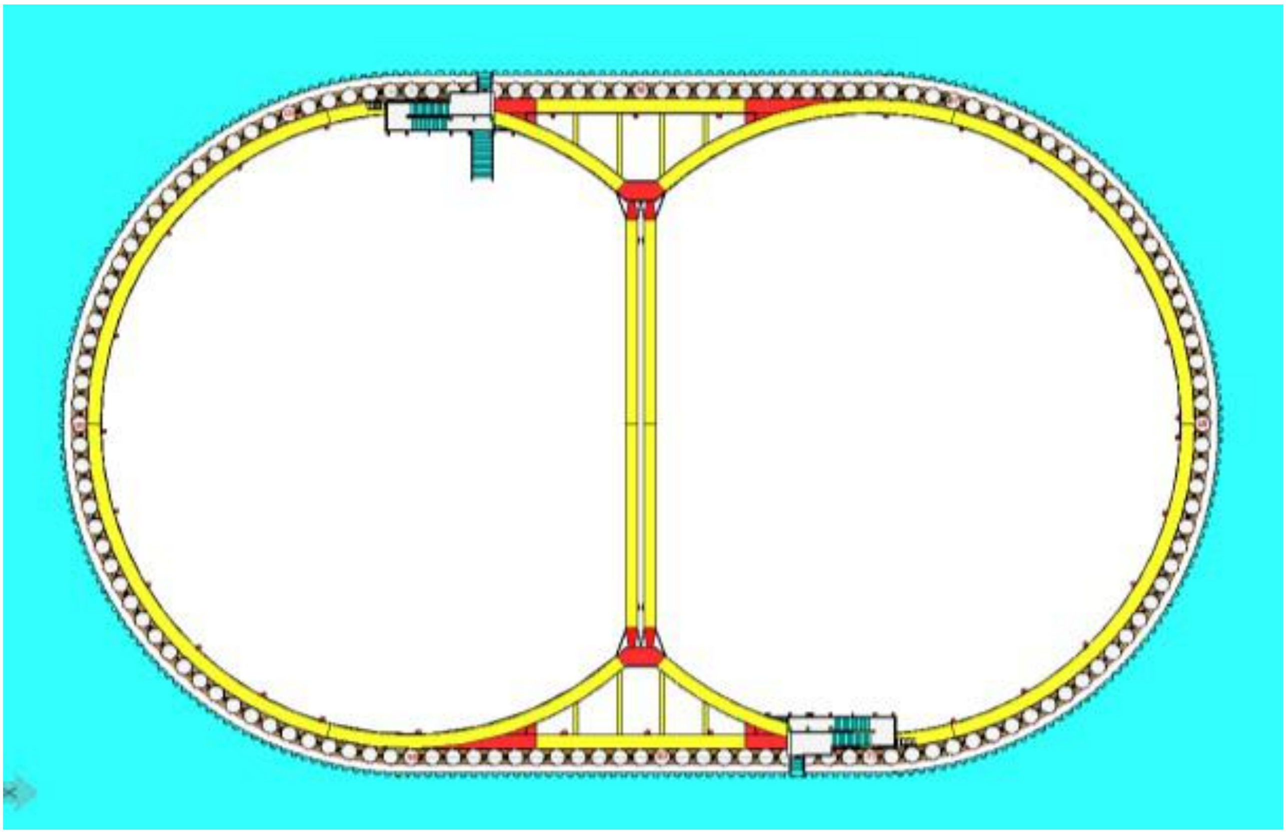
The system is designed following a modular concept. The ring section on the Bali and the Danshui sides is divided into three types of segments—20, 8, and 8 segments respectively—resulting in 36 segments, see Figure 7.

This segmentation, based on the fixed curvature of the ring, enhances construction efficiency. All circular segments intentionally have the same constant radius.

Additionally, the remaining straight sections consist of three segment types (4, 4, and 8 segments), totalling 16 segments, along with four special double-ring joint blocks.

All components were fabricated in accordance with the approved construction drawings.





Figures 5 and 6: Option A above proposed by Wiecon Engineering;
Option B below proposed by 創緯 (Arch) Engineering Consultants

Construction

The construction within the cofferdam was executed in two phases. Although the first and second support installations followed the same process, they were carried out at different times. Both supports had to be fully installed prior to the start of the backfilling and lowering operations.

To ensure smooth bolting, all circular units must be joined sequentially from one side to the other, without altering at will.

Since the bolt holes are not slotted, a high level of construction precision is required for the support system. Therefore, the trial assembly carried out before leaving the factory is critical and must be performed with great care.

V. ENGINEERING BENEFITS

Direct benefits

In contrast to the traditional spatially constrained excavation approach, this innovative method optimised the construction site condition.

Most system components are positioned along the periphery (the side area within the cofferdam), thereby increasing the free working space for machine operation.

This results in a site experience that is distinctly different from conventional deep excavation projects.

The installation of the central double-ring steel box girders within the double deck offers direct benefits, primarily through material reduction, simplified construction procedures, and a shortened construction schedule, as summarised in Table 1.

Ancillary benefits

In addition to the direct benefits, the innovative support system also provides enhanced construction safety, strengthened cofferdam structure, and pre-qualification of labour welding techniques, as shown in Table 2.

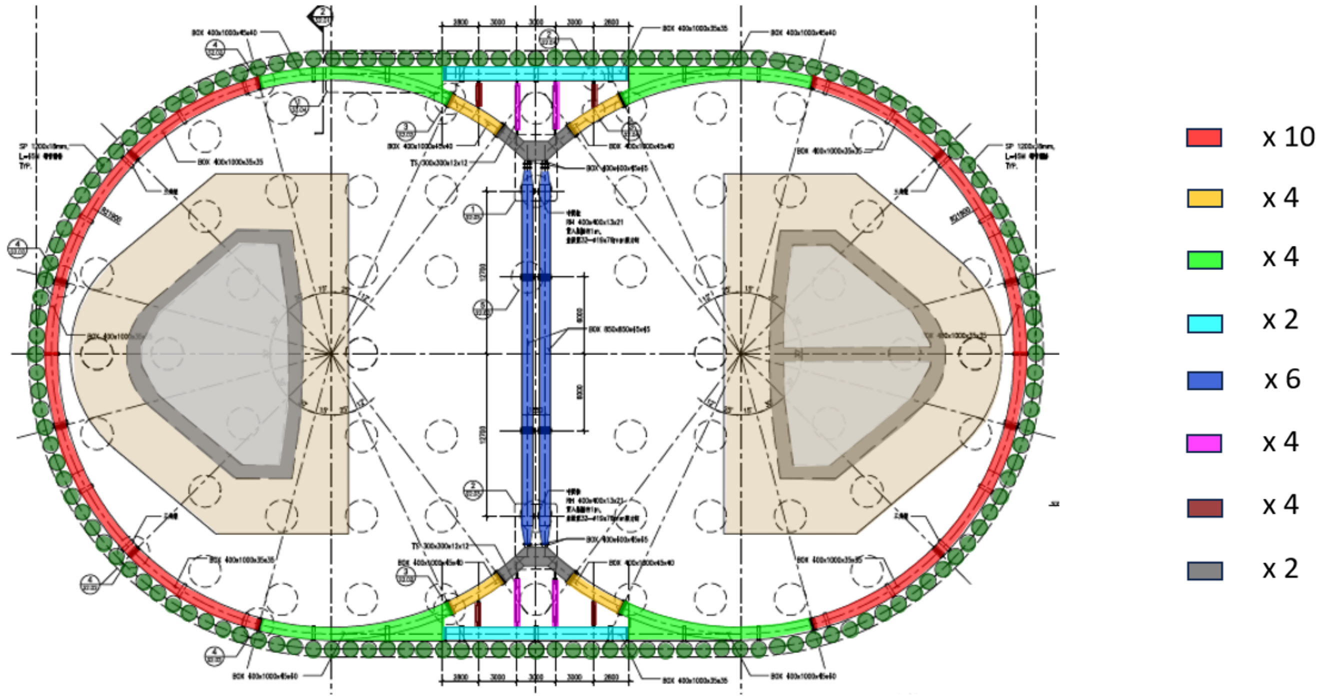


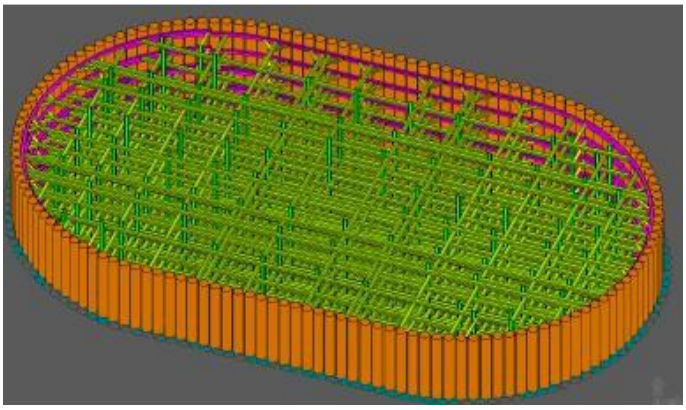
Figure 7: Circular segment (red), 10 segments per layer, so a total of 20 segments for the entire system.
Circular segment (orange) 4 segments per layer, so a total of 8 segments for the entire system.
Circular segment (green) 4 segments per layer, so total 8 segments for all system.
Straight segment (pink) 4 segments per layer. Straight segment (deep brown) 4 segments per layer.
Straight segment (deep blue) 6 segments and Straight segment (light blue) 2 segments per layer, so total 8 segments per layer.

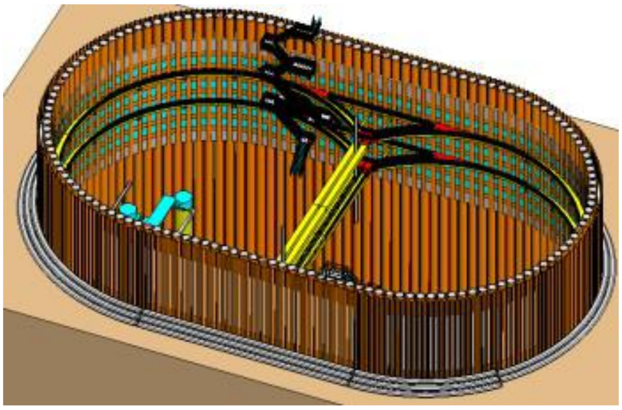
Assessment indicators	Explanation
Quantity of work	The amount of steel in the selected support system is approximately 766 t, representing a significant savings compared to the steel requirement for a traditional method.
Streamlined Construction	1. Only two central columns are required for the whole system. 2. With virtually no vertical structures, construction operations are greatly reduced and obstacles to subsequent excavation are minimised. 3. Horizontal structures need only be locally fitted and the number of joints to be made on site is greatly reduced. 4. Due to the backfilling of the cofferdam, the ring steel box girders were constructed directly on the working surface or the downcutting surface at the construction elevation without the need for temporary construction support or platform facilities. 5. There is no conflict between the support system and the construction activities related to the erection of the two bridge tower pylons. The system requires no adjustments or modifications, no dismantling or reinstallation of supports, and no removal or reinstallation of intermediate columns, unlike traditional support methods. 6. Compared with traditional methods, the construction sequence is considerably simpler.
Construction Period	The original schedule was 90 days. On-site excavation was completed on the 82nd day, which was aligned with the original approved construction period (8 days ahead of schedule).

Table 1: Direct Benefits of Ring Steel Beam Support System

Assessment Indicators	Explanation
Construction Safety	The upper ring steel box girder was lifted to the working platform and bolted into place, while the lower steel components were assembled either on the working platform or near the excavation surface. This approach eliminated the need for work at height, thereby minimising safety risks.
Cofferdam Structural Stiffening	Due to the horizontal ring support, the maximum unsupported length of the cofferdam's steel piles is more than twice that of the traditional method, see Figures 8 and 9. As a result, the piles require additional reinforcement to ensure continuity of the auxiliary system and to increase the overall rigidity of the cofferdam structure. This requirement, incorporated as an operational measure, can be regarded as a subsidiary benefit of the system.
Welding techniques	The main element of this case study was a closed box girder section fabricated by welding plates (with a maximum thickness of 50 mm). This provided an opportunity to simulate the welding of permanent steel box girder segments and to review and reconfirm the welding techniques of the existing workforce.

Table 2: Ancillary Benefits of the Ring Steel Beam Support System





Figures 8 and 9: Excavation support system; traditional (left) and creative system (right) *Courtesy of Splendid Technology Ltd.*

VI. FEEDBACK

Ring support geometry control

Due to the curvilinear block structure and the on-site driving of the cofferdam steel piles, fabrication tolerances and on-site sampling were considered to account for potential manufacturing and construction deviations. The construction sequences were to ensure that the loads acting on the cofferdam are transferred to the ring support in a sufficiently uniform manner.

Lifting of ring supports

The two layers of annular stiffeners were constructed sequentially in coordination with the downward excavation process. The two ring supports were built independently according to their respective planar positions.

After completing the upper annular ring and the downward excavation to the lower ring level, the construction team adjusted the lifting position and used a traction rope to guide the steel ring elements into place.

In some cases, a two-stage installation is used due to limited vertical space during the lifting procedure (see Figure 10).

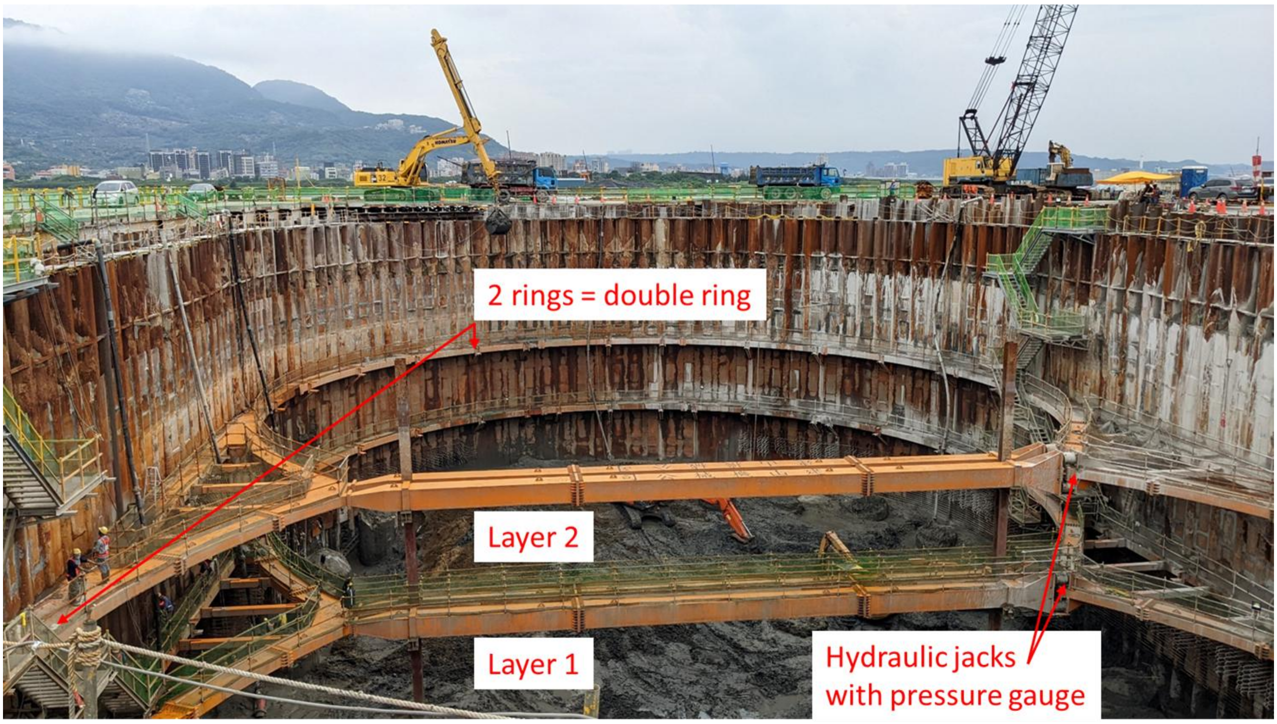


Figure 10: Two layers and two ring supports

Enhanced cofferdam structure

The cofferdam structure consists of 144 steel piles of 45m in length and 1.2m in diameter. There is no connection between adjacent steel piles except at the annular ring levels.

To satisfy the fundamental assumption in the ring support structural analysis—that the cofferdam behaves as an integrated system—the construction team reinforced the steel pile bodies by strengthening the on-site plates to improve continuity and integrity. At the same time, this approach reduces the potential for relative displacement between piles at the connections to the annular rings. In this sense, the system can be regarded as achieving "two functions in one".

Straight-forward design

The structure is a circular, horizontally supported box girder subjected to external water pressure from outside the cofferdam. The axial compressive forces generated by earth pressure are self-equilibrated within the system, due to its inherent arch behaviour, through configured in-plane stress loops.

As a result, no additional forces are transmitted vertically or as out-of-plane loads within the structural system. This in-plane self-balancing mechanism eliminates the need for vertical transmission or out-of-plane resistance.

The structural analysis software commonly used in the industry, based on linear elastic small-displacement theory, is sufficient to evaluate and meet these requirements.

In the steel structure design, it is required to conduct local buckling analysis and verification of the steel box sections and plates. Among these components, the horizontal and lateral steel box beams installed at the centre of the ring support are the most critical ones. These two components (a total of four in the system) are key to the overall success of the support system.

It was essential to implement an around-the-clock stress monitoring system throughout construction, with particular attention to critical stages. The system employed customised Load Cells and incorporated an integrated hydraulic jack unloading mechanism to ensure safety during dismantling.

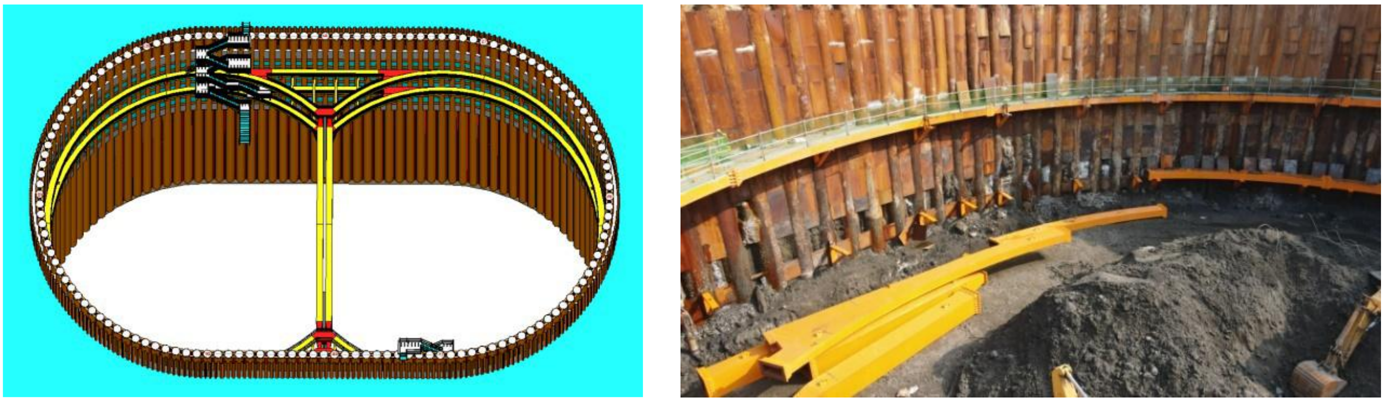
VII. COMPLETION REVIEW

This innovative ring support system provided a safe and efficient working environment for the construction team and successfully enabled the construction of the large-diameter pile foundation for the P130 Main Bridge Tower.

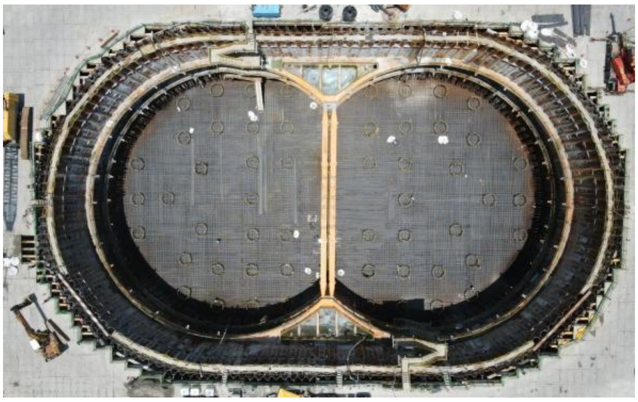
The stability and safety of the cofferdam structure were clearly demonstrated during the foundation excavation.

The safety of the structure is ensured by the double-layer, double-ring support system, consistent with the initial planning and design assessments.

Although leakage occurred due to locally weakened continuity at the joints between the cofferdam steel piles during in-water construction, this did not undermine the conclusion that the system represented the most suitable method for this project.



Figures 11 and 12: BIM model for reference after completion (left) and situation on site (right)
Courtesy of Splendid Technology Ltd.



Figures 13 and 14: The cofferdam under construction (left) and upon completion (right)

VIII. CONCLUSION AND OUTLOOK

The Danjiang Bridge P130 pile foundation—featuring a pile cap measuring 77 m in length, 45 m in width, and 5 m in thickness—is the first of its kind in Taiwan. Excavation serving as the key pre-construction operation.

The cofferdam's internal support system was designed with constructability as a priority, making effective use of the double-ring structural configuration. This approach significantly reduced the complexity and difficulty of the structural design, while also providing a more efficient and safer working environment for the construction team. The system contributed substantially to time savings and to the overall progress of the bridge construction.

Based on the construction requirements of the engineering design target, it is recommended—both from the design and construction perspectives—to make full use of the mechanical characteristics of different structural systems when planning, configuring, and executing the works. This approach helps to create the most suitable construction environment within the excavation area (e.g., an unobstructed working space).

This paper presents a case study intended to be shared with domestic and international geotechnical, structural, and civil engineers, encouraging further consideration of future directions and efforts in construction practice.

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3D FORMWORK AND CLIMBING SOLUTIONS FOR THE DANJIANG BRIDGE PYLON

Jun Hirasawa, Robert Zalewski, Peri

Figure 1: Pylon erection

INTRODUCTION

The Danjiang Bridge is designed to harmoniously integrate the local landscape, culture, and surrounding environmental needs, featuring a beautifully lined cable-stayed bridge.

The main pylon reaches an impressive height of about 200 m, with a maximum span of 450 m. Upon completion, it will be recognised as the world's longest single-tower asymmetrical cable-stayed bridge.

The project connects Tamsui and Bali, significantly shortening the distance and travel time between the two areas. After completion, trips between Tamsui and Bali will no longer require a detour via Guandu Bridge, and the journey will be reduced by approximately 15 km and cut travel time by about 25 minutes.

This project will link the Northern Coastal Highway, West Coast Expressway, Taipei Port Special Zone, and Bali Left Bank recreational activities, thereby saving travel time and promoting the development of the tourism industry in northern Taiwan.

Additionally, it will improve external transportation in the Tamsui and Sanzhi areas, enhancing the service function of the Northern Coastal Highway system.

According to the plan, the pylon, excluding the foundation (U01), is 208 m high with a standard casting height of 4 m. PERI's formwork solution has been applied to all 52 segments (U02 to U53).

PROJECT CHALLENGES

The formwork and climbing brackets, as construction structures, must be sound against dead loads and, primarily for formwork, live loads such as lateral pressure conditions. Also, the climbing brackets must meet the conditions for safe use within the allowable stress range (elastic range) against strong winds at high elevations. Moreover, we had to address the challenges of changing complicated geometry in each section while ensuring safe and cost-effective construction support.

Levels -8m to 40m (U2 to U13): The inside radius changes, so for every casting step the elements must be taken down and adapted to the next section. Since both pylon legs are symmetrical, it is required that the components be reused. The straight elements must be shortened in certain areas, and the corners must be adapted to the new angle.

Levels 40m to 72m (U14 to U21): Different forms were required for all casting steps, which are round-shaped, because the radii change at every level. The straight elements are shortened accordingly and adapted to the adjacent bent area. The angles between the straight elements change as well, which is why these elements must also be modified.

Levels 72m to 84m (U22 to U24): At this height, the pylon legs join. Formwork requires completely new elements for that area, which also change from section to section.

Levels 84m to 92m (U25 to U26): The round elements change radius continuously; therefore, 3D-form components are required. All straight panels are bent due to changes in angles at the corners. The formwork must be custom-made as well for this section.

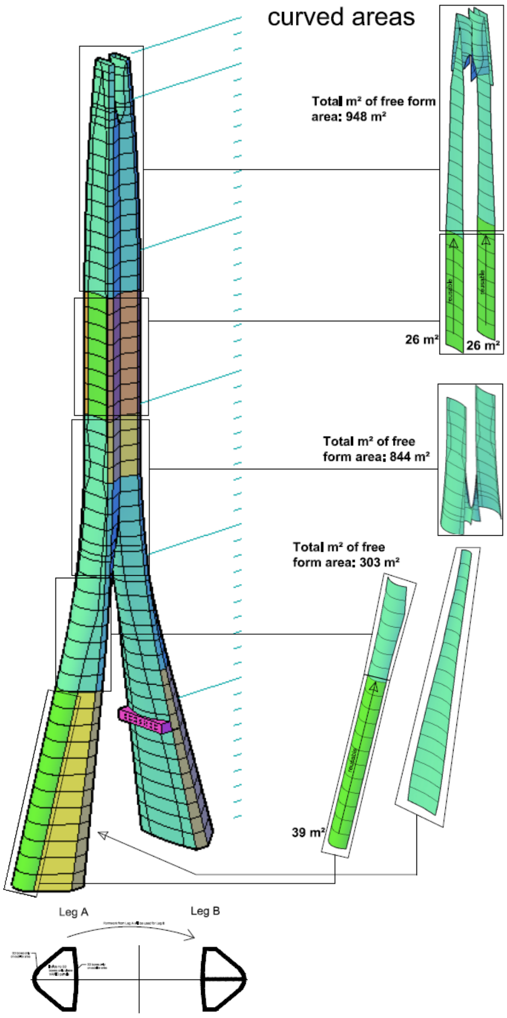


Figure 2: Wall Formwork Plan

Levels 92m to 104m (U27 to U29): Attention must be paid to prevent concrete leakage from the bottom of the external formwork as it changes from convex to concave. The elements must be adapted to the changing radius and bent areas. For all sections, adaptations are required due to the changing angles of the straight wall connections and corners.

Levels 104m to 184m (U30 to U49): Due to minimal changes in geometry, it is required to use more efficient formwork and climbing brackets to ensure safe construction at higher elevations.

Levels 184m to 188m (U50): As the geometry of the pylon begins to split again, the external formwork requires an entirely new design and modification of elements.

Levels 188m to 200m (U51 to U53): External formwork again necessitates an entirely new design and modification of elements.

Figure 3: Wall Formwork VARIO+3D Boxes adapt 3D curve geometry. The optimised 3D box sections were reused to plan cost-effectively

Figure 4: The SCS Climbing System ensures safety by providing horizontal working areas on inclined walls

SOLUTIONS OVERVIEW

The VARIO GT24 Wall Formwork (All sections): With girder wall formwork, the arrangement of the individual system components can be freely selected, and optionally, integrated 3D boxes can be used for adapting curve geometries.

Additionally, through the elongated holes in the walers and coupling with flush, aligned, and tight panel connections, the VARIO GT24 Wall Formwork can be adapted to suit all geometries and requirements.

SCS Climbing System (Level -8m to 108m, 188m to 200m): The SCS Climbing System is characterised by a high level of cost-effectiveness as the modular concept with multi-piece brackets facilitates optimum adaptation to suit this project's specific requirements and geometries.

An especially remarkable feature is the provision of safe, horizontal working areas through inclinable platforms, which can easily be adapted to suit inclined structural elements.

ACS Self Climbing System (Level 104m to 184m): Efficient and robust self-climbing formwork for bridge pylons or high piers makes the construction of concrete structures high-speed, cost-effective, and safe.

The climbing units, comprising wall formwork and platforms, are moved from floor to floor by means of integrated hydraulic systems.

The efficient sequence of operations facilitates a very high level of productivity, thus resulting in increased workplace safety.

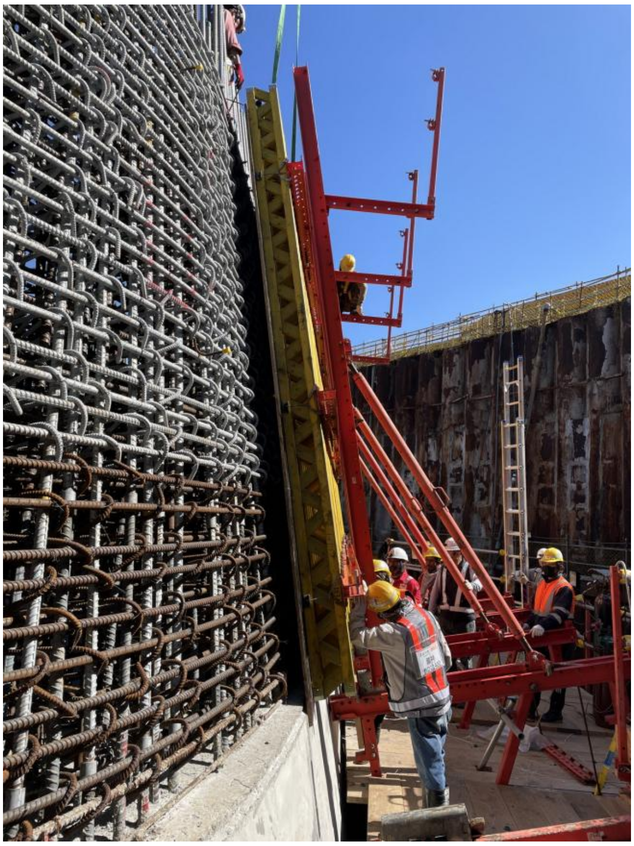


Figure 5: Wall Formwork Installation VARIO on the SCS Climbing System

Figure 6: The Adjusting Unit SCS is used to position the wall formwork. The base of the formwork is pressed tightly against the previous concreting section. This method proved to be highly effective in preventing concrete leakage in complex-shaped structures

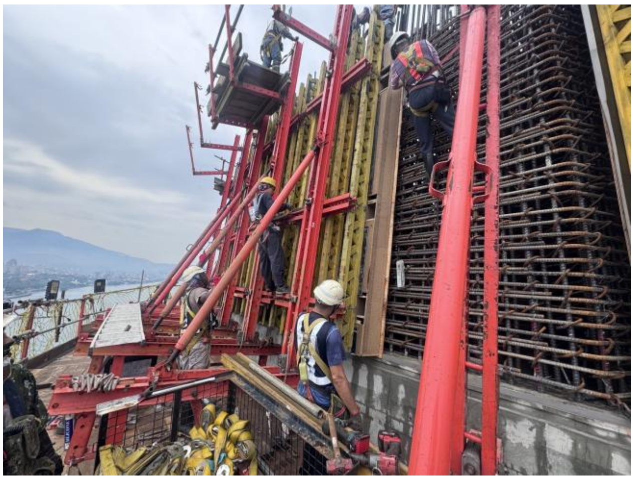


Figure 8: Wall Formwork VARIO+3D Boxes adapt to the outside radius changing from convex to concave at Level 91 (U26)

Figure 9: ACS self-climbing system. After completing concreting at Level 104m (U29), we gradually installed the ACS. The self-climbing successfully covered the range from Level 104m (U30) to Level 184m (U49)

Figure 7: At Level 72m (U21), the pylon legs merge into one piece. The wooden boxes absorbed the slight discrepancies on both sides, allowing for proper installation

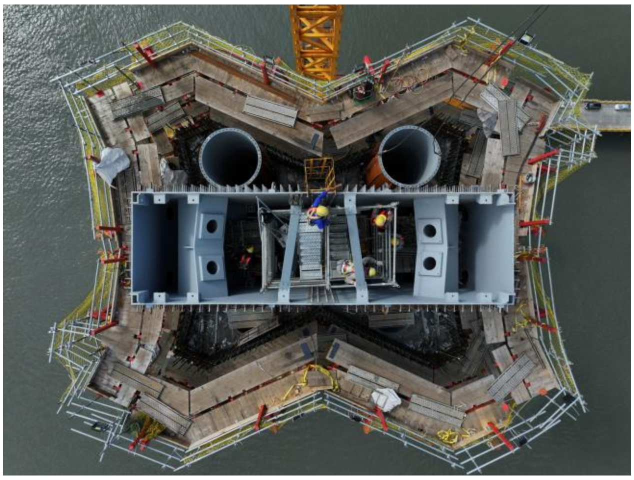


Figure 10: The self-climbing system eliminates the risk of falling by ensuring that all eight platforms climb simultaneously. On the other hand, the pump control allows each unit (with two cylinders) to operate the cylinders independently. This means that in case of any issues, we can respond quickly and flexibly with just a single button on the remote control

Figure 11: As a preparatory step for platform climbing, the ACS needs to raise the climbing rails to form the track. Although the structure is relatively vertical between Levels 104m(U30) and 184m (U49), it becomes narrower as the height increases. Therefore, the climbing rails of each platform must incline not only forwards and backwards but also left and right during climbing. By switching the remote control, hydraulic control for each unit is possible, allowing for fine adjustments.

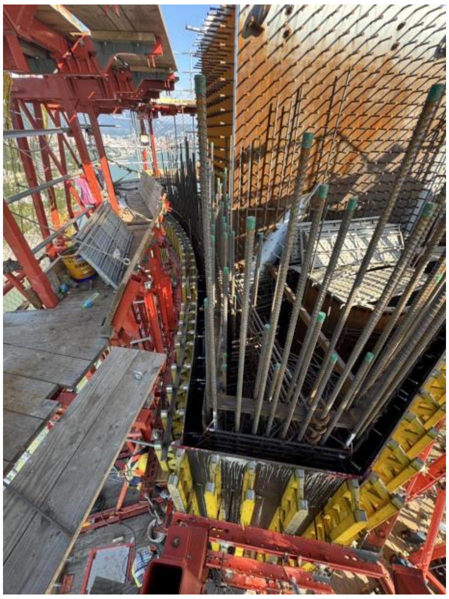


Figure 12: The upper two layers of the ACS platforms are foldable to facilitate the removal and installation of formwork.

The formwork can be removed and installed while the platform is folded

Figure 13: Concreting from the platform level +1

Figure 14: Level 28m (U10)

Figure 15: Level 40m (U13)

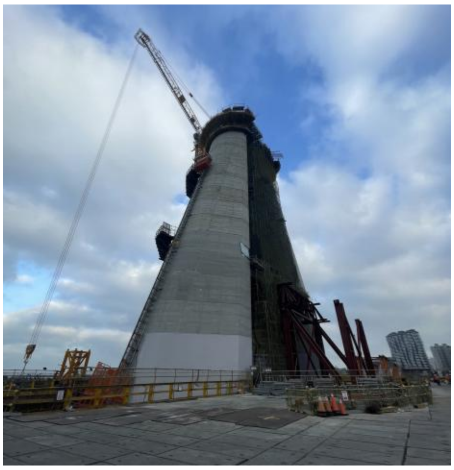


Figure 16: Level 68m (U20)

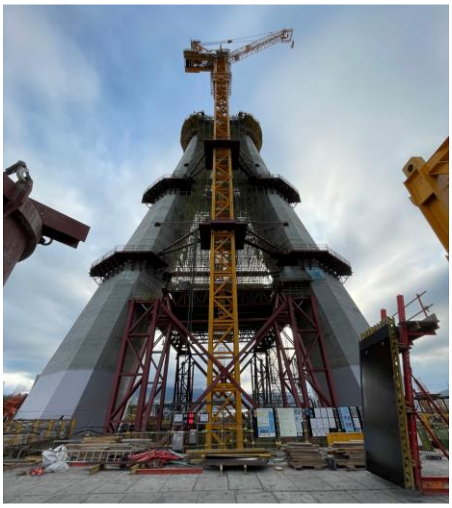


Figure 17: Level 76m (U22)

Figure 18: Level 92m (U26)

Figure 19: Level 108m (U30)

Figure 20: Level 116m (U32)

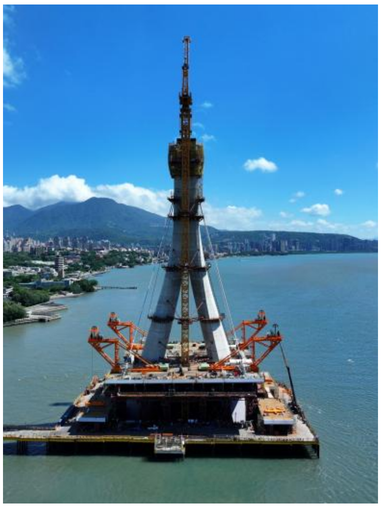


Figure 21: Level 120m (U33)

Figure 22: Level 176m (U47)

DETAILED DESCRIPTIONS OF 3D BOXES

We were able to adapt the 3D Boxes to the VARIO Wall Formwork for complex 3D geometry.

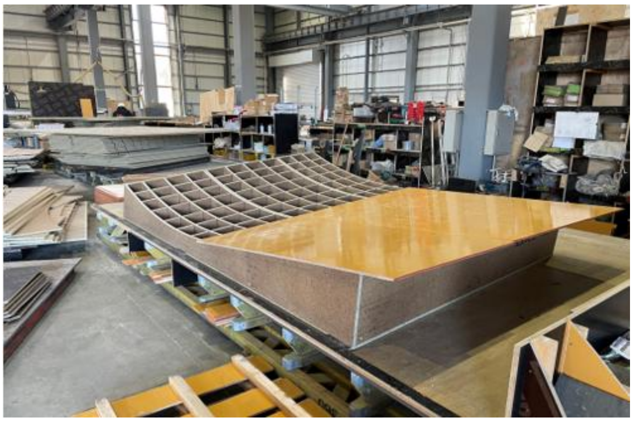
Due to the many special parts that cannot be reused, we used 21.5mm particle board for the frame members and 12mm urethane-coated Formlinings, a standard product in Japan, for the panel to reduce product costs.

The planning and design were carried out by the German headquarters, which has extensive experience with this kind of 3D formwork technology. Meanwhile, the detailed design was done in the Philippines and Malaysia, and localisation and manufacturing were carried out in Japan, implementing the best methods by the PERI global team.

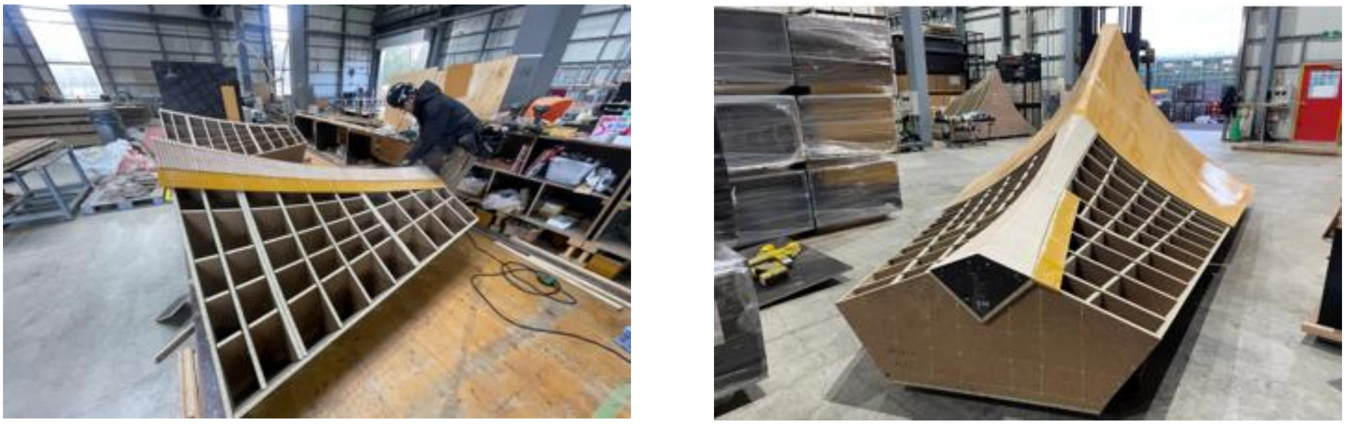
The frame members are CNC pre-cut and converted into parts, improving assembly efficiency. After skilled workers assemble the formwork, it is inspected with a 3D scan before shipment to check the dimensions and any harmful deformations.

Furthermore, after being transported to the site and attached to the pre-assembled VARIO Wall Formwork, it undergoes another 3D scan inspection before being installed on the structure.

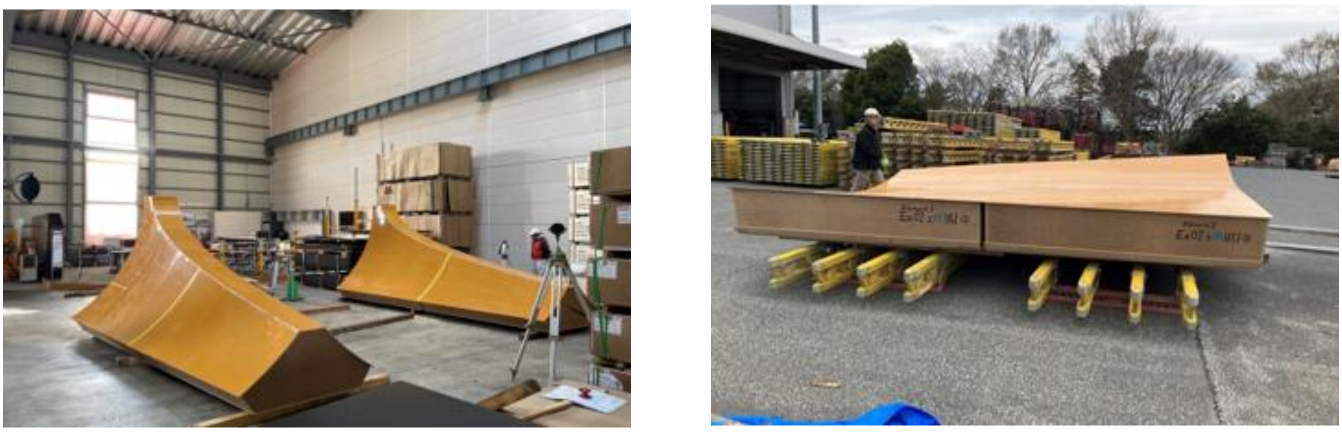
Thus, by utilising digitalisation in manufacturing, we were able to provide high-quality and cost-effective services for complex geometries.



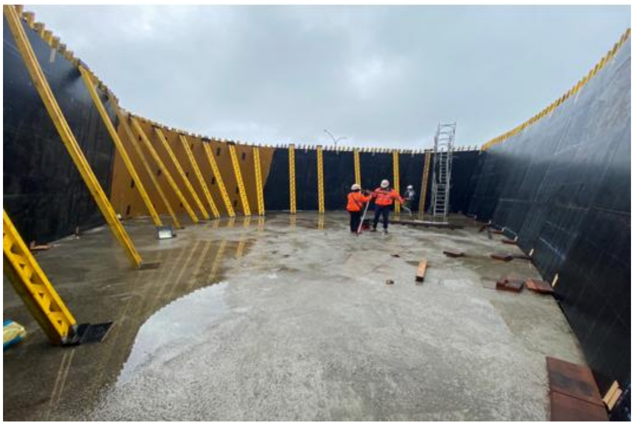
→ *Figure 23: 3D Boxes assembly*



Figures 24 and 25: Finishing adjustments by skilled craftsmen



↑ *Figures 26 and 27: Pre-shipment 3D scanning*



← *Figure 28: On-site 3D scanning*

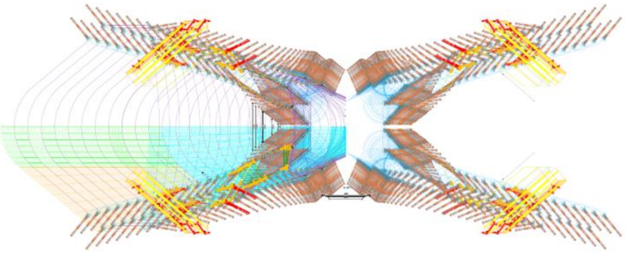


Figure 29: Initial climbing path concept assumed installation of the ACS system before integration of the pylon legs. This idea proved unfeasible due to geometrical limitations

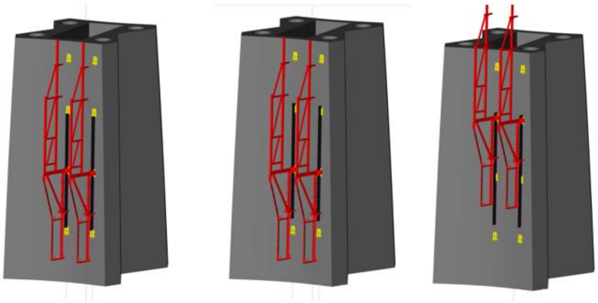


Figure 30: ACS Climbing cycle – first, the climbing rails are moved up with hydraulic cylinders, then the whole unit follows the track of the rails and climbs up using same cylinders

DETAILED DESCRIPTION OF ACS CLIMBING SYSTEM

FINDING CLIMBING PATH

Automatic Climbing System (ACS) utilises hydraulic climbing of both the working platform and formwork at the same time. This is carried out by the use of climbing rails, which are lifted by hydraulic cylinders to the next position.

At the next stage, the whole climbing unit is moved up using the same cylinders and by following the climbing rails.

The main challenge was to find the optimal position of ACS anchors with a changing pylon geometry. PERI design engineers had to find a climbing path for these anchors that would be within ACS system limits and allow utilisation of the climbing system on as many concreting steps as possible.

The final solution limited ACS use for levels U30 and U49. To verify that assumed climbing can follow pylon geometry, a detailed 3D analysis was performed to check the climbing sequence for each construction step.

One of the challenges for designers was cable anchorages, which limited the location for ACS anchors.

Due to the position of cable anchorage points, four ACS platforms had to be installed on level U32. Therefore, for levels U30 and U31, a combination of SCS and ACS platforms was used to optimise the solution.

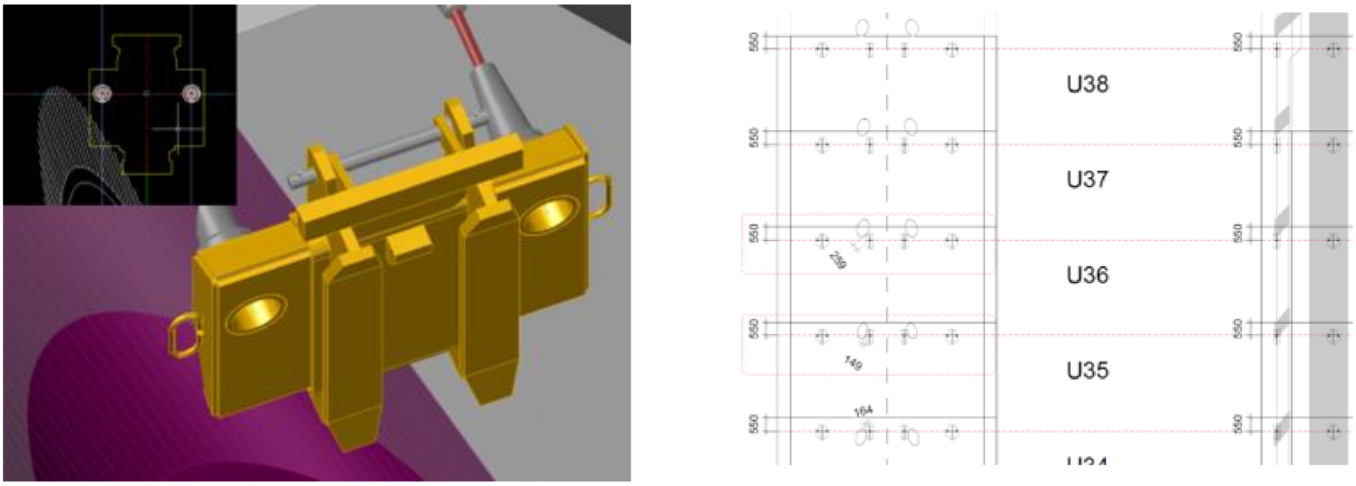


Figure 31: ACS anchors had to be declashed with stay cable anchorage points.

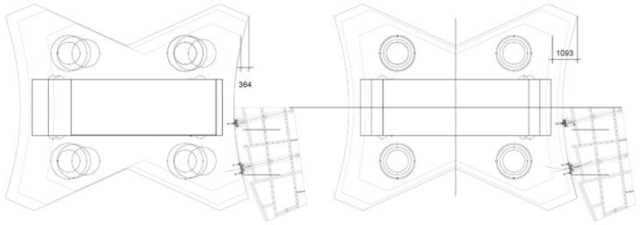


Figure 32: Changes of pylon geometry on levels U30 and U49 that had to be taken into account for VARIO formwork design

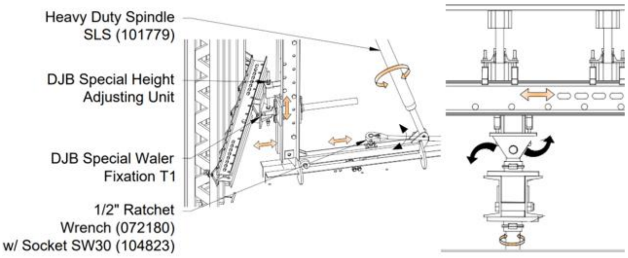


Figure 33: Special mechanism that allowed adjustment of VARIO formwork panels on the Bali/Tamsui sides

ACS VARIO FORMWORK

VARIO formwork was optimised for use with the ACS system. The goal was to minimise the number of panels that needed modification at each step.

The geometry of the pylon on the River Side and the Sea Side consisted of a straight part that did not change along the height of the structure. This allowed the use of a single “V” shaped VARIO panels, which were used for all construction steps, from U30 to U49. Only the internal part had to be modified after each climb of the system.

The Bali and the Tamsui sides of the pylon are curved, and the radius changes on every step. On this side, the VARIO formwork was also adapted, with internal panels remaining the same across all heights and external panels being modified.

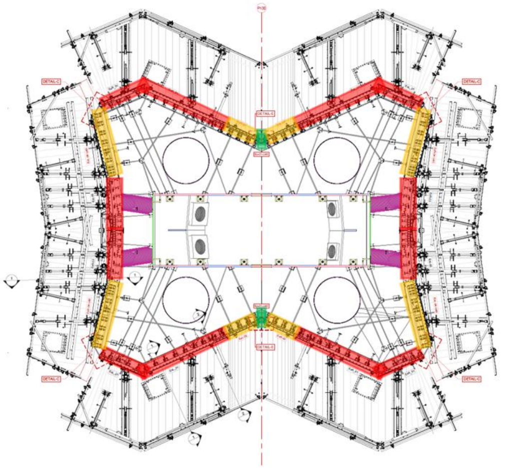


Figure 34: VARIO formwork design for ACS. Red colour indicates panels that stay the same for levels U30 and U49, yellow indicates panels that need to be modified every time the system climbs. The green panel stayed the same for all levels; however, it was not fixed to ACS units and had to be lifted by crane

Internal formwork panels had to allow adjustment to changing curvature, and thus a special mechanism was designed to enable this.

VARIO formwork was not designed as a single-sided system, and DW15 tie rods had to be implemented. The internal layout of cable stay anchorages, steel tubes and steel boxes limited space to install ties. In the original PERI solution, various DW15 couplers were used to declash ties with those embedded parts.

Due to the complexity of the tie rod layout, this was not a final solution. The construction site decided to design a steel frame, welded to an internal steel box and left after concreting. The frame was positioned precisely at the level of formwork walers. This allowed the installation of ties directly to this frame. It allowed a much simpler tie rod layout and handling on site.

ACS PLATFORM DETAILS

Each ACS unit consisted of the following working levels:

- Level 0 is the main working area where VARIO formwork can be adjusted and final reinforcement can be done.
- Level +1 was a concrete pouring and reinforcement platform.
- Level +2 was used for initial reinforcement works and also for the installation of the tie rod template for VARIO formwork.
- Levels +1 and +2 were installed on a custom-made steel truss that also allowed installation of a tube guardrail covered with a safety net.

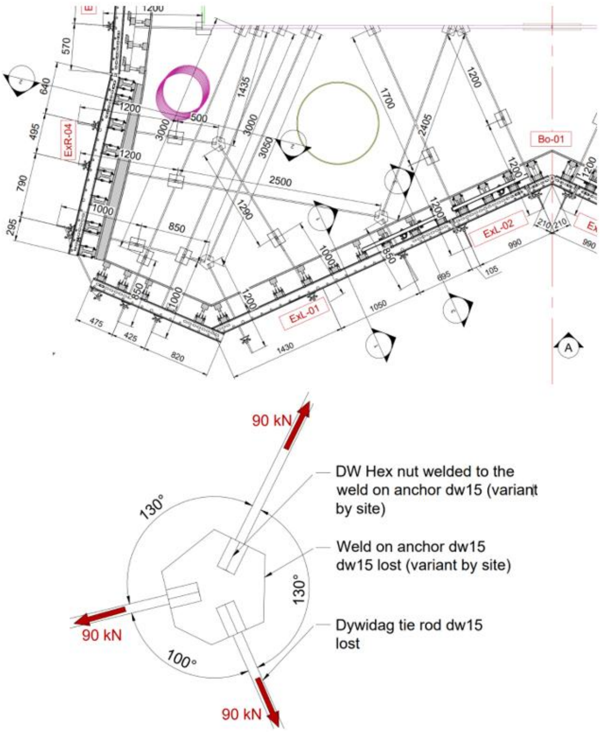


Figure 35: Partial view of VARIO formwork layout and detail of special DW15 connector – original PERI solution - that allows declashing of formwork ties with pylon embedded parts

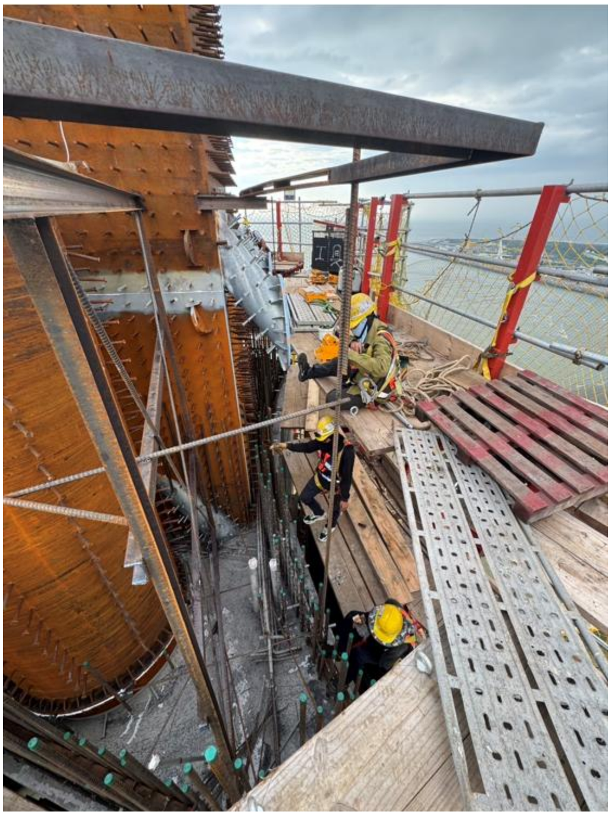
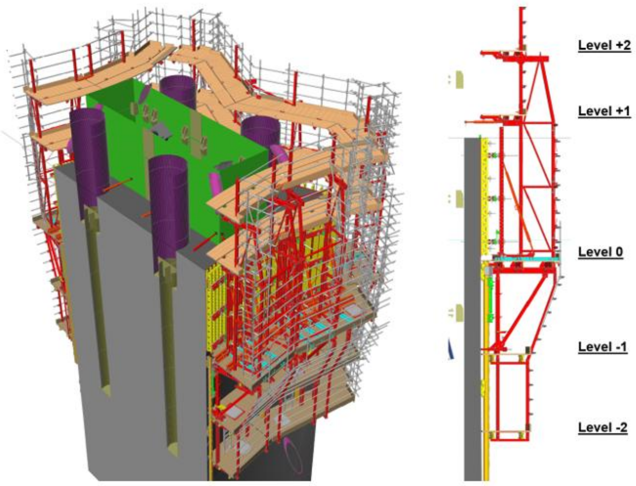


Figure 36: Horizontal steel frame welded to internal boxout for installation of VARIO formwork ties

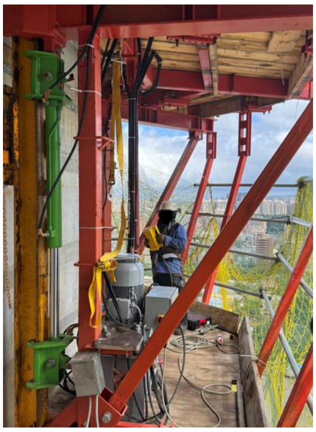
- Level -1 allowed access to the hydraulic pump and cylinders, the heart of the ACS system. From this level, the operator observed the climbing process and could set the system for rail or platform climbing.
- Level -2 is a service platform which allows dismantling of ACS anchors and finishing works on pylon surface, i.e. filling holes left by anchor cones and DW15 ties.



↑ Figure 37: Flap deck of levels +1 and +2 in open position before installation of external VARIO panels on Bali/Tamsui sides

← Figure 38: Typical section of ACS platform showing all working levels

Figure 39: Telescopic cantilevers on ACS Level 0



↑ Figure 40: Hydraulic cylinders and pump on level -1 – heart of ACS. The operator controls the climbing of all ACS units with a single push of the remote control button

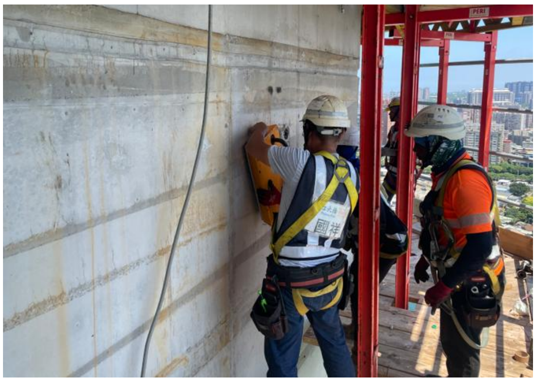


Figure 41: Dismantling of ACS anchor from level -2

Some VARIO formwork panels had to be removed after each climbing as previously described. For this reason, levels +1 and +2 had to be equipped with flap decks that allowed access to those panels.

Due to the decreasing width of the pylon sides, all platforms had to be able to change geometry as well. The main working levels 0, +1 and +2 were designed with a telescoping cantilever. This allowed for sliding in part of the deck before climbing to the next level. With this solution, the working surface was always even and without significant gaps, which allowed safe working conditions. Levels -1 and -2 were equipped with a simple cover. Although it created a step between ACS units, it was also a much simpler solution and met safety requirements.

The ACS system was designed to increase efficiency and safety of works at all stages – reinforcement, shuttering, striking, climbing and finishing works. PERI VARIO formwork and ACS systems utilised most of their core components, and by incorporating custom steel designs, they were fine-tuned to meet all requirements.

ADVANTAGES – ACHIEVING CONSISTENT TIME EFFICIENCY

Following the integration of the pylon legs, the construction process has become more complex, and the vertical concreting of segments alone is no longer the critical factor. The addition of steel-box installation, tension cable work, and the installation of steel segments of the super-

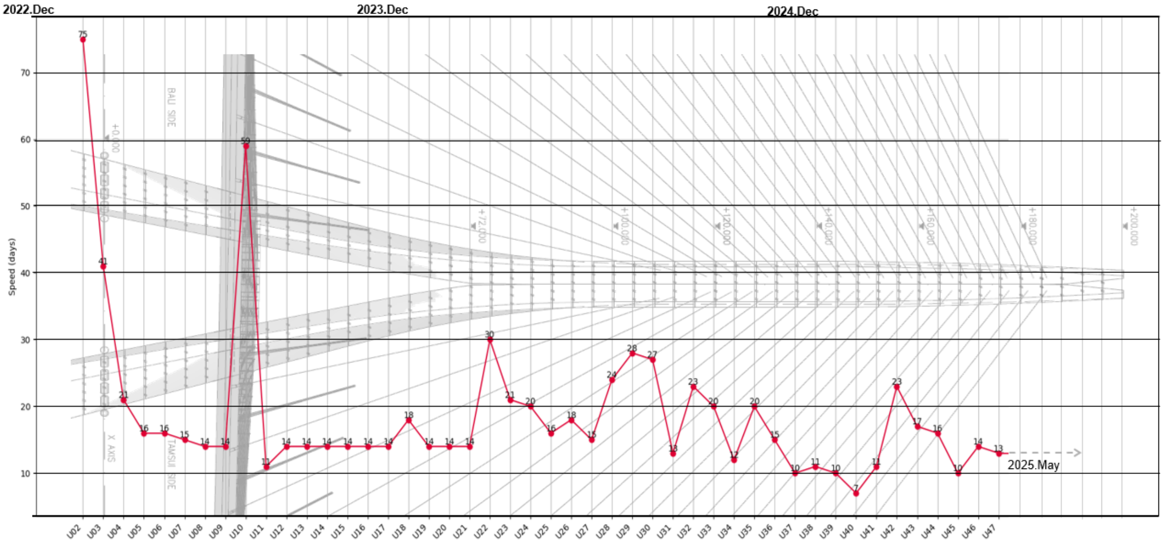


Figure 42: Construction speed

structure, along with adverse weather conditions such as lightning strikes, strong winds, and heavy rain, has negatively impacted the operation of tower cranes, leading to instability in the process.

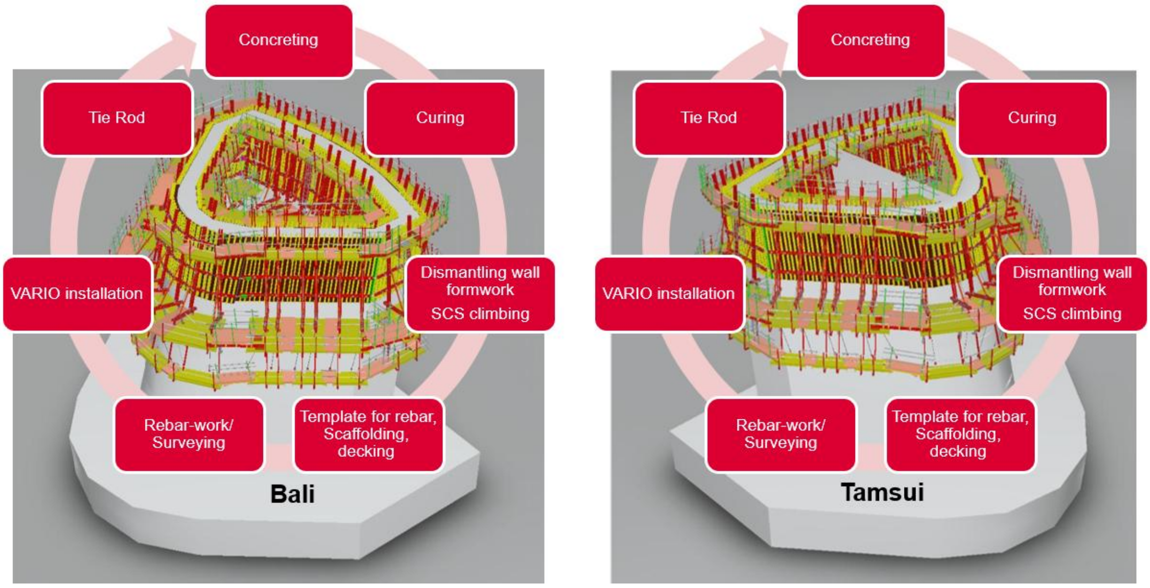
Nevertheless, the use of the ACS self-climbing system has allowed for independent climbing, thereby reducing the load on the tower cranes.

Consequently, in this complex process, reducing the load on the cranes has minimised the impact of uncontrollable factors on the construction timeline, preventing further delays.

CONCLUSION

PERI faced the unprecedented challenges of a global pandemic and unstable international conditions. Despite these obstacles, PERI successfully developed, manufactured, and supplied innovative 3D formwork and climbing solutions in a remarkably short time.

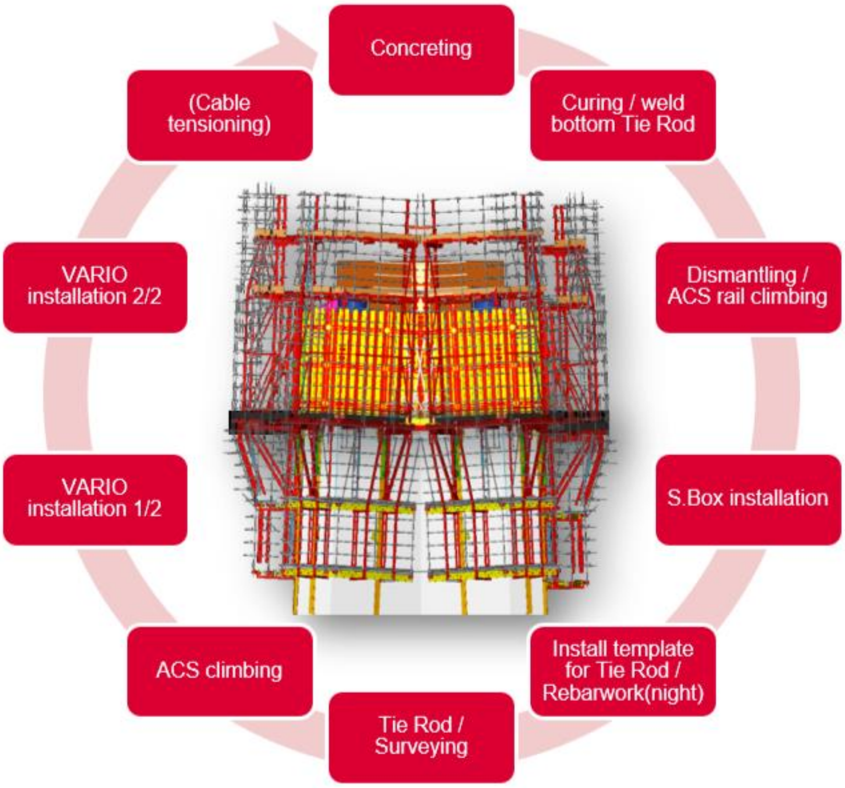
By leveraging its global network and digitalisation, PERI contributed significantly to the successful construction of the tower of the world's longest single-tower asymmetrical cable-stayed bridge.




Concreting Dismantling SCS climbing Template assembly


Rebar-work VARIO installation (external) VARIO Installation (internal) Tie Rod

Figures 43 and 44: SCS Typical cycle for Levels 8m (U2) – 108m (U30) (14 days/section)




Concreting
Welding bottom Tie Rod
Rail climbing
Steel-Box installation


Template assembly
Rebar-work
ACS climbing
VARIO installation

Figures 45 and 46: ACS Typical cycle for Levels 104m (U30) – 184m (U49) (10 days/section)

SEISMIC ISOLATION DESIGN OF THE DANJIANG BRIDGE, TAIWAN

Kilian Karius, Project Co-Manager, Leonhardt Andrä und Partner, Stuttgart, Germany
Wen-Kai Chen, Branch Manager, Leonhardt Andrä und Partner, Taipei, Taiwan
Johnny Ro, Project Manager, Sinotech Engineering Consultants Ltd., Taipei, Taiwan
Yung-Chieh Chen, Branch Director, Highway Bureau, MOTC, Taipei, Taiwan
Min-Chung Cheng, Section Chief, Highway Bureau, MOTC, Taipei, Taiwan

INTRODUCTION

The construction of the Danjiang Bridge and its connecting road network represents a major transport infrastructure project for northern Taiwan.

Located at the mouth of the Tamsui River near the Taiwan Strait, the design of the bridge aims to complement the renowned scenic beauty of the Tamsui Sunset.

The Highway Bureau organised an international design competition, inviting domestic scholars, experts and local community members to form a selection committee.

The winning team was a joint design team comprising Sinotech Engineering Consultants of Taiwan, Leonhardt Andrä und Partner of Germany and London's Zaha Hadid Architects.

Our concept of the bridge takes humanity as the starting point, with "Serene Dancer" as the theme, blending the magnificence of "mountain" and the softness of "river" with minimalist lines.

The final Danjiang Bridge features the following key aspects:

- With a main span of 450 m and a back span of 175 m in length, the asymmetric structure is said to be the world's largest single-tower cable-stayed bridge. It accommodates six traffic lanes, two 2.5 m wide motorcycle lanes, and a 5 m wide walkway on either side.
- The design life is 120 years. This requirement reflects the scale and significance of the structure, as well as the resources invested in its construction. A 120-year design life is standard for comparable new bridges worldwide.
- Danjiang Bridge is classified as a lifeline structure, providing access to emergency and rescue services after major seismic events.
- The steelwork using painted weathering steel was fabricated locally in Taiwan and transported to site by truck and barge.
- The challenging construction of the bridge is nearing its completion, marking a significant milestone in Taiwan's construction technology development.

SEISMICITY AND SEISMIC RESISTANCE

Taiwan is located at the intersection of the Eurasian and Philippine Sea plates. Due to the collision and compression of these plates, Taiwan experiences frequent earthquakes and geological changes. In fact, minor earthquakes are felt in the Taipei area on a weekly basis.

Danjiang Bridge is located in seismic zone Taipei 2 for which the seismic code specifies a reference peak ground acceleration of 0.24 g at a return period of 475 years.

Risks from active faults have been evaluated in the design. The bridge does not cross any active faults, but three faults are located not far from the project area at a distance of about 7-8 km in the southeast.

The latest activity of the Shanchiao fault occurred around 10,000 years ago, and the Central Geological Survey of MOEA considers it an active fault of Pleistocene age.

The bridge's asymmetrical geometry and long span configuration posed significant challenges for its structural design and seismic resistance. A floating support system incorporating a variety of carefully selected seismic isolation and energy dissipation devices was adopted, along with a secondary seismic protection system.

Experts from Taiwan’s renowned National Centre for Research on Earthquake Engineering (NCREE) were commissioned to review the concept. Working together with T.Y. Lin International Taiwan, who were acting as project managers (PCM) on behalf of the Highway Bureau, the design team achieved a solution with built-in redundancy that efficiently reduces seismic forces while ensuring optimum performance under non-seismic conditions.

OVERVIEW OF THE BRIDGE ARTICULATION

Danjiang Bridge employs a floating support system, meaning that the bridge deck is not vertically supported at the interface with the pylon.

Its self-weight and any vertical loading applied to the superstructure are transmitted to the pylon via the stay cables. This configuration avoids a “hard point” which would lead to significant negative bending moments in the deck.

A soft support by means of vertical cables in the pylon axis was omitted for aesthetic reasons. Lateral laminated rubber bearings (Elastomeric Bearings) installed at the Bali side leg of the pylon are free to slide in the vertical direction and hence do not bear any vertical forces.

At the other piers, the deck is supported by unidirectional friction single pendulum bearings (FPB). Hold-down cables inside of piers P120 and P140 ensure that the friction pendulum bearings remain under compression at all limit states.

The friction pendulum bearings are free to slide in the longitudinal direction of the bridge. Longitudinal forces are taken mainly by Hydraulic Fuse Restrainers (HFR) connected with spherical hinges to the Tamsui side leg of the pylon. The HFR provide nearly rigid restraint under non-seismic loads. When a certain seismic intensity is exceeded, a fuse is activated and the HFR act as fluid viscous dampers (FVD).

Minor additional longitudinal support and damping is provided by FVD arranged at the expansion joints and by shear deformation of the pylon lateral rubber bearings.

In the transverse direction, the deck is rigidly supported at the pylon and at the transition piers P100 and P160. Flexible lateral support and damping are provided by the FPB at the intermediate piers P110, P120, P140, and P150.

Figure 1 provides an overview of the bridge articulation and seismic isolation.

DESIGN SEISMIC RATING AND PERFORMANCE REQUIREMENTS

Seismic design is one of the most critical aspects of bridge design in Taiwan.

As a lifeline structure, Danjiang Bridge must not only be repairable after an extreme seismic event but also be able to maintain at least one traffic lane operational to serve as an emergency access route for rescue vehicles.

To achieve this goal, the overall design adopts a performance-based design approach (PBD), explicitly defining limits of structural strain and damage for each structural element at three different levels of seismic intensity:

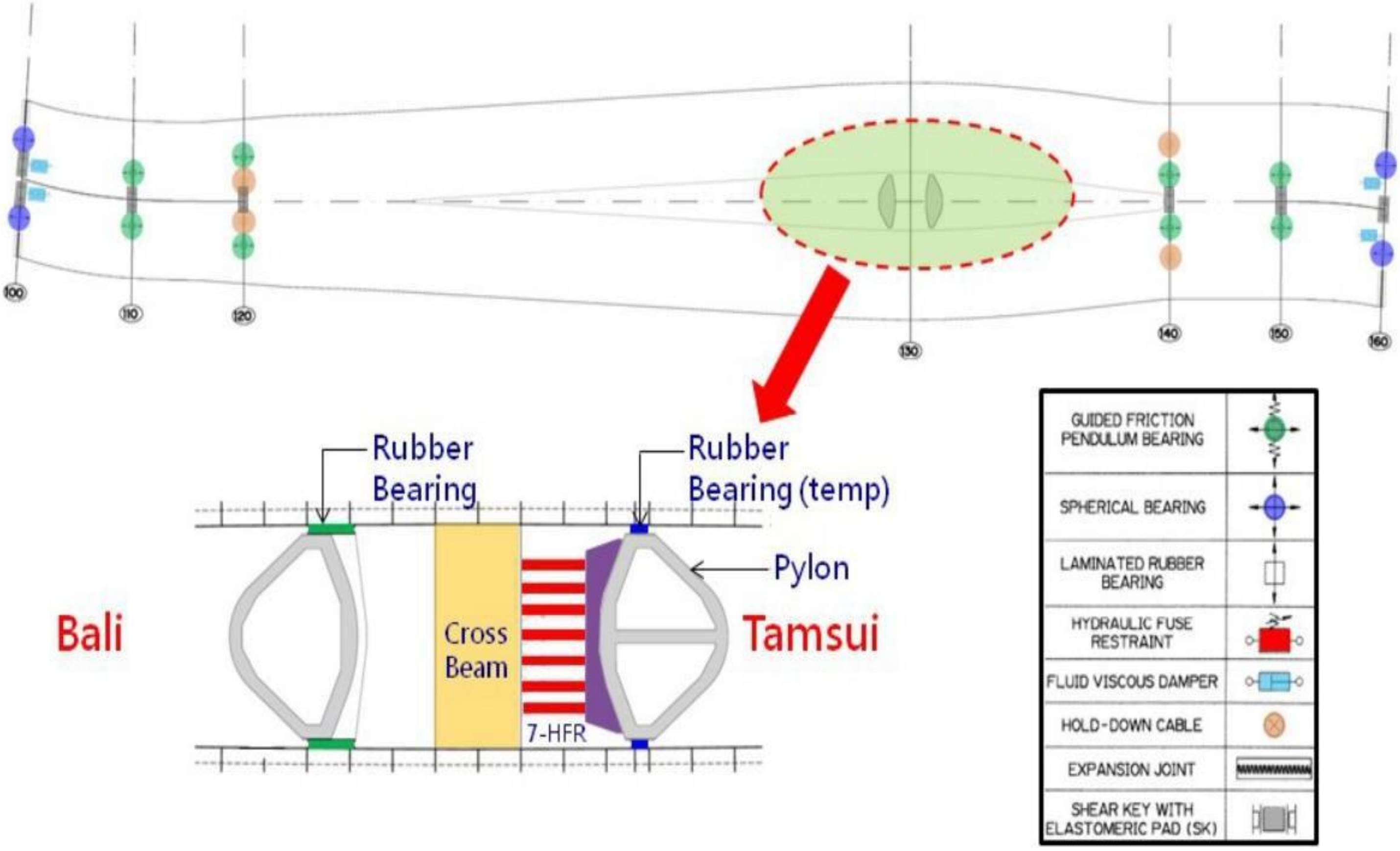
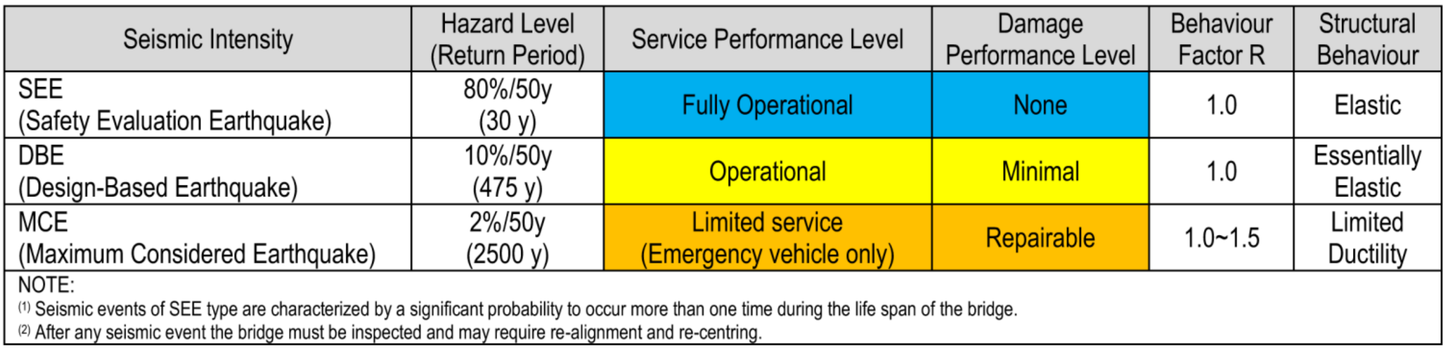


Figure 1: Bridge articulation

- SEE (Safety Evaluation Earthquake or Functional Evaluation Earthquake): an earthquake with a return period of 30 years and an 80% probability of exceedance within 50 years. During such an event, the entire bridge structure shall remain within the elastic range, with no structural components sustaining damage, enabling the bridge to maintain full operational service.
- DBE (Design-Based Earthquake): an earthquake with a return period of 475 years and a 10% probability of exceedance within 50 years. During such an event, the bridge structure shall remain essentially within the elastic range. Minor damage may occur, but the bridge is still operational.
- MCE (Maximum Considered Earthquake): an earthquake with a return period of 2475 years (denominated as the "2500-year earthquake") and a 2% probability of exceedance within 50 years. Limited plastic behaviour and repairable damage may occur. The bridge shall not collapse and at least one traffic lane can be used for the passage of emergency rescue vehicles.

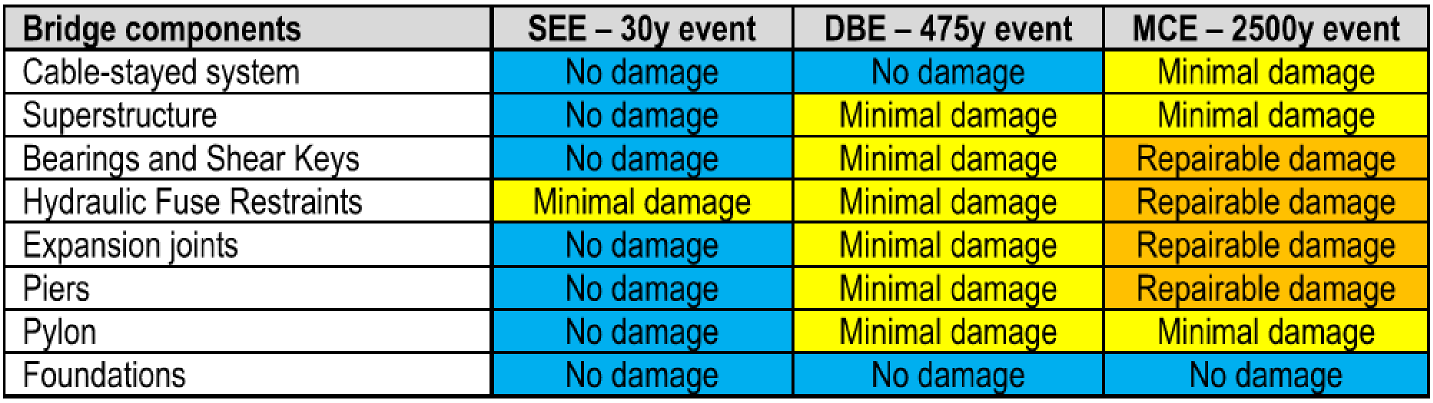
The performance requirements for all three levels are summarised in Tables 1 and 2.



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

NOTE:
(1) Seismic events of SEE type are characterized by a significant probability to occur more than one time during the life span of the bridge.
(2) After any seismic event the bridge must be inspected and may require re-alignment and re-centring.

Table 1: Definition of the seismic hazards and design performance levels



Bridge components	SEE – 30y event	DBE – 475y event	MCE – 2500y event
Cable-stayed system	No damage	No damage	Minimal damage
Superstructure	No damage	Minimal damage	Minimal damage
Bearings and Shear Keys	No damage	Minimal damage	Repairable damage
Hydraulic Fuse Restraints	Minimal damage	Minimal damage	Repairable damage
Expansion joints	No damage	Minimal damage	Repairable damage
Piers	No damage	Minimal damage	Repairable damage
Pylon	No damage	Minimal damage	Minimal damage
Foundations	No damage	No damage	No damage

Table 2: Performance requirements for each bridge component

THE SEISMIC ISOLATION SYSTEM

The overall layout of the seismic isolation system is shown in Figure 1. This section describes the single elements in more detail.

At the pylon (axis 130), the bridge is equipped with seven HFR (Hydraulic Fuse Restrainer) located at deck level between the pylon legs and aligned with the bridge axis. Under normal service conditions, the HFRs function as rigid restraints, providing a total axial restraint force of up to 7 × 7500 kN = 52500 kN.

During an earthquake, the axial support force may reach the trigger limit of 7500 kN. At this point, the group of HFR transitions from a rigid restraint to a velocity-dependent viscous damper via valve activation, providing seismic isolation and energy dissipation. When the restraint is "fused", the HFR perform according to the hysteretic law $F = C \times v^{\alpha}$, where F = force, velocity exponent $\alpha = 0.05$ and damping constant $C = 7.142\ \mathrm{MN(s/m)}^{\alpha}$. The maximum design stroke is ±400mm.

After the earthquake, the HFR internal hydraulic system allows time for the bridge to recentre itself by the balancing forces of the stay cables and the restoring energy of the deformed lateral rubber bearing pads. If bearing friction at the intermediate piers prevents the deck from recentring sufficiently, it can be recentred manually using a hydraulic pump.

Piers P110, P120, P140 and P150 are equipped with two unidirectional Friction Pendulum Bearings (FPB) at the top of each pier, i.e. the friction pendulum is activated only for movements transverse to the bridge axis.

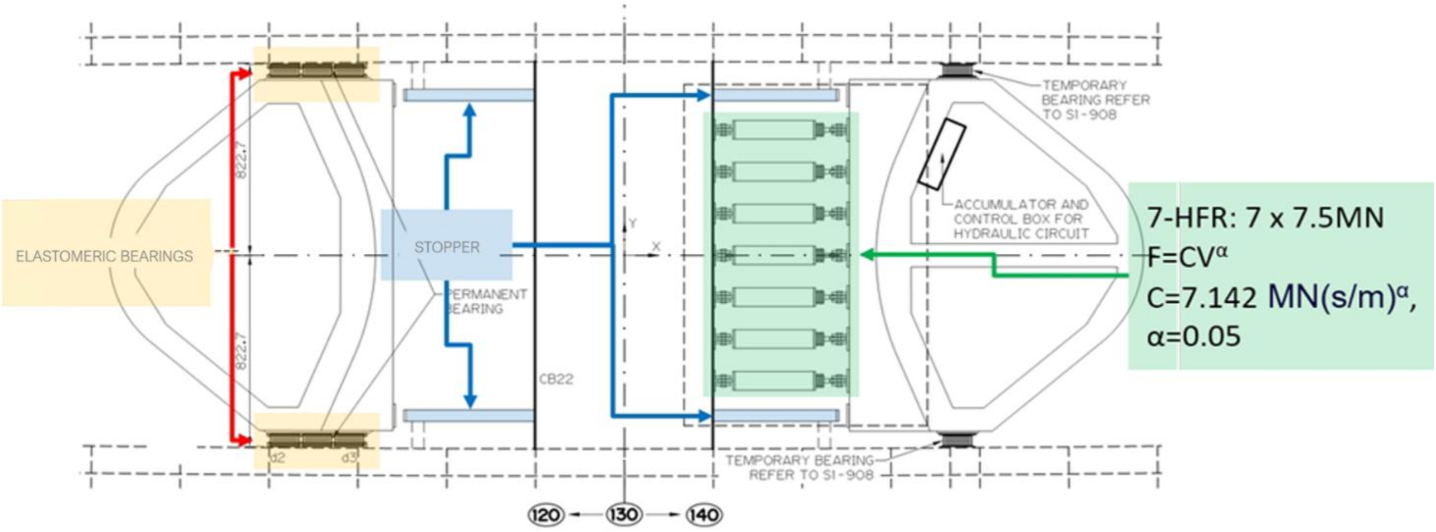


Figure 2: Configuration of seismic devices at the pylon

Since transverse movements under service loads are not desired, a balance had to be achieved between the breakaway force, the restoration capability after a seismic event, and energy dissipation.

Iterative analysis was conducted to determine the optimal combination of curvature radius and friction coefficient for all piers. The final chosen system is shown in Figure 3.

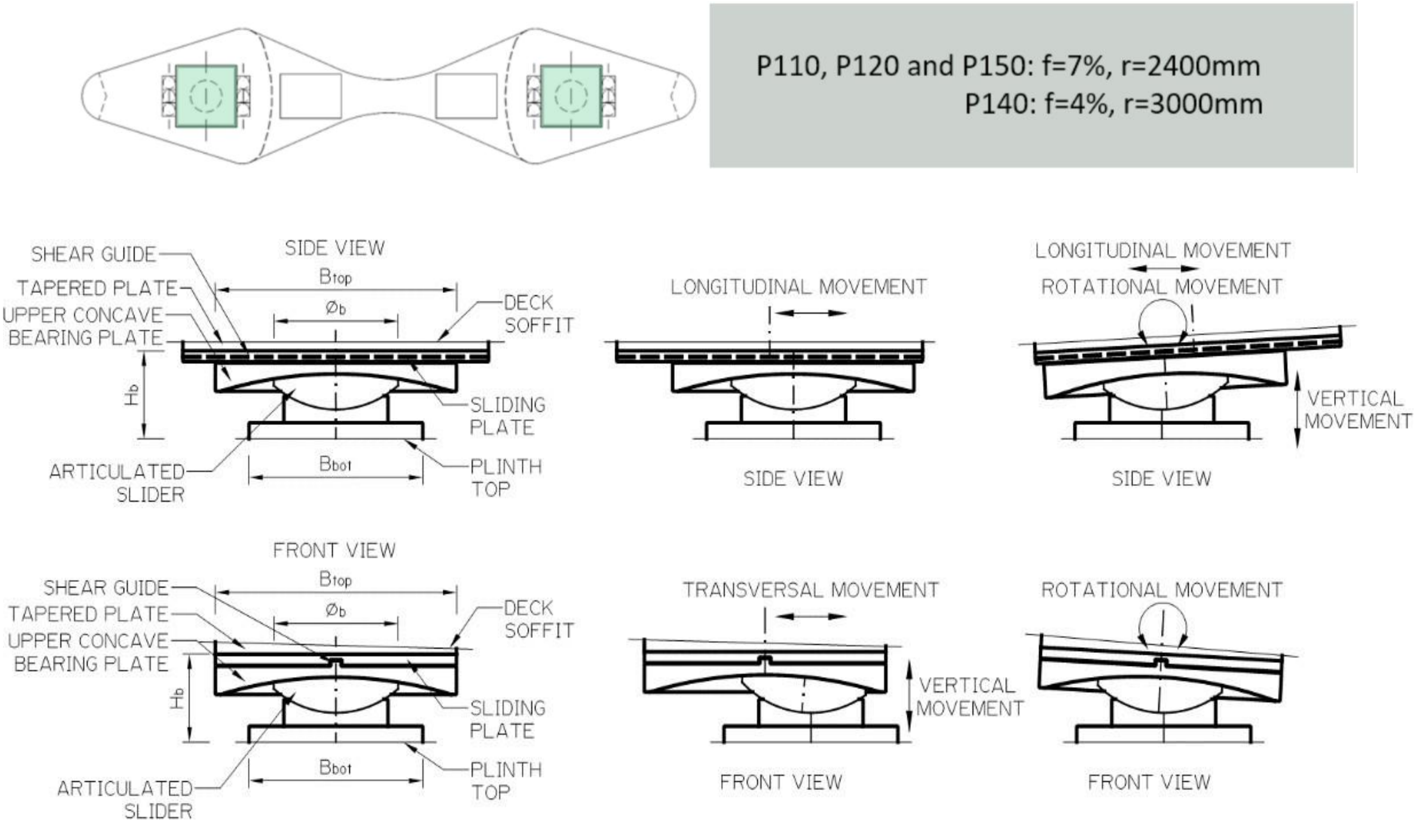


Figure 3: Friction single pendulum bearing parameters and scheme

The support system at piers P100 and P160 consists of shear keys, Fluid Viscous Dampers (FVDs) and spherical bearings.

The shear keys restrict the lateral displacement of the deck girder while allowing it to move along the bridge axis. The spherical bearings allow movement and rotation in all directions.

However, since the shear keys constrain the lateral displacement of the box girder, no relevant lateral movement occurs at the spherical bearings.

The fluid viscous dampers have a capacity of 5000 kN each, with a damping coefficient of 5.0 MN(s/m)$^{\alpha}$. They serve as a second line of defence in case the functionality of the HFR at the bridge pylon is compromised.

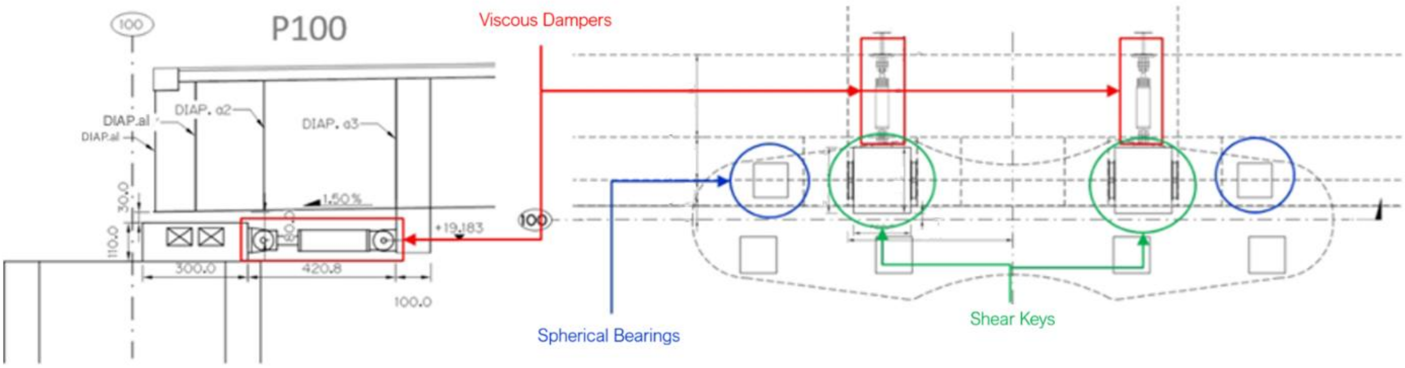


Figure 4: Pier P100 support system

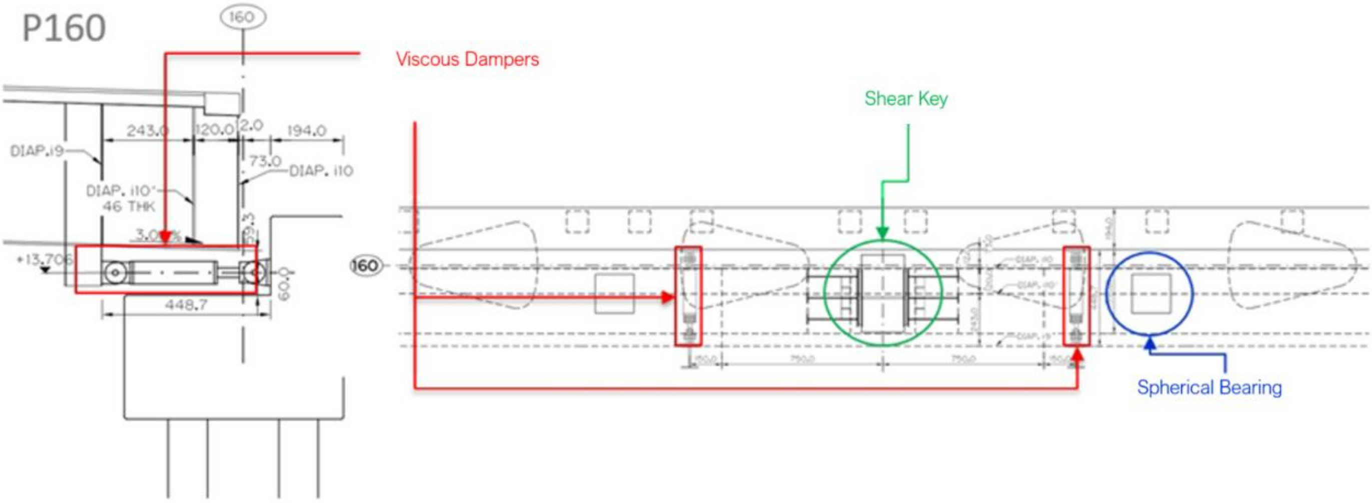


Figure 5: Pier P160 support system

SECONDARY SEISMIC PROTECTION SYSTEM

To ensure that Danjiang Bridge continues to serve as a lifeline for emergency services in the event of an extreme earthquake, a number of secondary anti-seismic protection measures safeguard the bridge in the event that the primary equipment is damaged.

Should an earthquake exceed the intensity of the maximum considered earthquake, i.e. the 2500-year return period earthquake, the HFRs at the deck and pylon interface may be damaged due to movements exceeding the design stroke. Steel stoppers mounted on both sides of the central cross beam on the deck are the backup system for this condition.

In the event of excessive movement, the stoppers will collide with concrete corbels on the pylon legs, transmitting any residual forces directly to the pylon.

This arrangement is shown in Figures 2 and 6.

Excessive lateral displacement during an earthquake, beyond that considered in the design, could damage the friction pendulum bearings at piers P110, P120, P140 and P150. This could result in the deck becoming dislodged from the bearings.

To prevent this, the steel box girder is fitted with shear keys that align with concrete stopper blocks in the pier tops, as shown in Figure 7.

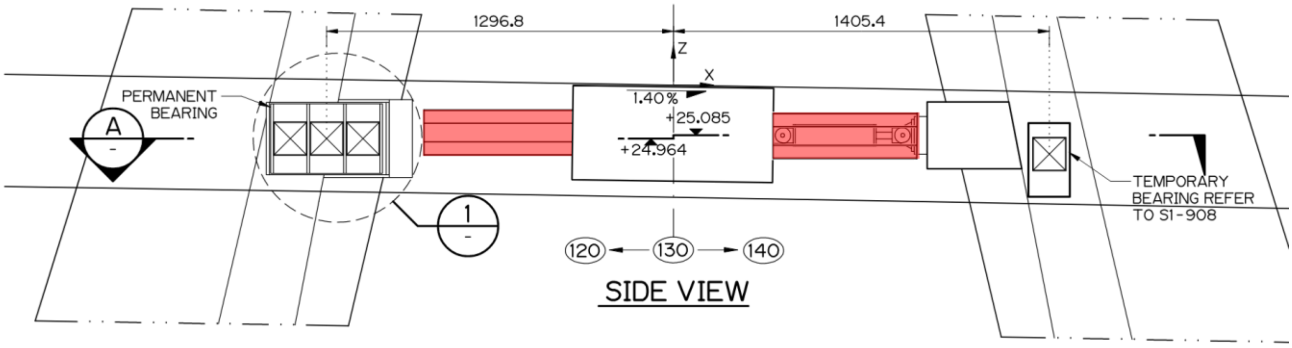


Figure 6: Rigid longitudinal stoppers at pylon

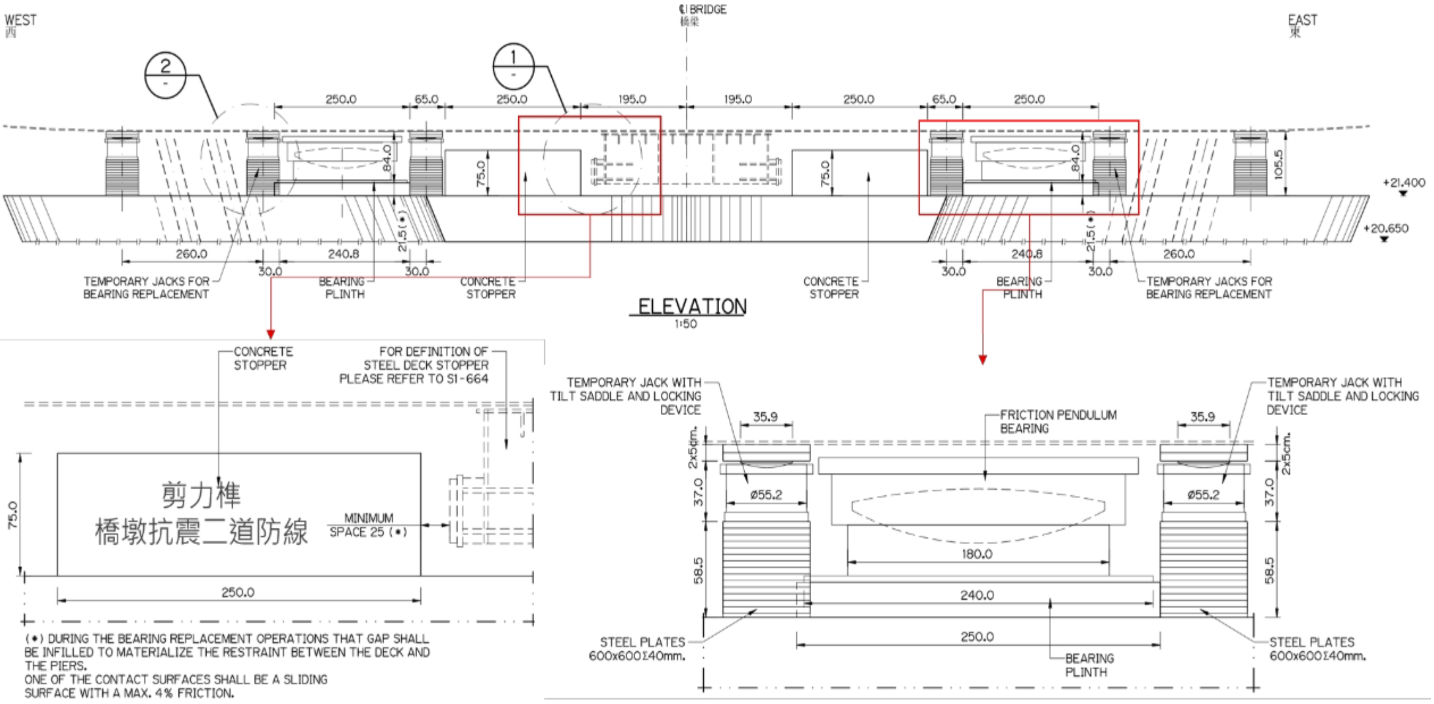


Figure 7: Rigid transverse stoppers at bridge piers

The presence of an open gap between the shear keys and the stoppers ensures that the stoppers will only be activated if a seismic event exceeds the Maximum Considered Earthquake.

During the construction phase, this gap was blocked to provide temporary lateral support to the deck. The gap would also be blocked for temporary lateral support in the event of a future bearing replacement.

The FVDs arranged at the transition piers P100 and P160, as illustrated in Figures 4 and 5, also form part of the secondary seismic protection system. However, they help to reduce displacements in any earthquake. Their properties are chosen such that slow movements are not restrained.

SEISMIC ANALYSIS

Global seismic analysis was carried out on a 3D model of the bridge set up in software SOFiSTiK, as shown in Figure 8.

Initially, response spectrum analysis was carried out, using linearised elements to represent the seismic isolation system.

This was followed by a non-linear time-history analysis incorporating the actual non-linear properties of the seismic isolators and material non-linearities.

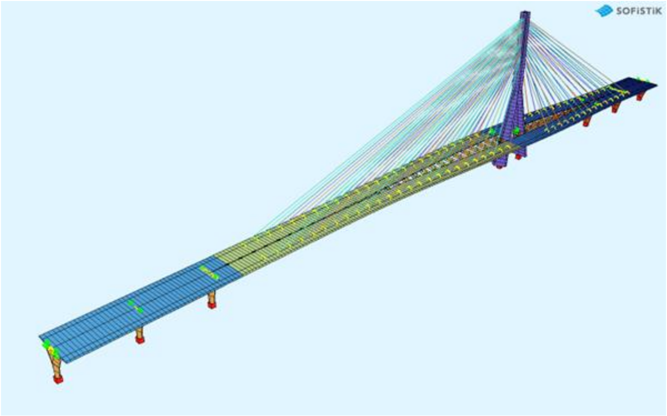


Figure 8: Global analysis model

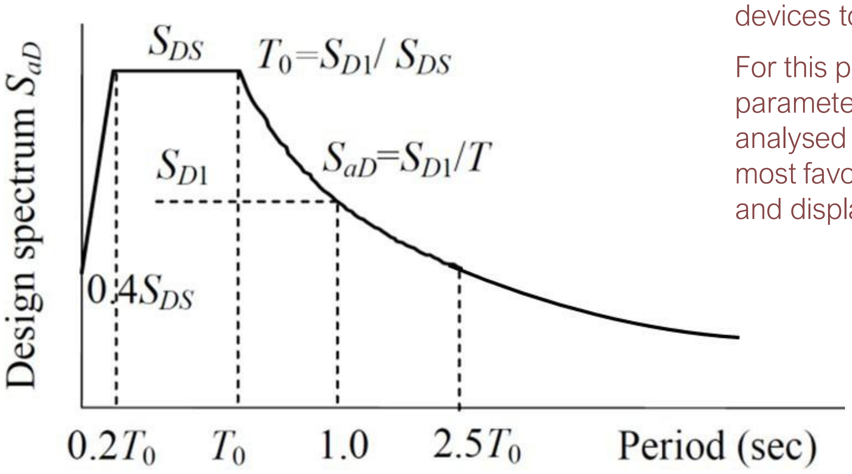
According to the acceleration response spectrum set out in the Ministry's Seismic Design Code for Highway Bridges [2], the acceleration decreases significantly when the structural vibration period exceeds T_0, as shown in Figure 9.

The hazard analysis confirms the low accelerations in the long period range.

Therefore, enhancing the structure's overall flexibility to reduce its vibration period is one method of mitigating seismic forces.

However, this typically increases structural displacements, necessitating the installation of appropriate seismic isolation and energy dissipation devices to limit structural movement.

For this project, the stiffness and energy dissipation parameters of the isolation equipment were analysed and adjusted iteratively to achieve the most favourable equilibrium between seismic forces and displacement.



Microzonation	S_{SS} [g]	S_{DS} [g]	S_{MS} [g]	T_0 [s]
Taipei Zone 2	0.17	0.6	0.8	1.3

Figure 9: Acceleration Response Spectrum and Parameters Zone Taipei 2

ACCELERATION SPECTRUM ANALYSIS

The seismic acceleration response spectra applicable to Danjiang Bridge are shown in Figure 10. The design response spectrum is specified separately for each component of the seismic action, that is, the longitudinal, transverse and vertical components.

To account for the level of damping present in the structure, the response spectra are modified using the damping reduction factors BS and B1, as specified in Code 2.

The code limits BS and B1 to a maximum reduction of 20%. As the damping level achieved by the seismic isolation system exceeds 20% in both horizontal directions at DBE and MCE, this cap is applied.

At SEE, however, the breakaway force of the friction pendulum bearings may not be reached, meaning the associated damping may not activate.

Therefore, the damping of the seismic isolation system at SEE has been capped at 10%. All assumptions were verified by non-linear time history analysis.

In the vertical direction, the piers, pylons and bearings cannot dissipate large amounts of energy because axial forces prevail and the natural periods of the vertical modes are short.

Additionally, the vertical modes of vibration primarily induce vertical bending of the deck, which is engineered to remain within the elastic range at all seismic design intensities.

Therefore, elastic inherent damping of 2% is used to characterise the vertical response spectra for each earthquake level.

Once the required iterations to develop and fine-tune the seismic isolation system were completed, it was determined that the overall structure's fundamental vibration period at MCE is 4.44 seconds, as shown in Figure 11.

In the second mode, the lateral stiffness of the pylon and the torsional characteristics of the separated steel box girder deck are key factors.

All primary vibration modes of the integrated structure fall within the low acceleration range of the response spectrum, which effectively reduces seismic forces.

Figure 11 also shows that 100 vibration modes have to be considered to ensure that at least 90% of the total mass is mobilised in each horizontal direction, as required by the code. The analysis considers the first 200 modes.

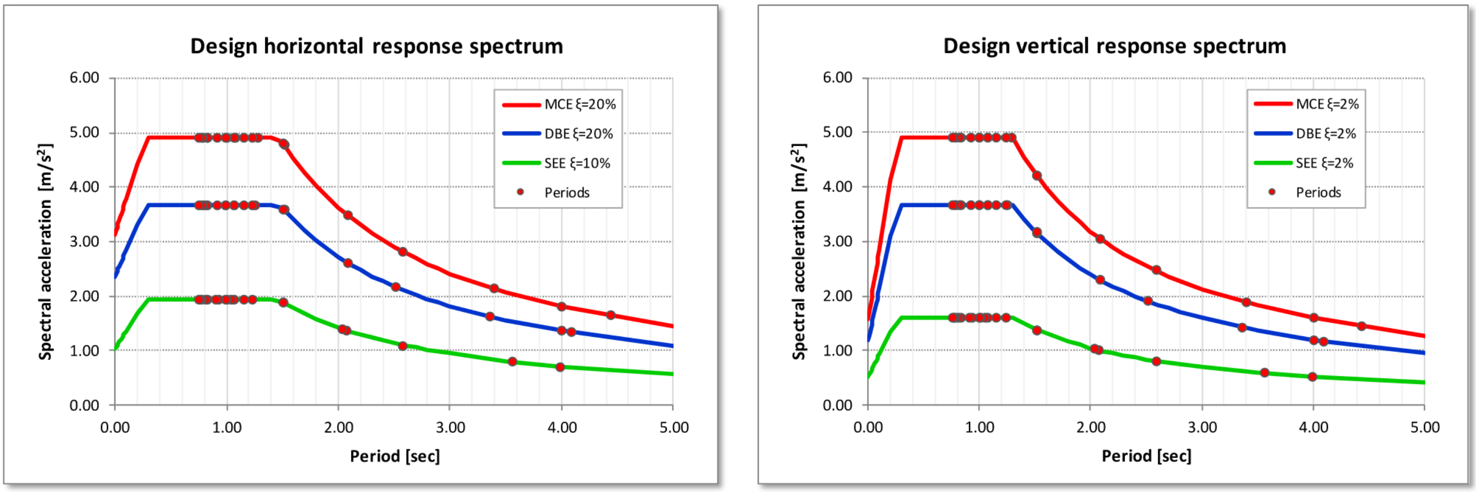
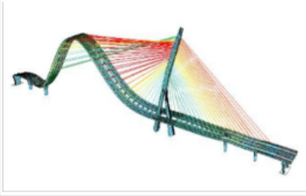
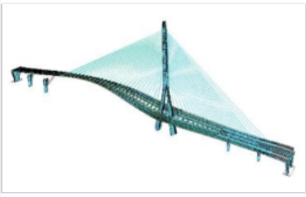


Figure 10: Horizontal and vertical design response spectra

		Participating factor			
Mode	Modal shape - MCE	T(s)	Mx(%)	My(%)	Mz(%)
1		4.44	22.6	-	1.1
2		4.00	-	8.9	-
3		3.40	5.9	-	3.6
4		2.50	-	7.2	-

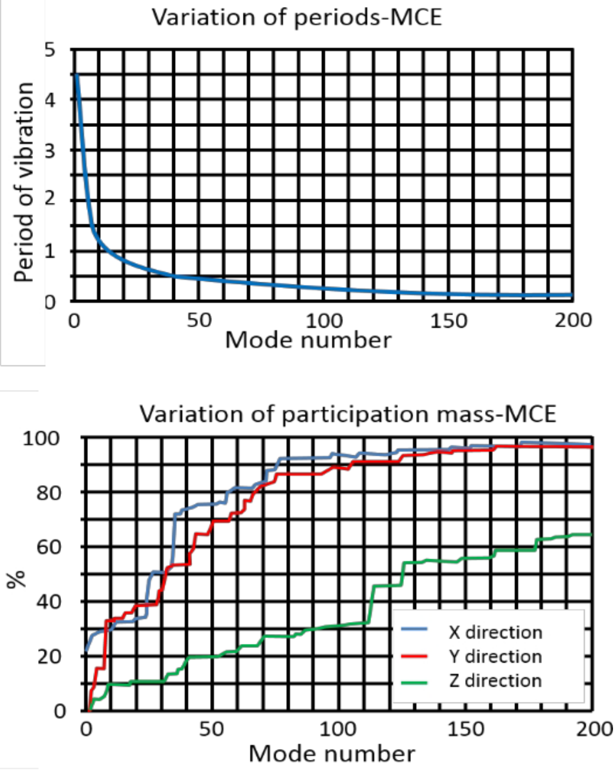


Figure 11: Fundamental modes of vibration; Frequencies and mass participation of the first 200 modes

NON-LINEAR SEISMIC TIME ANALYSIS

The nonlinear seismic time-history analysis conducted during the detailed design phase comprises two parts, as detailed below.

1. A seismic hazard analysis was conducted for the bridge site. The parameter deconstruction showed that the main sources of seismic activity contributing to the 2500-year return period hazard are nearby sources, the foothill faults, and distant subduction zone sources. The uniformly distributed Uniform Hazard Response Spectrum (UHRS) for the project site is shown in Figure 12.

   Based on the magnitude, distance, site Vs30, PGA and the UHRS profile, three real earthquake time histories were subsequently selected: the 1999 Chi-Chi earthquake, the 2002 “331” earthquake and the 2013 Hualien earthquake.

   These were fitted to the uniform hazard response spectrum to generate artificial seismic acceleration time history data for the bridge's nonlinear dynamic analysis, as shown in Figure 13.

2. Analysis was conducted on seven sets of artificial seismic time history data fitted to the acceleration response spectrum per the Highway Bridge Design Code [2], as illustrated in Figure 14, to verify the damping ratios and the displacement of each seismic isolation component.

The non-linear time-history analysis was carried out both for simultaneous excitation of all foundations and with a time lag to account for the spatial variability of the ground motion, as shown in Figure 15.

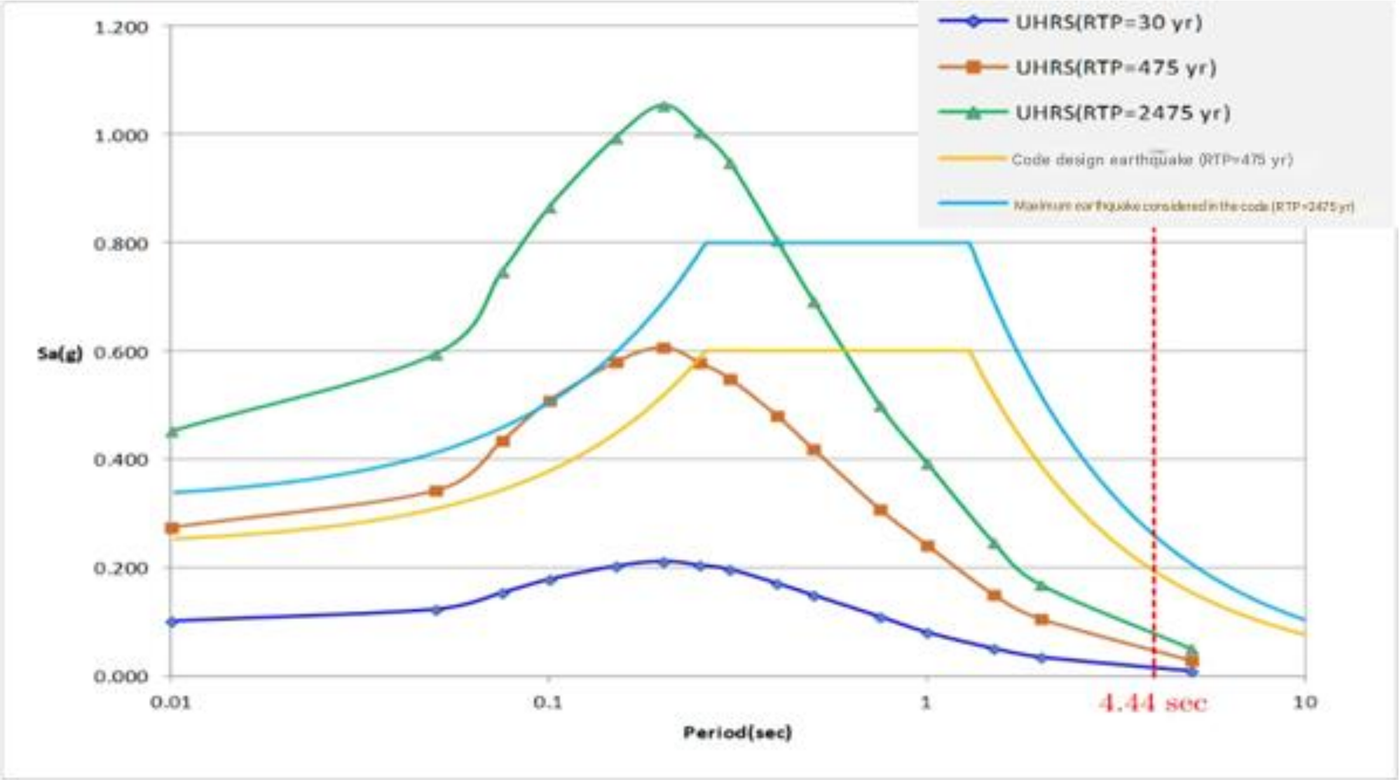


Figure 12: Comparison of the seismic hazard analysis results with the canonical seismic response spectra

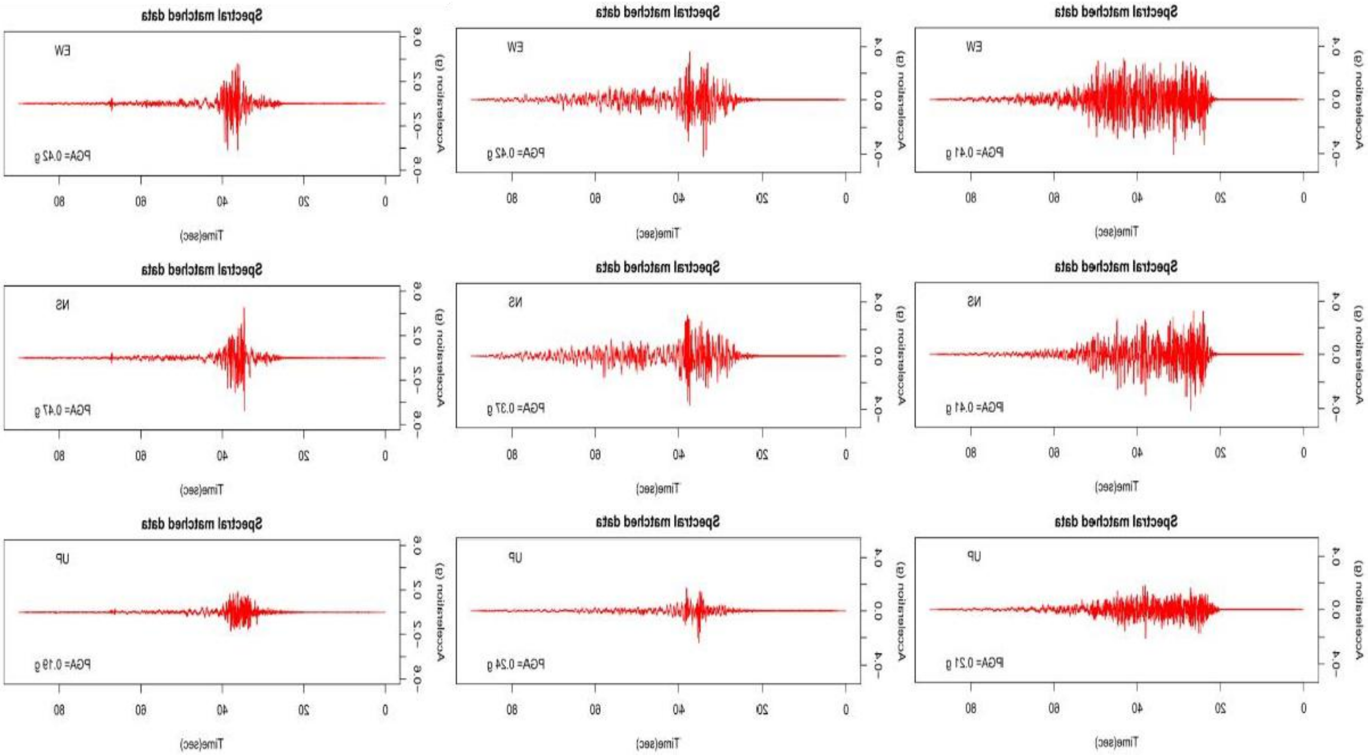
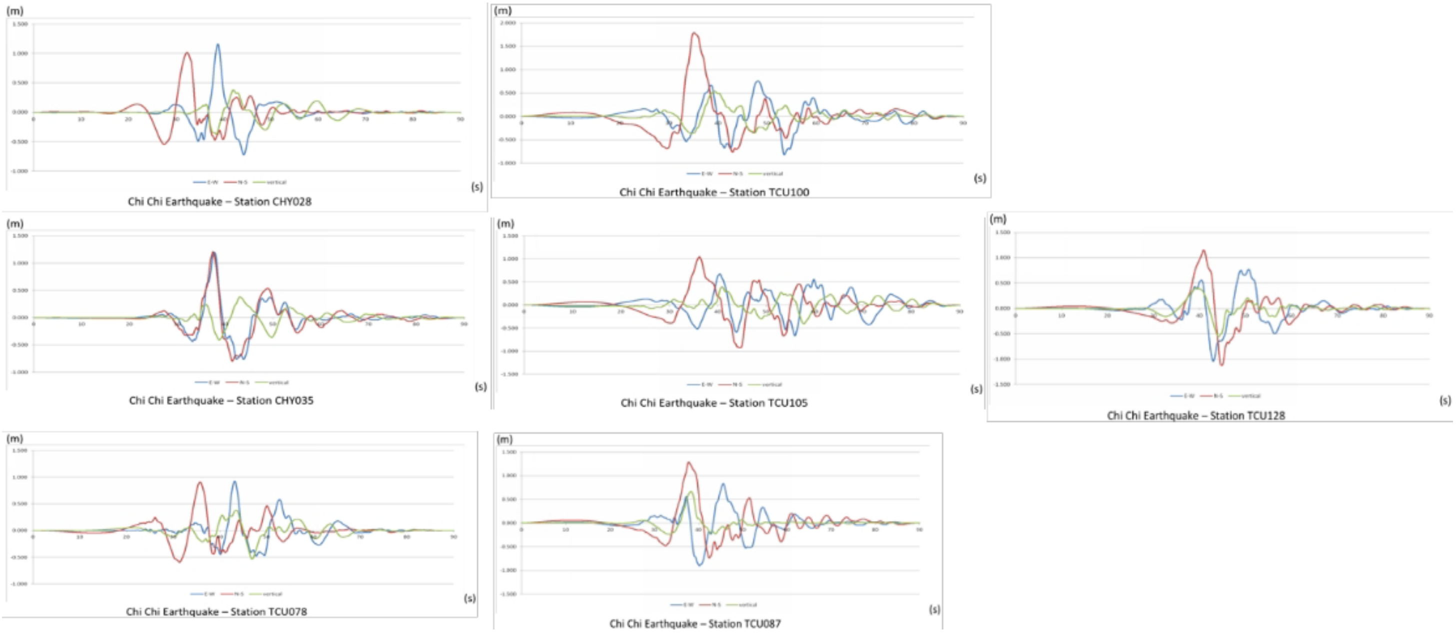


Figure 13: Seismic hazard analysis fitting of artificial seismic acceleration history



Chi Chi Earthquake – Station CHY028

Chi Chi Earthquake – Station TCU100

Chi Chi Earthquake – Station CHY035

Chi Chi Earthquake – Station TCU105

Chi Chi Earthquake – Station TCU128

Chi Chi Earthquake – Station TCU078

Chi Chi Earthquake – Station TCU087

Figure 14: Artificial seismic acceleration time curve matching the code spectrum

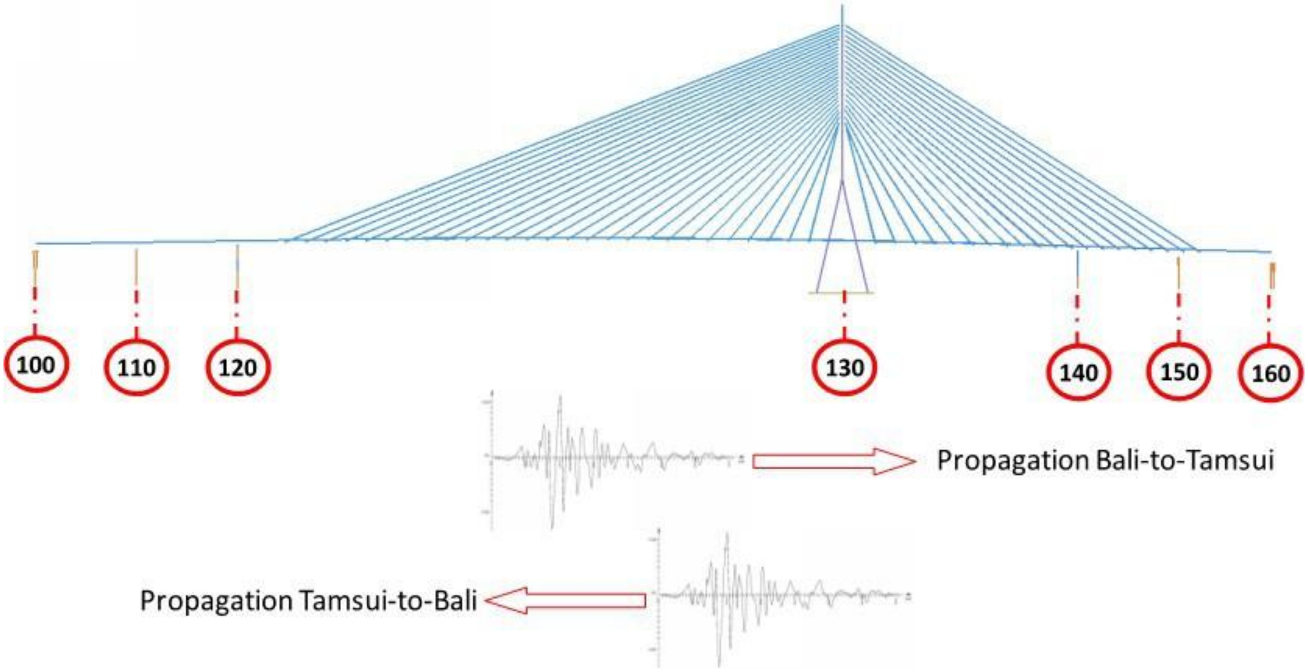


Figure 15: Directions of wave propagation considered in time history analysis

CONCLUSION

Danjiang Bridge shows how a record-scale, asymmetric cable-stayed structure can meet lifeline-level seismic demands through a purpose-built isolation strategy.

In a region shaped by frequent earthquakes and multiple nearby fault sources, the project demonstrates the value of performance-based design from the earliest stages.

The combination of HFR devices, friction pendulum bearings, viscous dampers, and secondary stopper systems establishes a layered defence that limits forces, controls displacements, and ensures recentering after major events.

Rather than relying on any single device, the system works through redundancy and coordinated behaviour verified by extensive nonlinear time-history analysis.

As the bridge approaches completion, its seismic design sets a strong precedent for long-span bridges in high-hazard environments.

The article offers a deeper look into how these isolation components, analytical methods, and performance criteria were integrated to achieve resilience without compromising serviceability or architectural intent.

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[2] Code for Seismic Design of Highway Bridges, Ministry of Transportation and Communications, R.O.C.

[3] AASHTO LRFD Bridge Design Specifications

[4] AASHTO Guide Specifications for Seismic Isolation Design

[5] Eurocode 8 - Design of structures for earthquake resistance

Figure 16: Installed hydraulic fuse restrainers

HIGH-PERFORMANCE STRUCTURAL PROTECTION COMPONENTS FOR THE DANJIANG BRIDGE

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Moustafa Imam, Head of IoT, mageba Group

INTRODUCTION

In 2026, a new marvel of engineering will open to the public – the Danjiang Bridge spanning over the mouth of the Tamsui River in Taiwan, designed by architect Zaha Hadid in collaboration with Leonhardt, Andrä und Partner. It will set new records and be the longest asymmetrical single-mast, cable-stayed bridge in the world with a 200m high pylon and a total length of 920 m.

The road and light rail landmark sets not only new standards in bridge engineering but also seismic design, requiring a new approach and innovative product design.

To withstand earthquakes exceeding magnitude 7 while simultaneously ensuring structural safety against hazardous daily operational challenges—such as fatigue, corrosion, and strong winds (typhoons)—a range of specialized products have been engineered including spherical bearings, friction pendulum bearings, laminated rubber bearings, shear keys, modular expansion joints with fuse elements, shock absorbers and multifunctional hydraulic devices named Hydraulic Fuse Restraints (HFR).

SCOPE

For the design, engineering, production, testing and supply of these high-end and complex devices, globally present specialist mageba was engaged to deliver products presented in Table 1.

All the above-mentioned products are built on an extra-large scale, with many of them integrated with high-tech, unique, integrated features to match the extraordinary design of the bridge and to have such capacity to control the potential extreme diverse external environments that could occur.

These devices are at the pinnacle of any products ever installed around the world.

MODULAR EXPANSION JOINTS WITH SPECIALIZED FUSE ELEMENTS

Two large-scale Modular Expansion Joints (MEJ) of type LR15-FE (15-gap) and LR17-FE (17-gap) made of each 5 sections were designed with +/-784 and +/-871 mm max. longitudinal displacement capacity and integrated fuse elements (FE).

The MEJ allows nominal +/-614 and +/-689 mm, respectively, at the ULS condition. When entering an ELS condition, the fuse elements break away and additional movement capacity +/-170 and +/-182 mm are released to accommodate the most severe situation during a maximum considered earthquake.

The displacement capacity has been verified through full-scale product testing, and the fuse breakaway has been verified through an equivalent reduced-gap joint sample (LR3-FE) with identical geometry in the section.

Device Name	QTY	Maximum Vertical load [kN]	Maximum Horizontal load [kN]	Maximum displacement +/- [mm]
Spherical Bearings (SB) RESTON®SPHERICAL	4	21,000	-	600
Friction Pendulum Bearings (FPB) RESTON®PENDULUM	8	133,000	11,000	550
Laminated Rubber Bearing sets (LRB) LASTO®BLOCK	2	64,000	4,600	320
Elastomeric Bearing for shear keys (SK) LASTO®BLOCK	12	53,000	-	500
Modular Expansion Joints (MEJ) TENSA®MODULAR	10	-	-	871
Hydraulic Fuse Restraints (HFR) RESTON®HFR	7	-	7,500x7	400
Fluid Viscous Damper (FVD) RESTON®SA	4	-	5,000	600

Table 1: A list of devices mageba delivered for the Danjiang Bridge

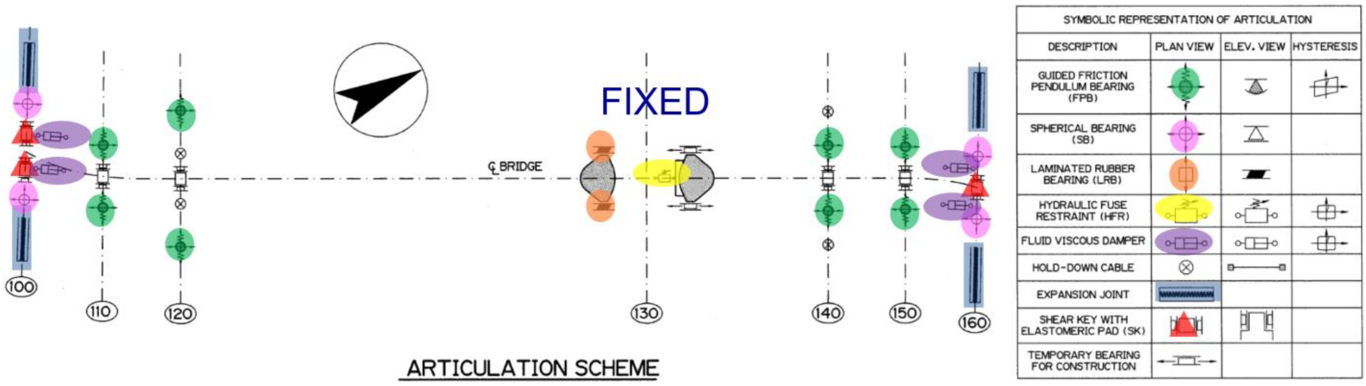


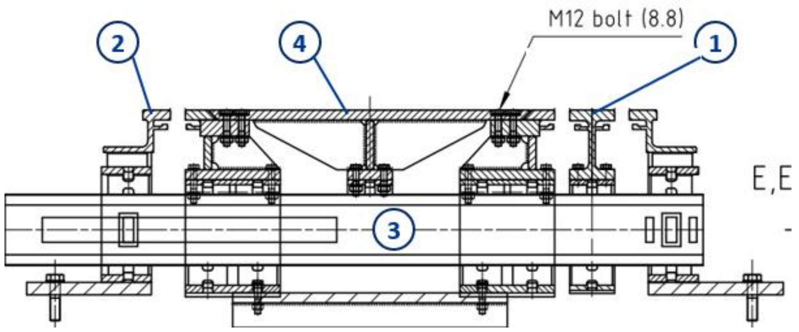
Figure 1: Articulation Scheme of the Danjiang Bridge

In order to verify the fuse function while keeping the same conditions as on a real joint, one test sample, LR3-FE, is proposed, which is deemed as representative in terms of the performance and behaviour of the final joint products.

The LR3-FE prototype consists of full components of the real modular joint LR17 of the Danjiang Bridge within one span (2 joist beams) and reduced gaps (17 to 3). The stroke capacities of the gaps and the fuse element are identical to the actual LR17.

All critical elements are included as follows:

Figure 2: LR17-FE full-scale test



1. Centre beam
2. Edge profiles
3. Joist beams
4. Seismic fuse-element units
5. Gap control springs
6. Gap-limitation belts

Figure 3: Section View of LR3-FE

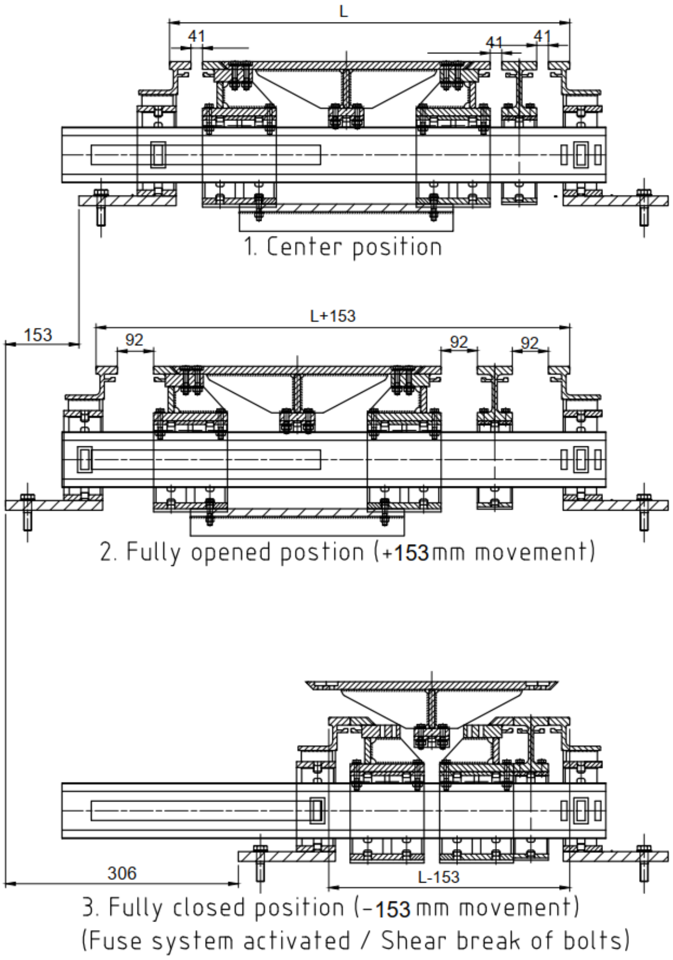


Figure 4: Section Views at centre / fully opened / fully closed position

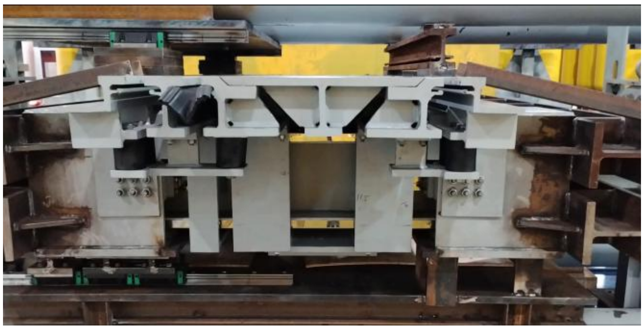


Figure 5: LR3-FE fuse break-away test – before break

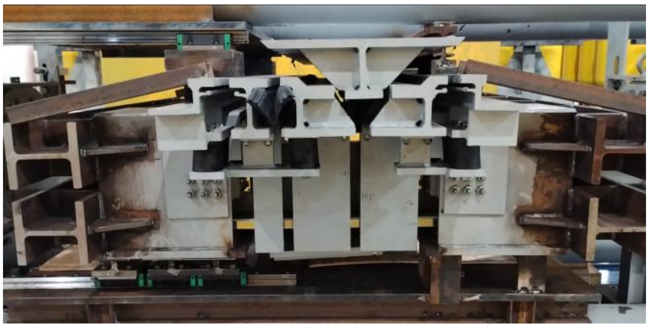


Figure 6: LR3-FE fuse break-away test – pop up

Figure 7: LR3-FE fuse break-away test – more stroke capacity released

Guided Friction Pendulum bearings

A total of 8 units of guided pendulum bearings (FPB) are placed on 4 piers (2 units per pier), of which the most demanding ones are located at P140; 2 FPBs with a vertical load capacity of 133 MN, resulting in a size of 2.6 x 2.2 m x 1 m and weighing over 24 tons each.

These bearings consist of 2 sliding interfaces and 1 rotational surface.

In longitudinal direction, flat sliding surface with greased sliding material ROBO®SLIDE with ultra-high strength and wear resistance, which allows "free" movement (with minimum friction resistance).

In the transverse direction, the internal guide transfers the shear force from the superstructure through the ungreased spherical sliding interface, behaving like a classical friction pendulum.

Due to the limited laboratory testing capabilities available, from the size and extreme load capacities of the devices, a scaled prototype was necessary, built according to the similarity law to enable the testing verification program to be implemented for the design concepts and performances.

HYDRAULIC FUSE RESTRAINTS (HFR)

HFR is the most challenging design out of all the products used in the bridge, representing the state-of-the-art solution to the most demanding design concept.

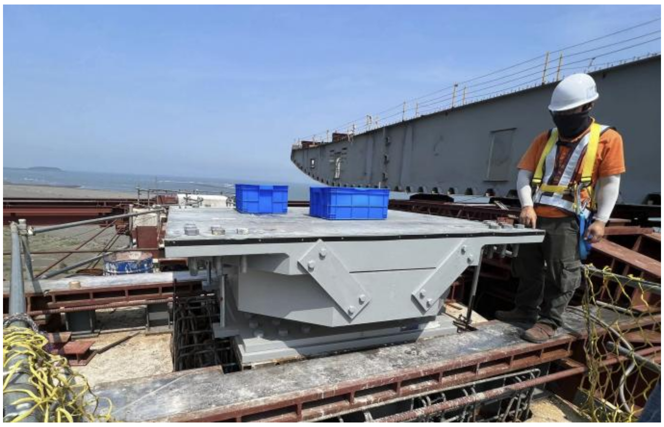


Figure 8: Pendulum bearing at the construction site - preparation before installation

Figure 9: FPB scaled prototype testing

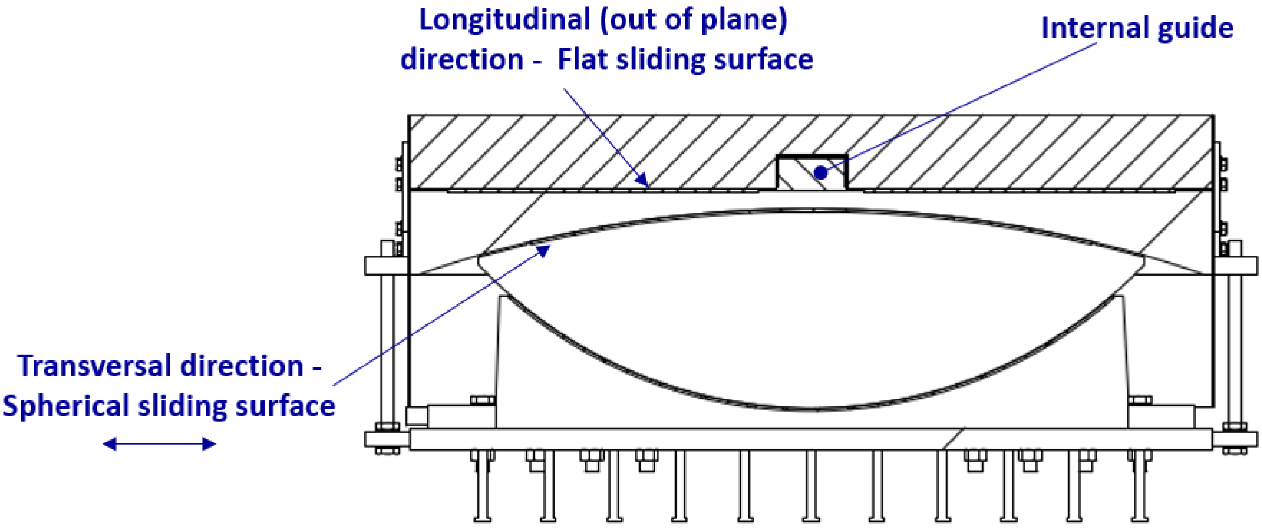


Figure 10: Main components of the pendulum bearing

Uniquely, through a specialised hydraulic and "smart" system design—which incorporates real-time data acquisition via integrated sensors—this HFR array integrates multiple functions: acting as a rigid link, providing safety limits via hydraulic fuse break-away, enabling high-speed damping, and locking up during transient actions, see Table 2.

Each HFR unit consists of 1 set of ① Pilot manifold (bi-directional) and 2 sets of ② Main pressure manifolds (unidirectional). ① Pilot manifold controls the stage upon the received hydraulic signal and alters the behaviour once threshold values of triggers are exceeded, see Figure 12.

It activates/deactivates the restraint status by opening/closing a set of special valves. ② Main pressure manifolds are activated in Stage 2, which controls the ultra-high flow rate (20000LPM =1.2m/s) at a high pressure.

Figure 11: HFR array installed and interlinked

↓ *Table 2: HFR different stages and behaviours*

#	Stage	Behaviour	Description
1	Normal	Hydraulic Fuse	Fully restrained for loads under threshold
2	During EQ	FVD	Hydraulic fuse breaks away. Damping actions over full load range
3	After EQ	STU	Allows slow velocity movement and recentres the bridge with the help of LRB deformation.
1	Normal	Hydraulic Fuse	Fully restrained for loads under threshold. The device recovers to the “Normal” initial state.

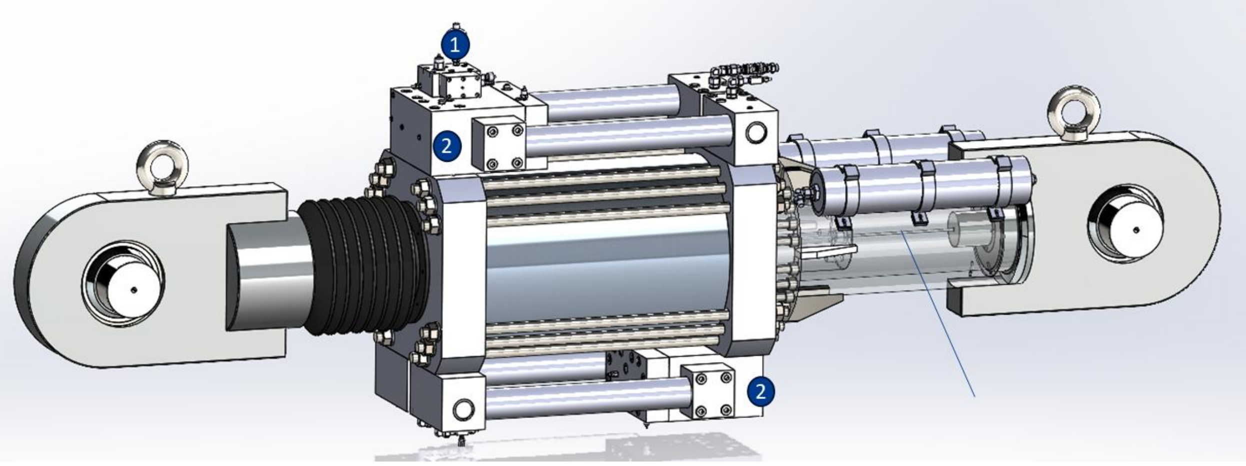


Figure 12: Schematics of the HFR structure and hydraulic elements

ULTRA DYNAMIC PERFORMANCES

7 units, each with a load capacity of 7,500 kN at 1.2 m/s act in parallel to provide a maximum group reaction force of 52.5 MN. The challenging hydraulic performance requires ultra-high flow relief – equivalent to a flow rate of 20,000 litres per minute at a pressure of 27 MPa.

Full-scale testing has been performed with full dynamic performance capacity 7,500kN at 1.2 m/s, +/-400 mm.

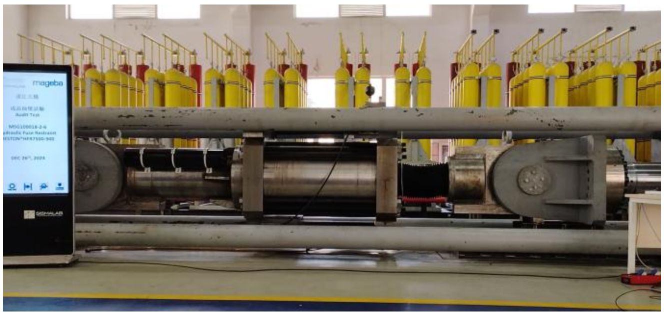


Figure 13: HFR full-scale dynamic testing - up to 7500kN at 1.2m/sec

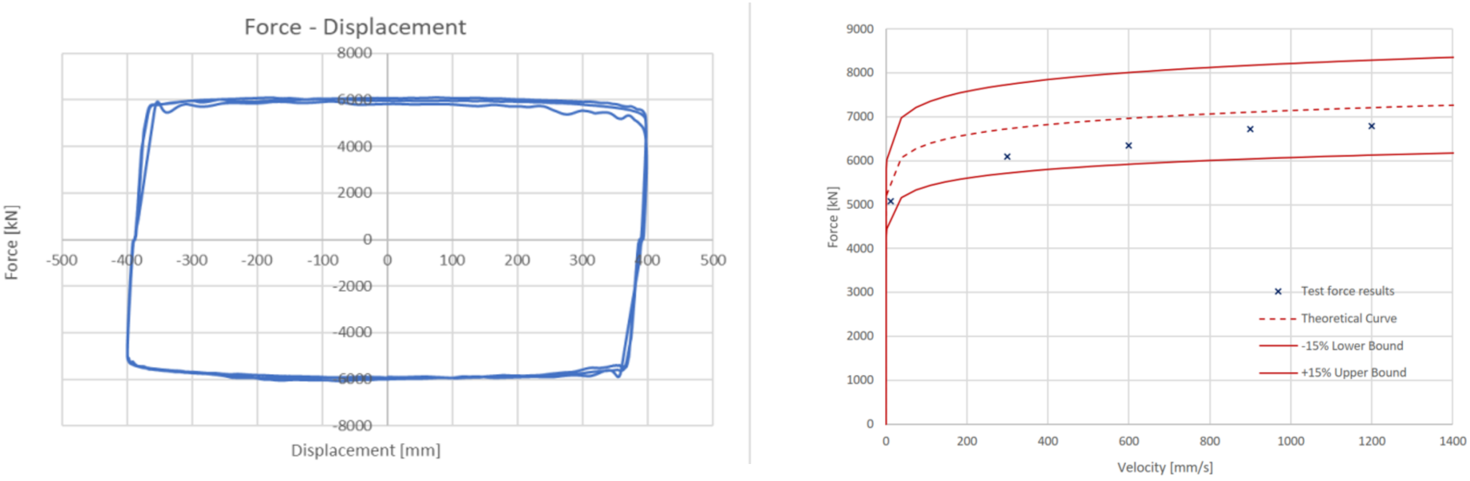


Figure 14: HFR full-scale dynamic testing

BREAK AWAY PERFORMANCE

Instead of sacrificial mechanical fuses, the hydraulic fuse can be deactivated (behaves as break-away) and reactivated (reset) easily and more precisely, controlled by a series of hydraulic valve elements.

Because of the nature of the hydraulic technology, this fuse solution is also insensitive to corrosion, temperature, fatigue, etc., which allows mageba to bring constant performance over years of operation.

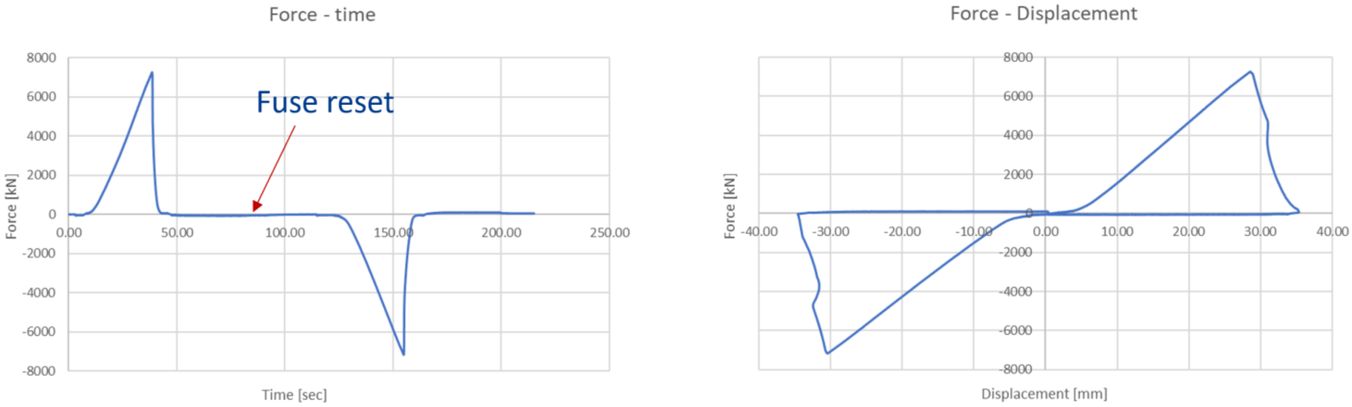


Figure 15: HFR full-scale break-away test

ULTRA DURABILITY

The piston rod, as the active sealing surface, is exposed to the external environment and vulnerable to corrosion issues. To be able to withstand the hazardous marine environment, mageba's specialised coating system is used on the HFR's piston rods, which enables it to resist over 1,000 hours of Salt Spray Test (10+ times over traditional solution performance).

Unlike a traditional viscous damper or STU device that allows slow movement, the HFRs act as a rigid link to resist service loads. The structure of the HFR is designed to be as robust as fatigue-free.

100,000 cycles and 4.8 million fatigue load cycle tests have been carried out on one full-scale and one 1:5 scaled HFR device, respectively, at a stress range ratio (divided by nominal design force) of 0.45.

GROUP FUNCTION

To grant the best possible pressure distribution, equal loading and avoiding fatigue effects during service load conditions, the compression and tension fluid chambers of all HFRs are interconnected. Each HFR has two Main Hydraulic Blocks, each of which connects to one of the two chambers of the cylinder, allowing access to all orifices and valves that regulate hydraulic behaviour. This group function has been verified by a set of scaled devices.

CONCLUSION

The synergistic combination, centred on the innovative HFRs and incorporating elements from SKs, FPBs, MEJs, FVDs and LRBs, enables mageba to fully fulfil the potential of the state-of-the-art bridge design concept for ultra-high performance.

Figure 16: Fatigue test – 100,000 cycles – full scale

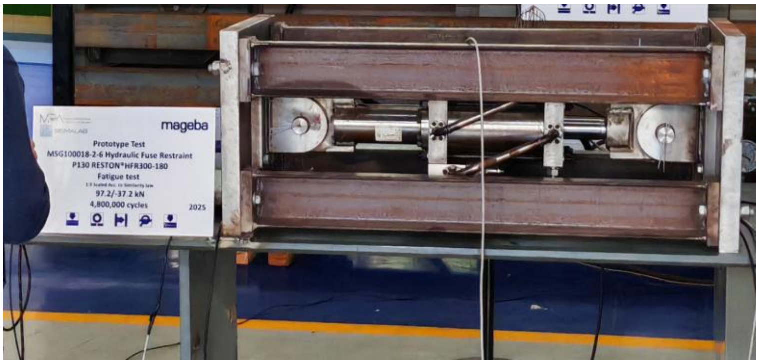


Figure 17: HFR fatigue test - 4,800,000 cycles - scaled

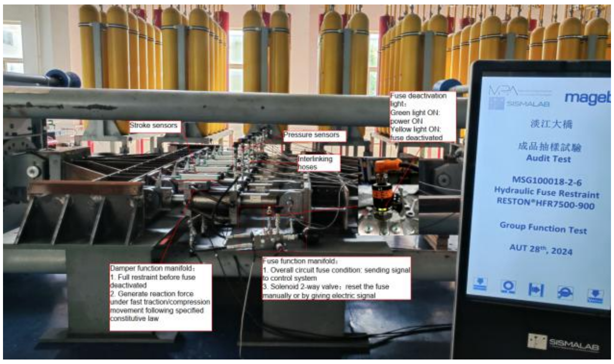


Figure 18: HFR group functioning test - scaled

DANJIANG BRIDGE CRASH BARRIERS

Marta Mastova, M.D.S. Handels -und Montagen GmbH

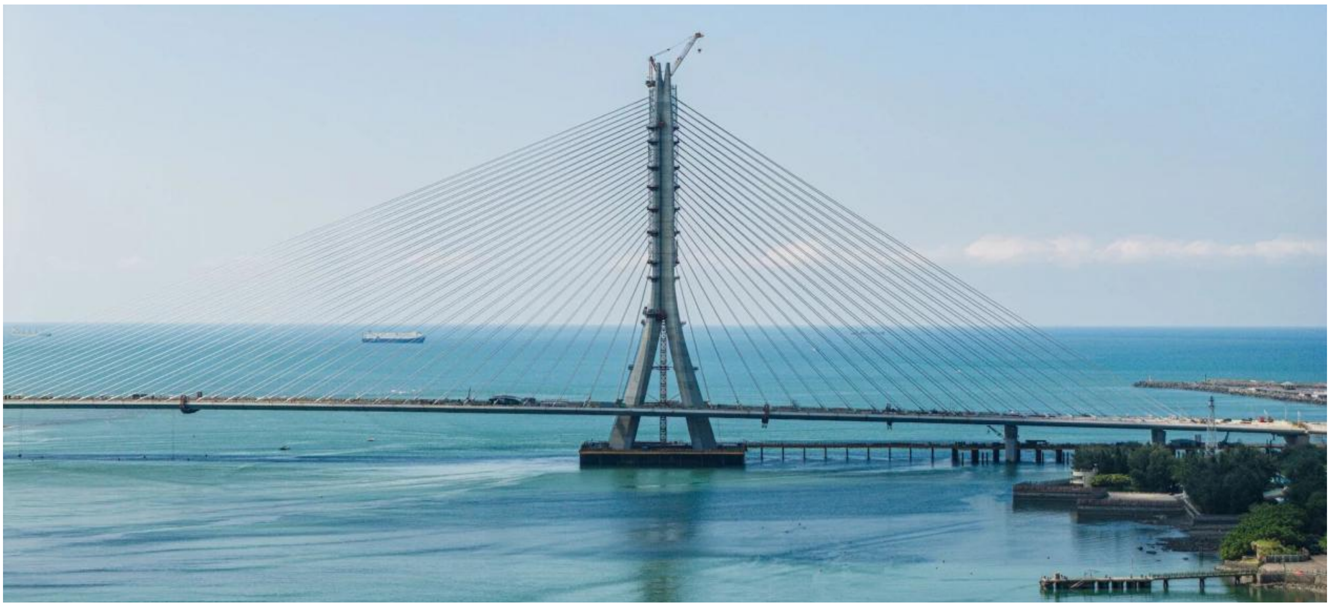


Figure 1: Danjiang Bridge under construction

STEEL SAFETY BARRIERS

Modular safety barrier Sergard MDS H2 has been chosen to protect vehicles, drivers and pedestrians on the Danjiang Bridge in Taiwan – the longest single tower cable-stayed bridge in the world.

High containment level and a lightweight structure were key factors for its selection. MDS barrier is going to be installed along multiple driving lanes for over 2,573 linear metres.

This steel barrier for bridges has been tested at the TÜV site in Germany under TB11 and TB51 crash test conditions, certified as compliant to European Standard EN1317 containment level H2, and also NCHRP 350 and MASH approved by FHWA as a TL-4 safety device.

Sergard MDS H2 barrier is composed of 6 m or 3 m long sections, made of S235JR sheet steel 2.5 mm thick and hot-dip galvanized in accordance with UNI EN 1461.

The single-barrier sections are constructed with loop connector hinges that, during installation, are vertically aligned to accept a steel connecting pin, which securely locks them together.

At the top, the sections are connected by two splice plates, and at the bottom by a bolt.

An upper steel handrail supported by pedestals on top of the barrier base is an essential component of the Sergard MDS barrier system.

Its role is to interact with an impacting vehicle in a way that it prevents penetration and overriding. The MDS H2 total height is 1.290 mm.

Sergard MDS H2-04 7D N barrier shape has been designed in line with the “original” concrete New Jersey barrier developed in New Jersey, USA.

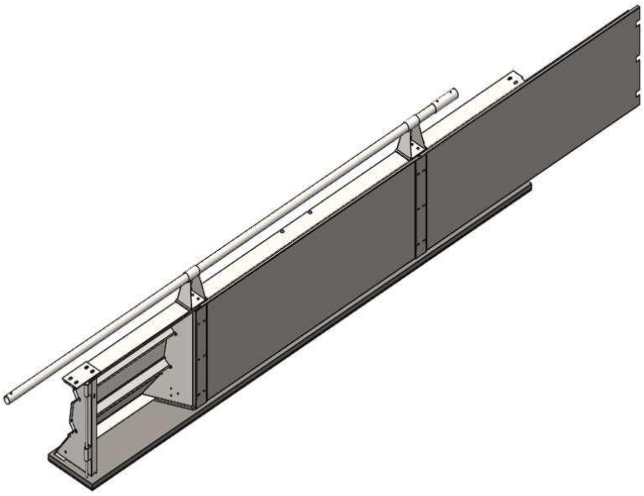


Figure 2: Sergard MDS H2 barrier back view

Figure 3: Sergard MDS H2 barrier front view

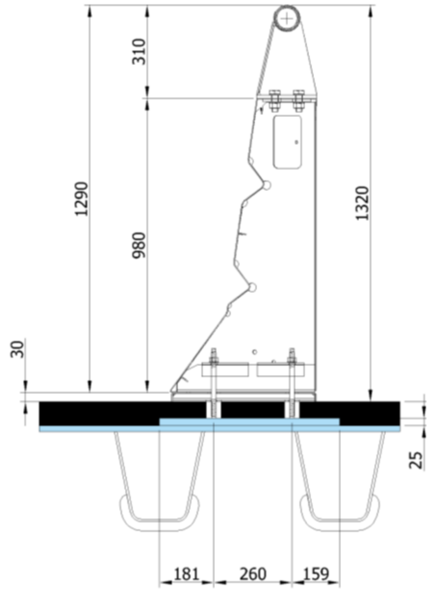
A significant advantage of its shape is the capacity to redirect the colliding vehicle with minimum damage to the vehicle and the barrier itself.

Sergard MDS adds to the above general performance a significant improvement due to the low deceleration imposed on the colliding vehicle and passengers. Crash tests carried out have shown a very low force transmission to the bridge deck structure.

Such a performance is achieved as a result of the synergy between the barrier plasticity and the anchorage system developed specifically for this purpose.

Low forces discharged to the bridge deck are proportional to the barrier's structural capability to deform itself and therefore to absorb an essential part of the crash forces, which leads to a less rigid impact, reduced damage to the vehicle, higher safety for passengers and protection of the bridge deck.

The Danjiang Bridge specifics require special barrier elements to be used to accommodate, for example, traffic sign gantries, to terminate the barrier row, to install barriers of varying lengths and special shapes, or to attach guardrails and concrete barriers to the MDS H2 system.



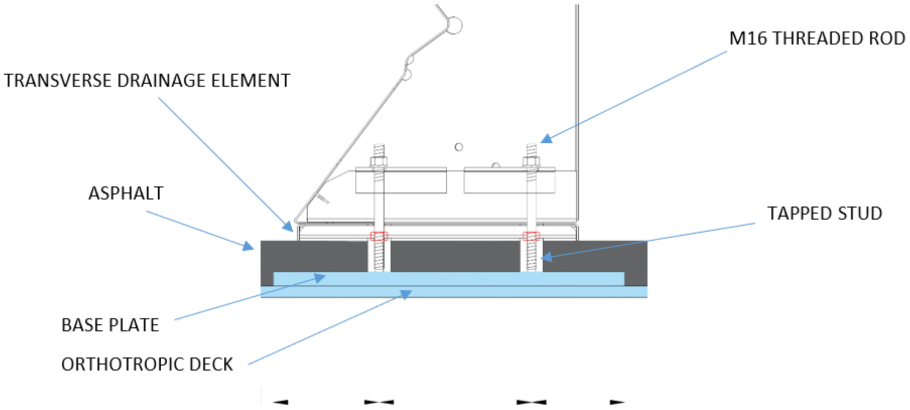


Figure 4: Sergard MDS H2 barrier section and anchorage detail

Long bridges need several expansion joints to connect single construction segments. To allow for larger movements in the longitudinal direction of the carriageway, MDS is supplying eight customised expansion joint barriers with variable length, designed to expand or contract following the bridge joint movements as they open or close due to temperature changes.

The sliding mechanism assembly of plates, brackets, and forks works together with the handrail sleeve.

MDS expansion joint barriers are installed at a preset position, with the expansion/contraction movement of +/- 350 mm allowed by the longitudinal slotted holes.

The traffic plan provides a lane dedicated to scooters. Here, the MDS H2 barriers offer protection not only on the front side but also on the rear side, equipped with accessory back panels made of aluminium alloy AW 5754, creating a closed box continuous surface for major safety.

To prevent the rain from accumulating on the bridge deck, optional transverse drainage elements are placed underneath the barrier modules, creating a 30 mm free gap to allow for the water to flow away from the road surface. Sergard MDS platform drainage system, allows water to drain without affecting the safety performance.

Sergard MDS modular barrier can be replaced after a statistically rare heavy accident with ease.

In a typical car collision, the barrier reacts within the “elastic field”, and replacement or repair is not required for either the barrier or the deck.

Even a severely damaged barrier still offers substantial protection to the traffic before it can be replaced.

The main advantages of using the Sergard MDS H2 barrier for the Danjiang Bridge are:

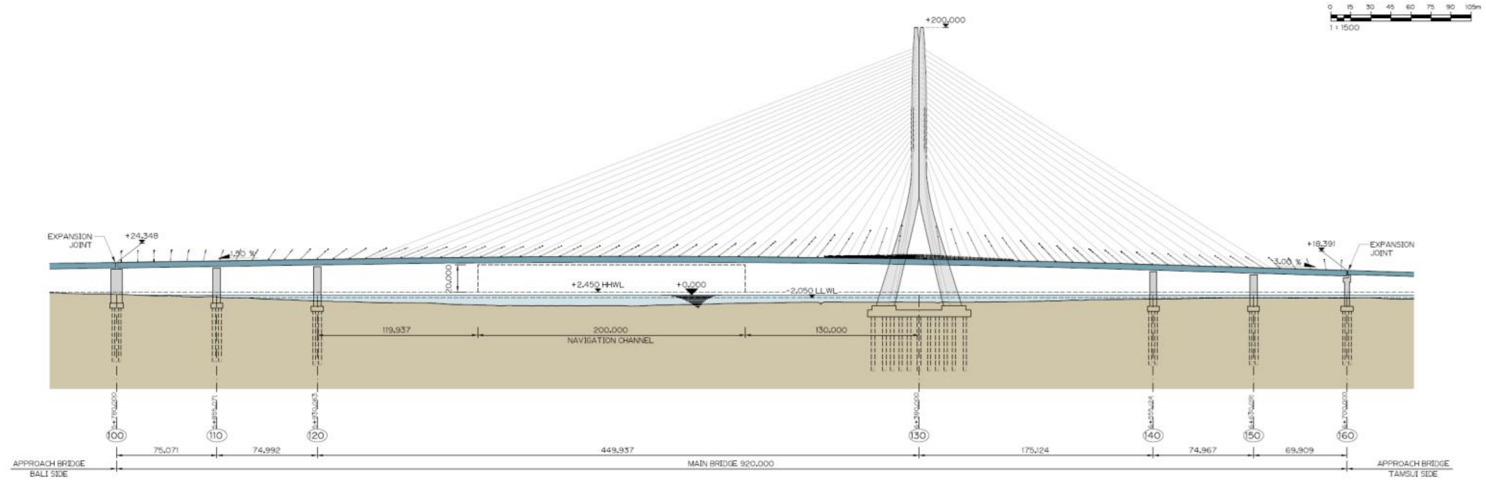
- Lightweight of 58,5 kg/m
- Modular preassembled sections for easy and quick installation
- High performance
- Long durability
- Cost saving
- Working width W3
- High-impact energy absorption and dissipation
- Transverse plates for deck drainage
- Easy to replace and repair
- Motorcyclists friendly
- CE marked and FHWA approved

Based on the experience, except for the above situations, MDS H2 barriers once installed do not require repair or maintenance for at least forty years.

Figure 5: Sergard MDS H2 barrier back view (USA)

Figure 6: Sergard MDS H2 barrier front view (Austria)

DRAWINGS



LONGITUDINAL VIEW
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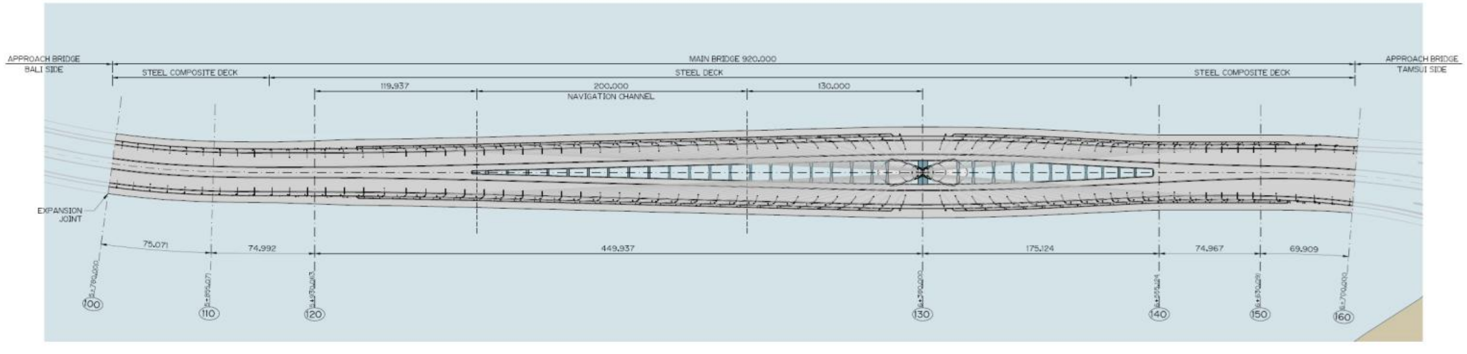

TOP VIEW
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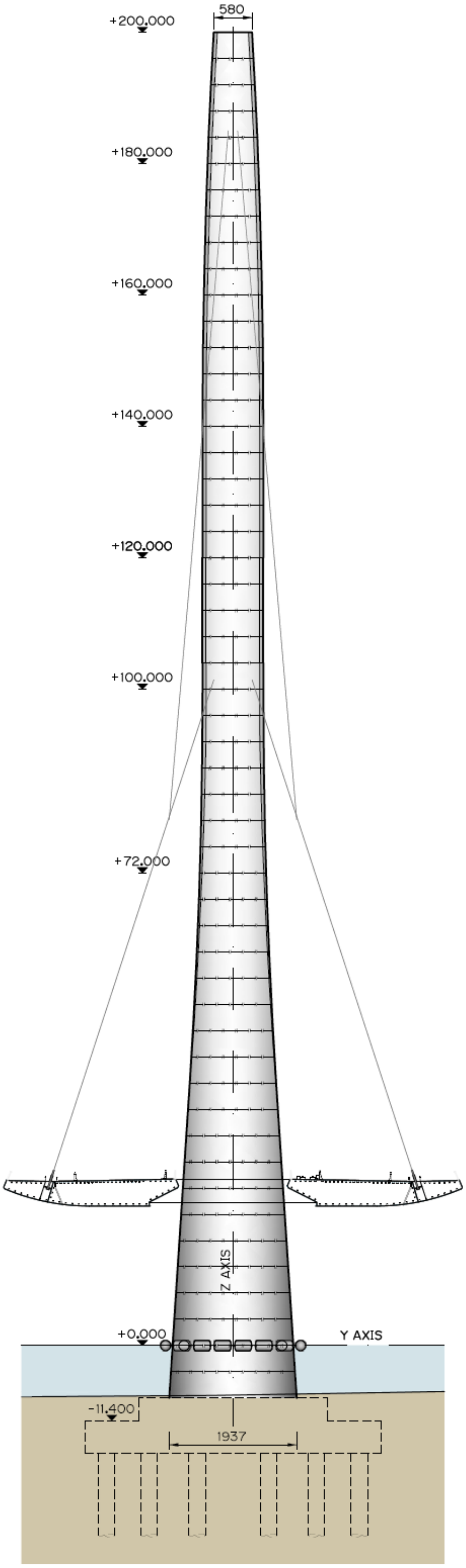
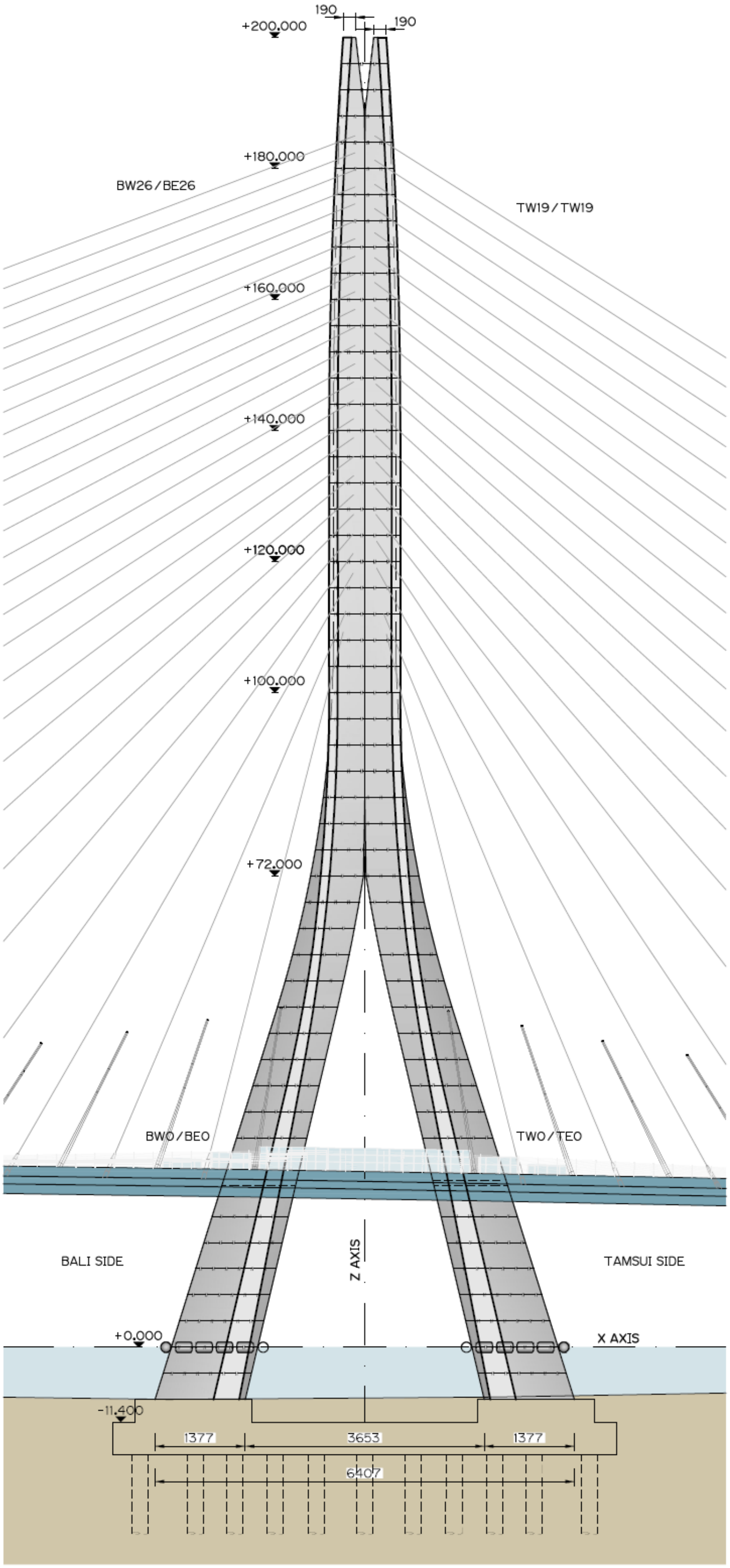
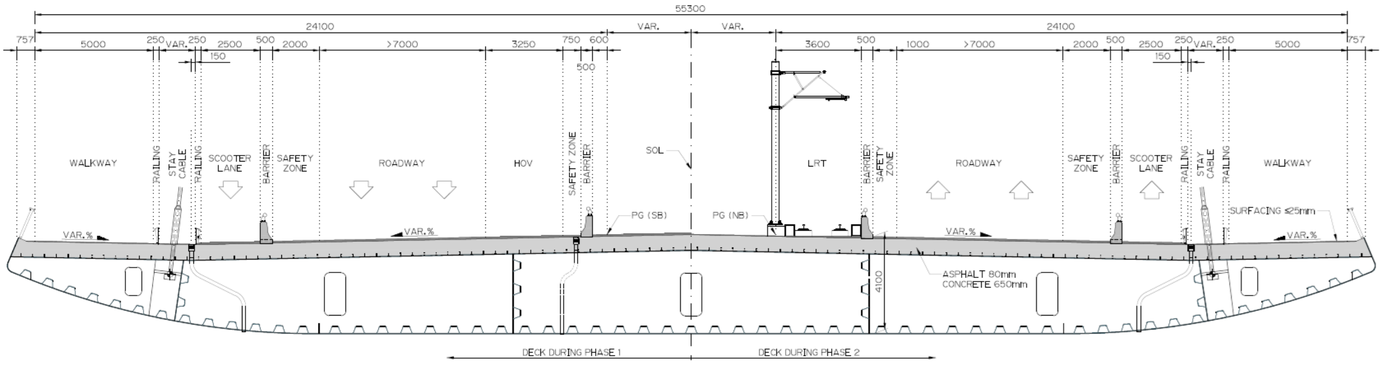


FRONT VIEW
1:500

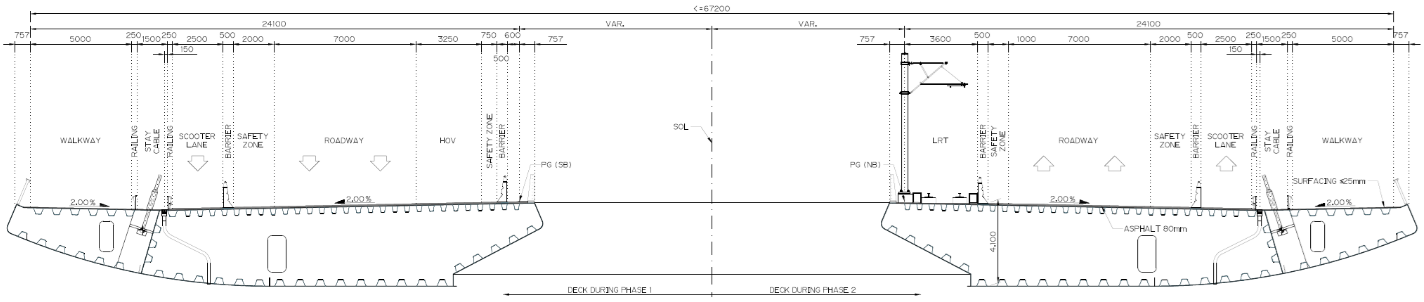


LATERAL VIEW
1:500



SINGLE DECK TAMSUI SIDE

1:100



TYPICAL TWIN DECK

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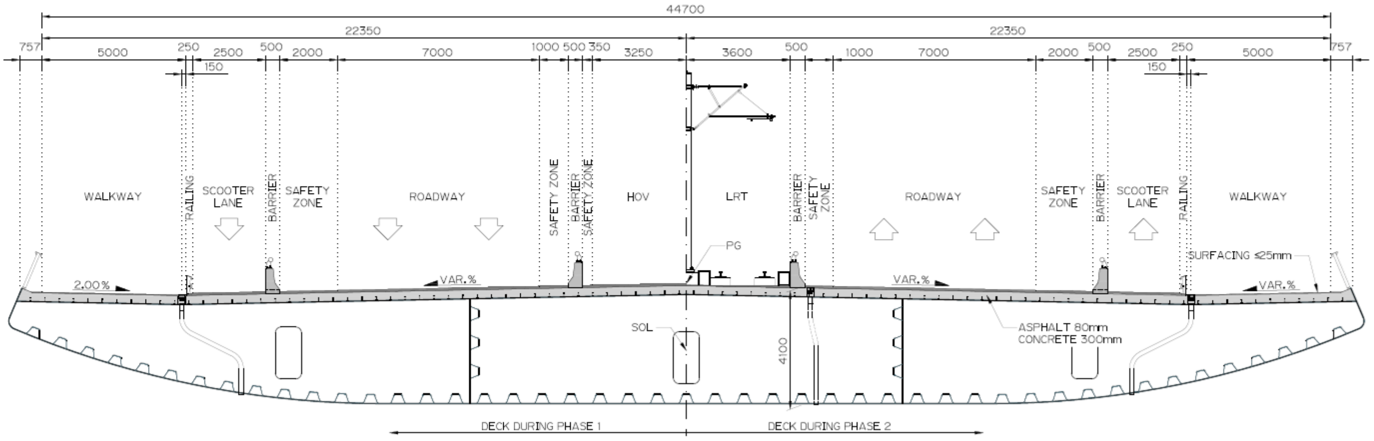

SINGLE COMPOSITE DECK BALI SIDE

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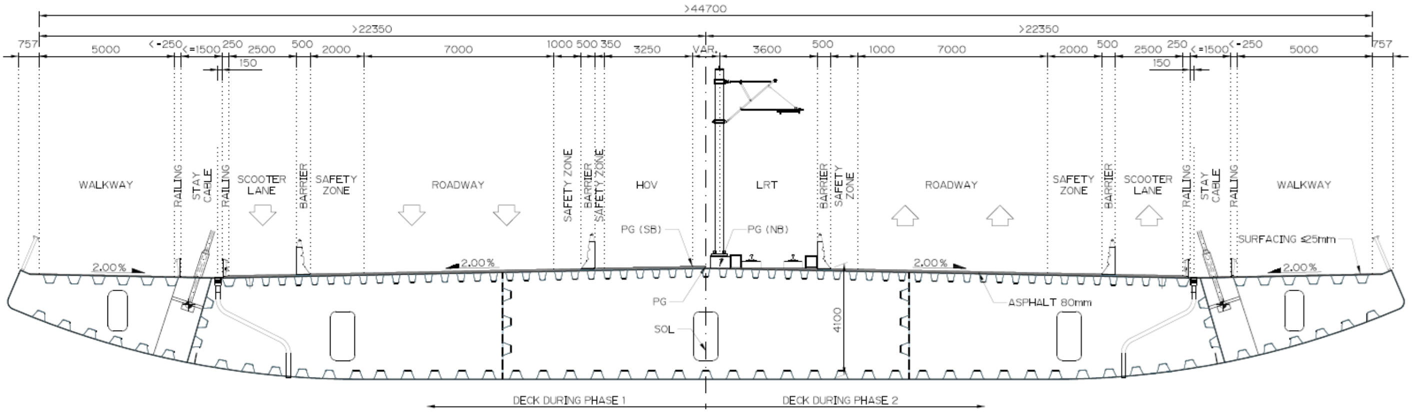

SINGLE STEEL DECK BALI SIDE

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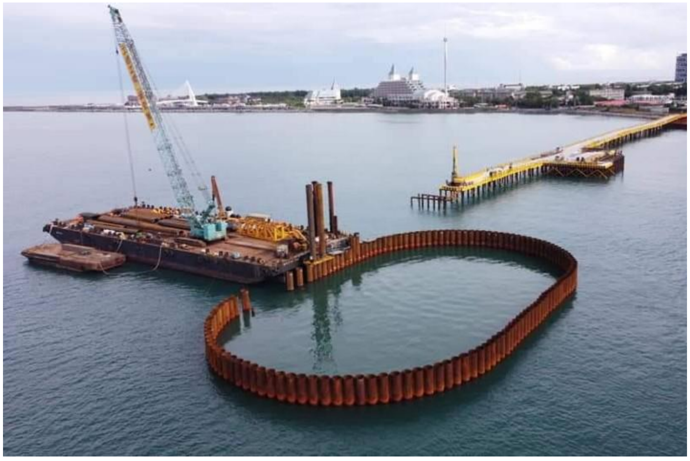
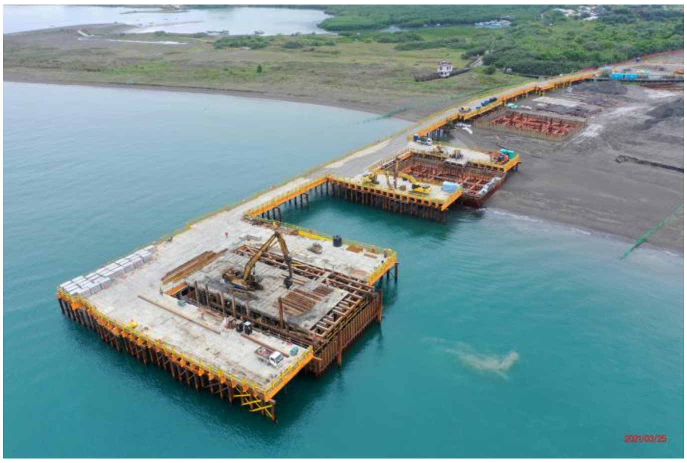
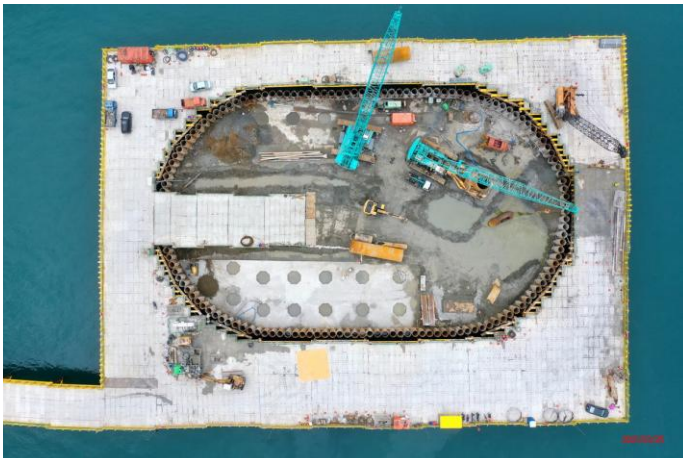
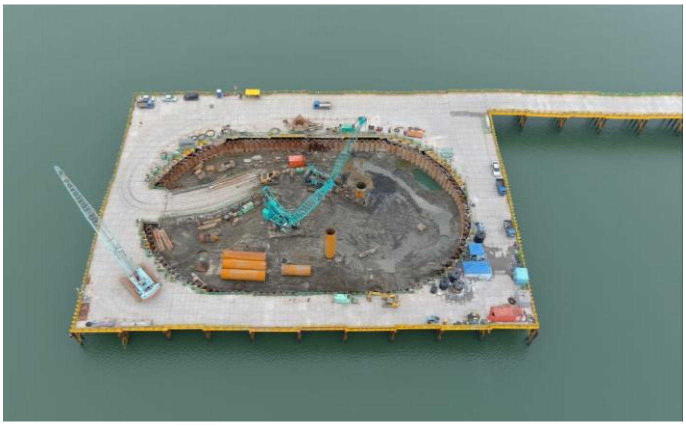
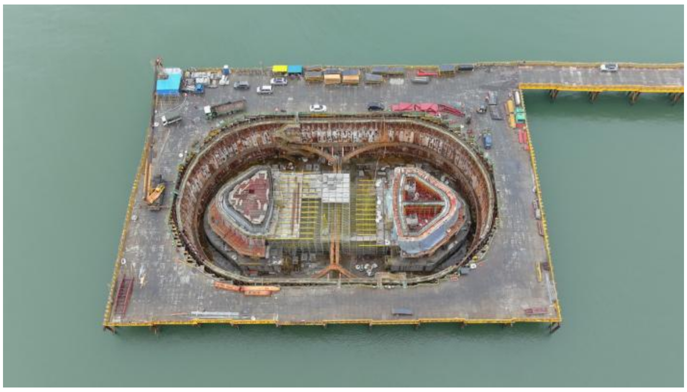
CONSTRUCTION GALLERY

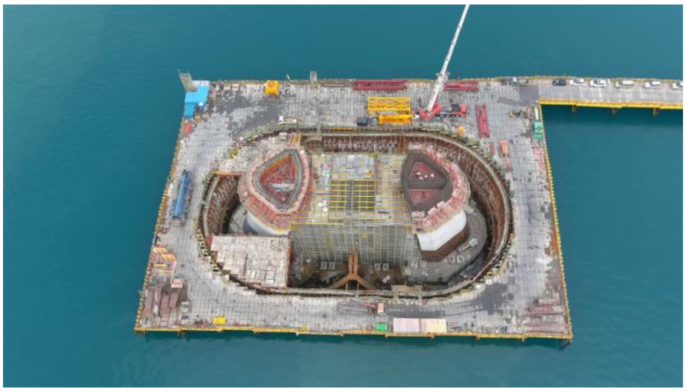


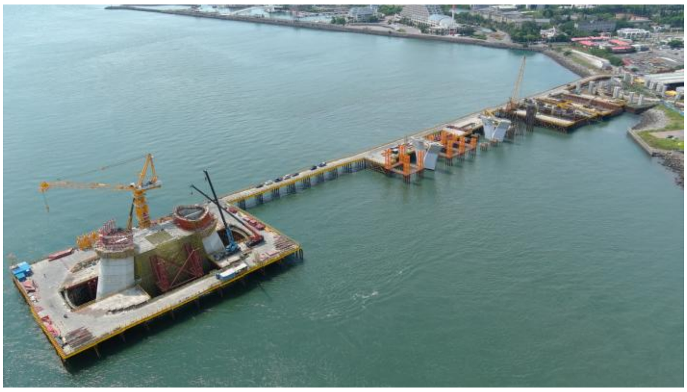


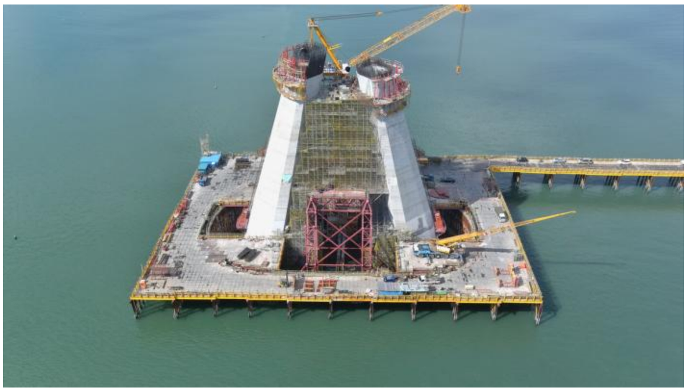


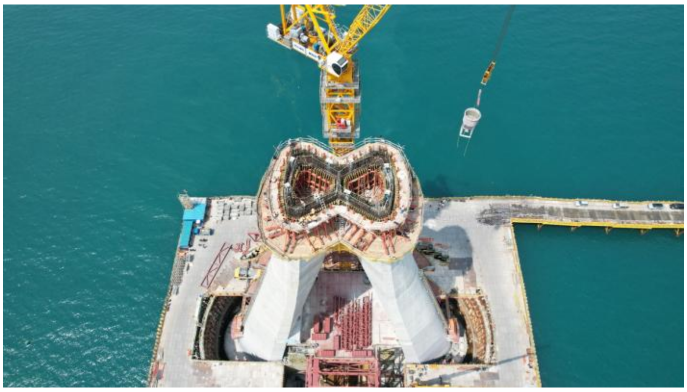












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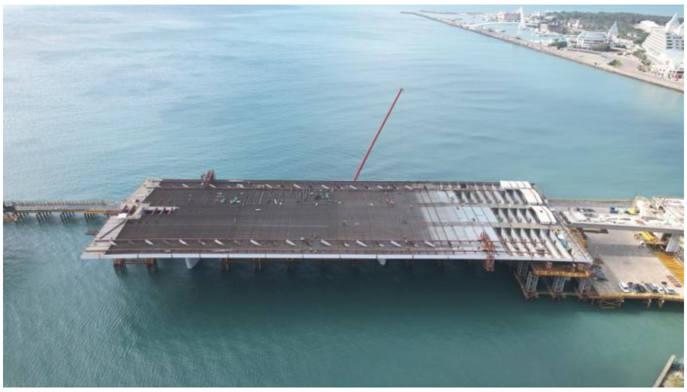

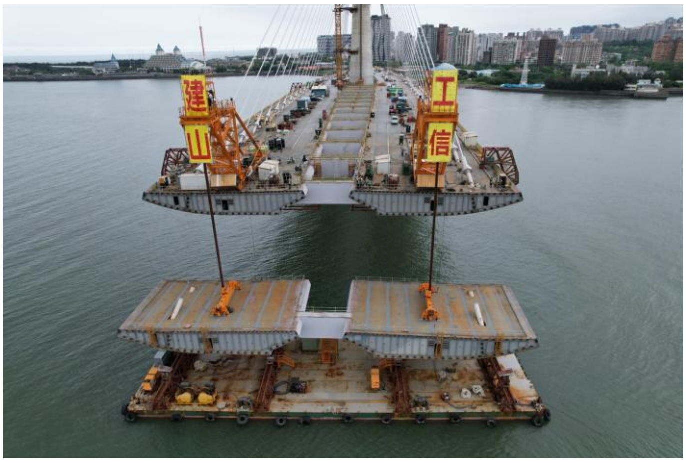
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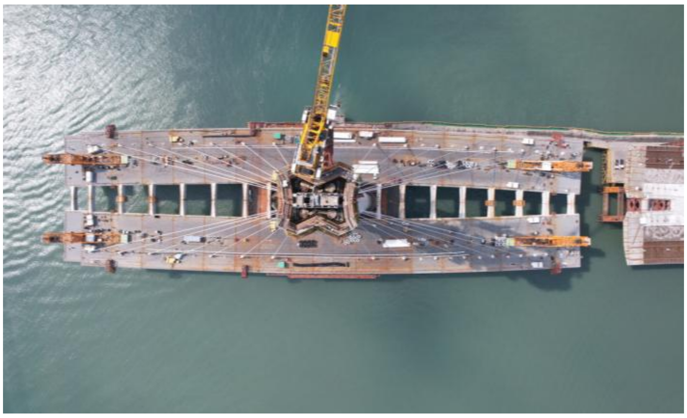

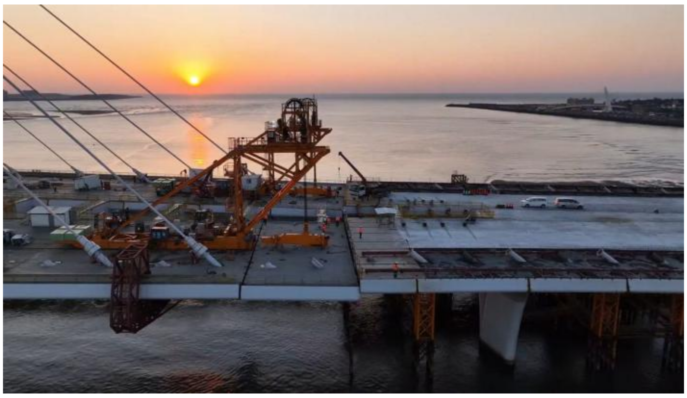

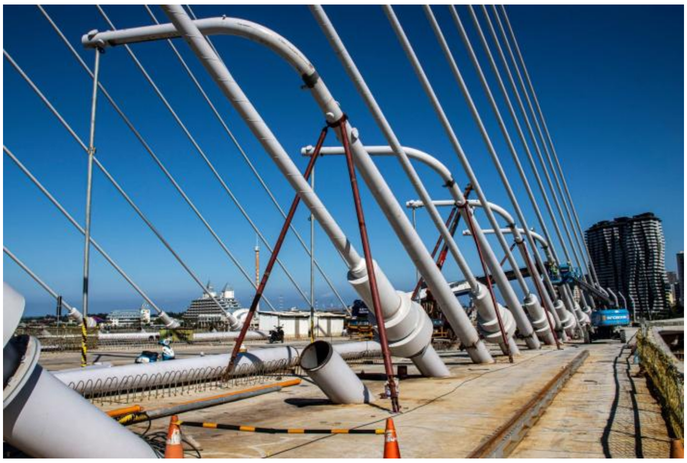

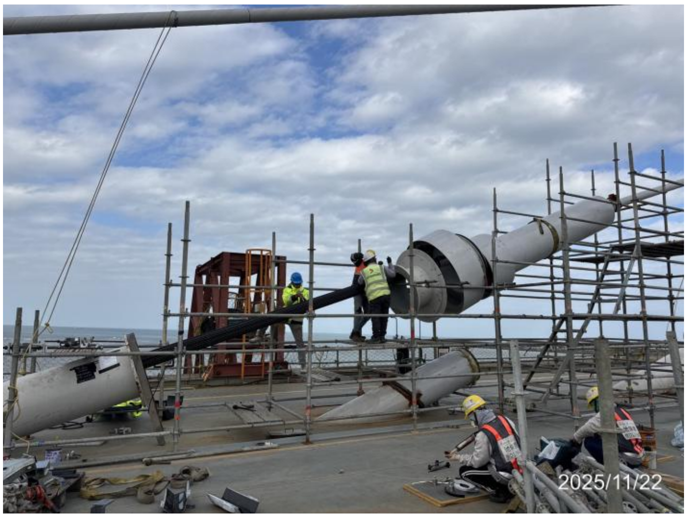

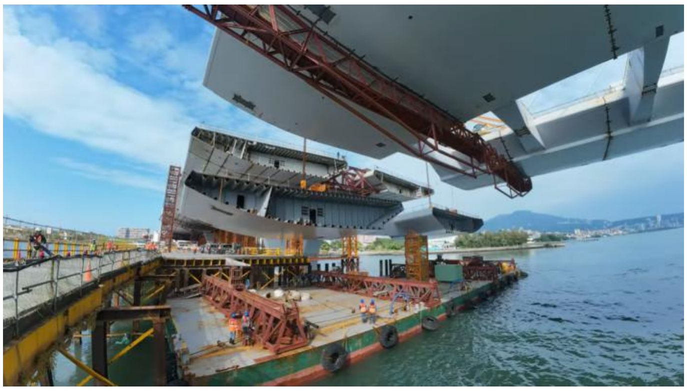

Video: Back span closure

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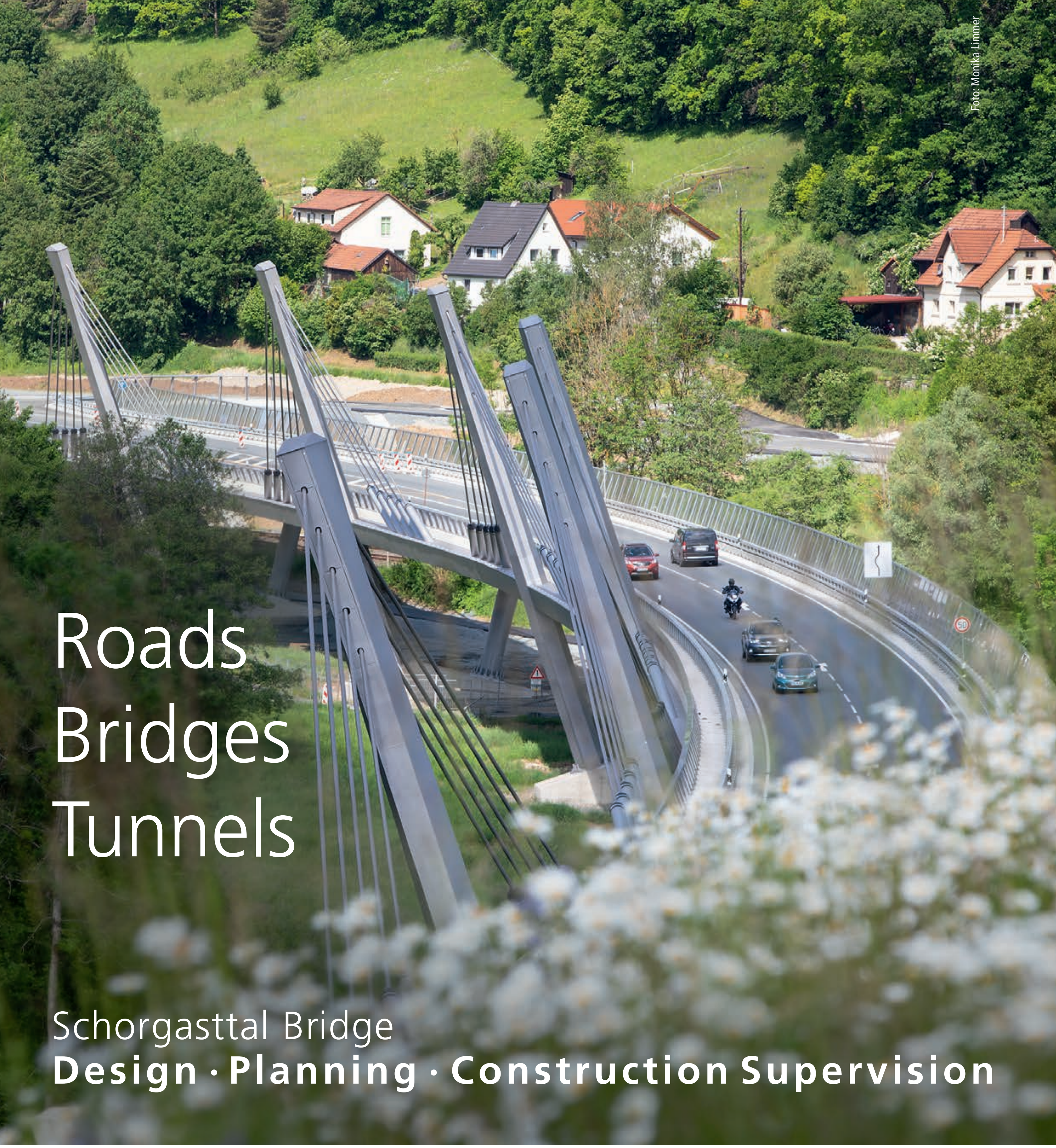
Everything we do today, makes for a safer tomorrow.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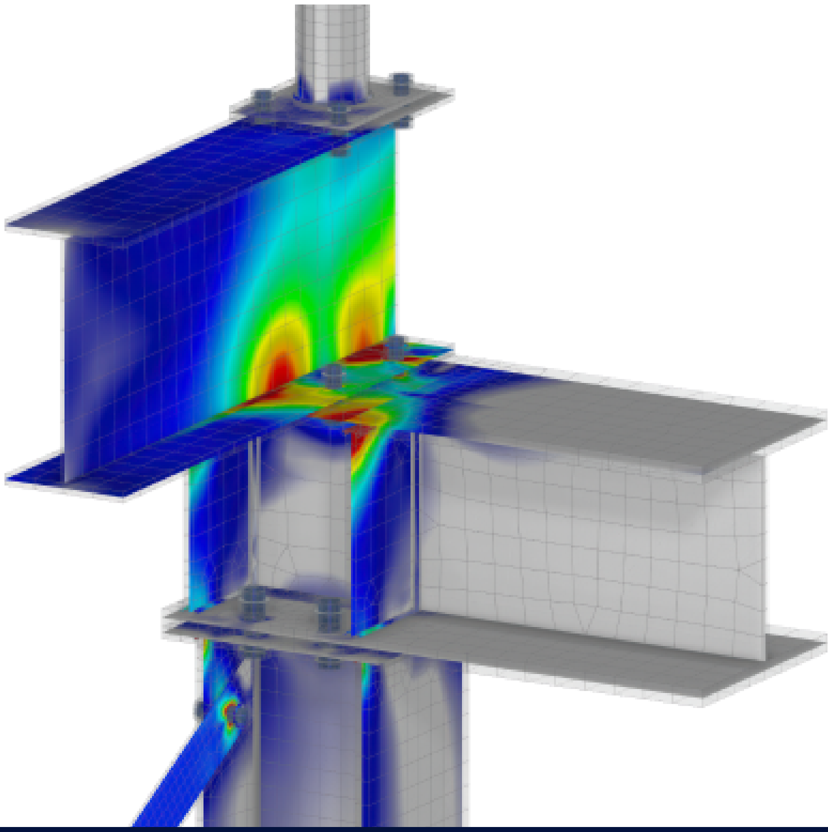
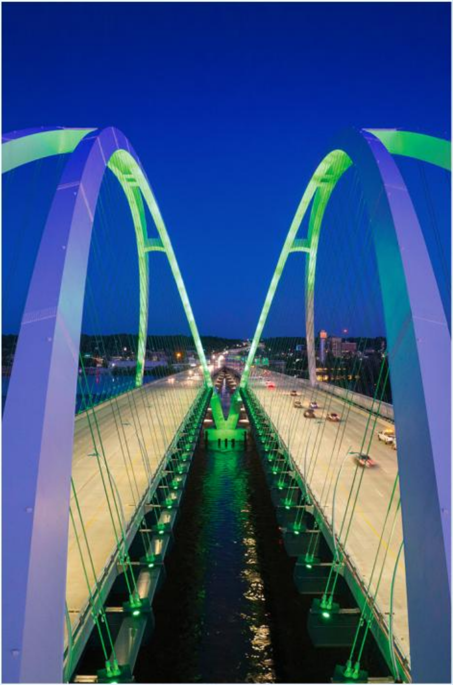
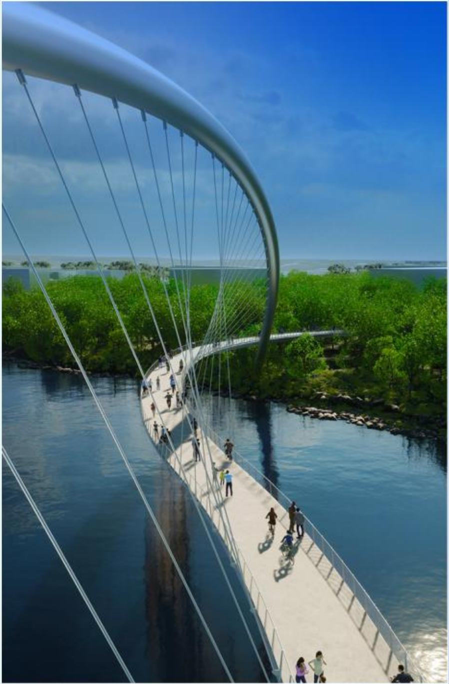
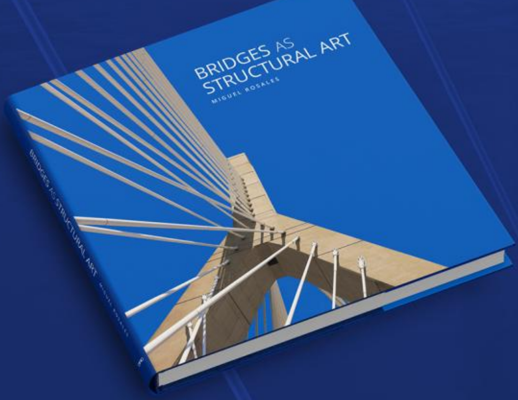


Temburong Bridge, Brunei © Arup



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Scope of application:
The installation of the MAURER Swivel Joist Expansion Joint shall allow access to and protect the bridge deck from horizontal over load during a seismic event.

Features:

- Unrestrained absorption of specified movements and simultaneous transmission of traffic loads
- Serviceability of the structure after the earthquake
- Protection of the bridge deck from horizontal overload caused by extreme closing movements during the earthquake
- High life time expectation through use of high performance components
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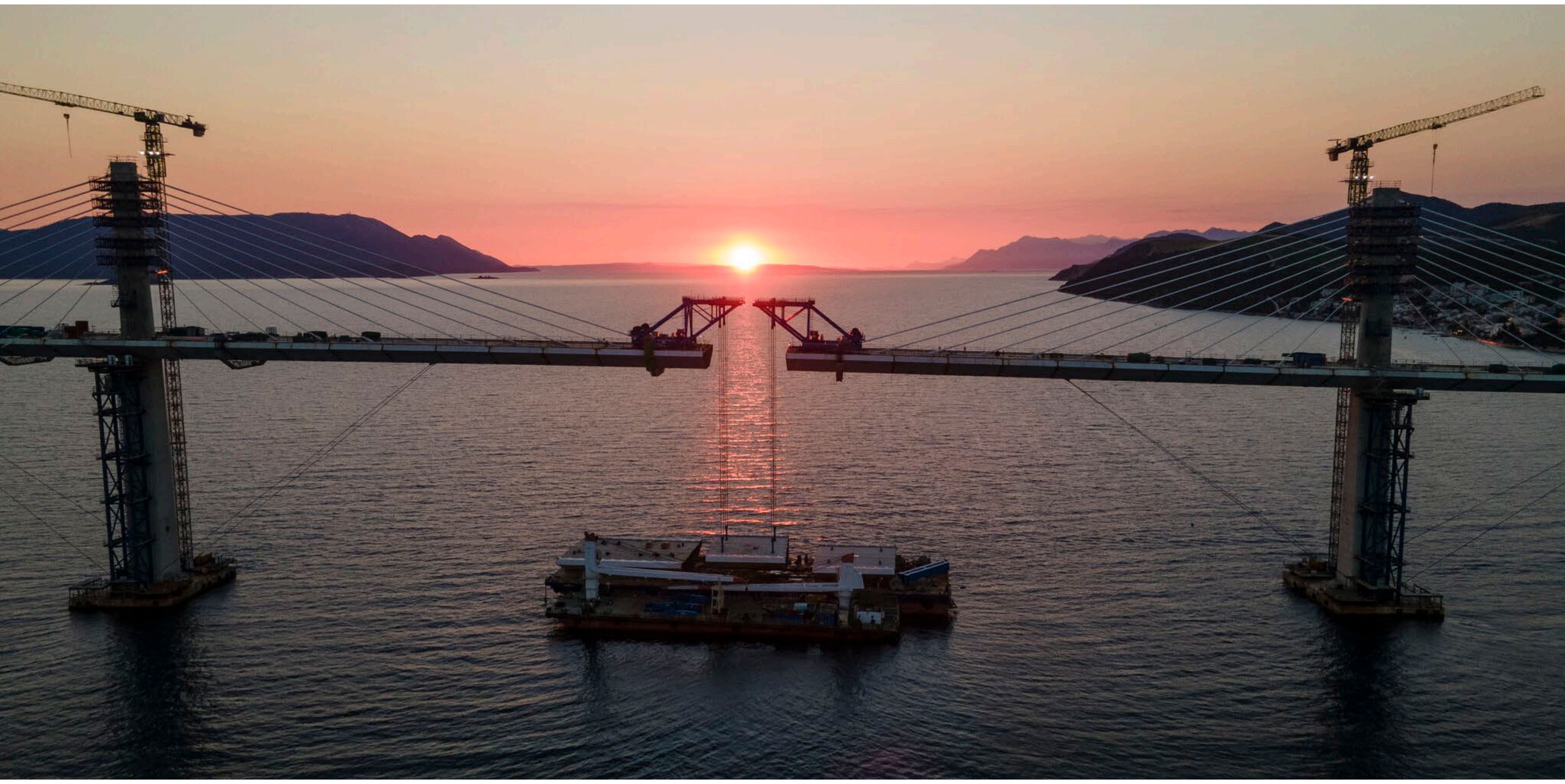
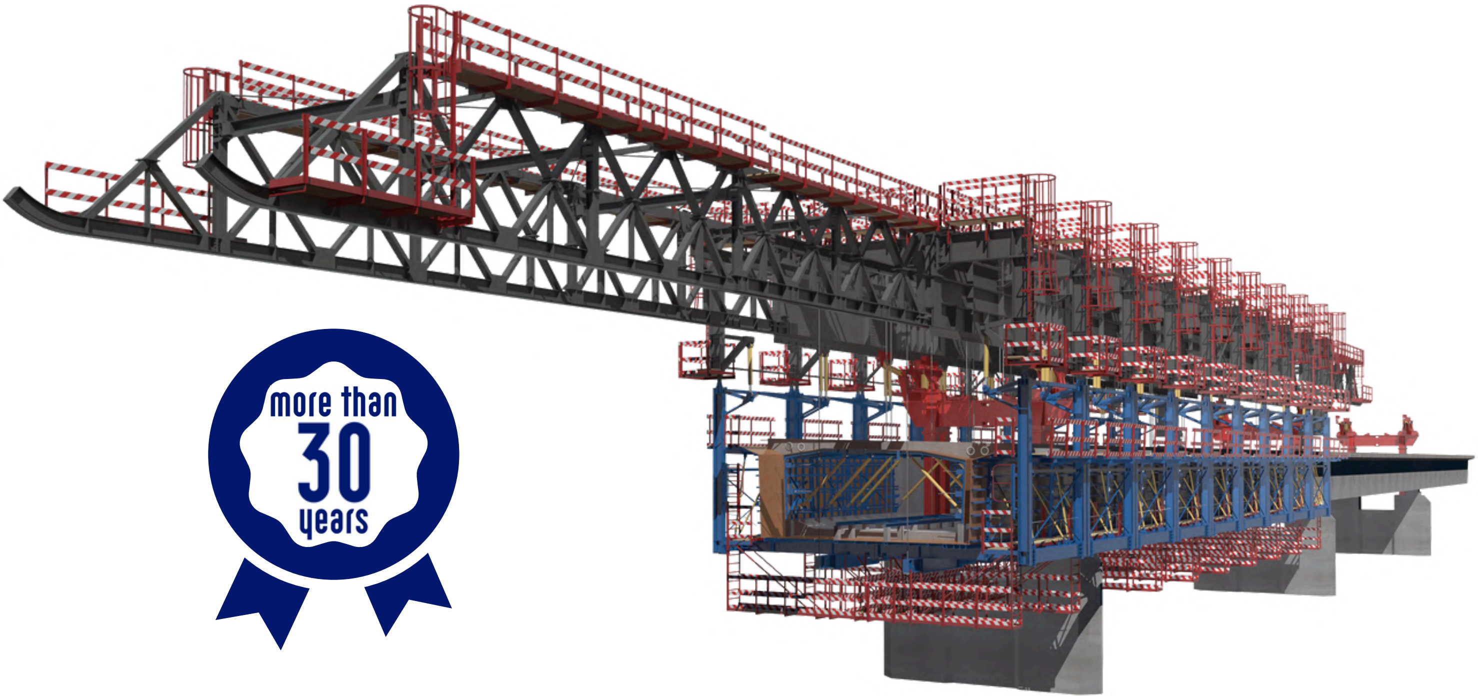
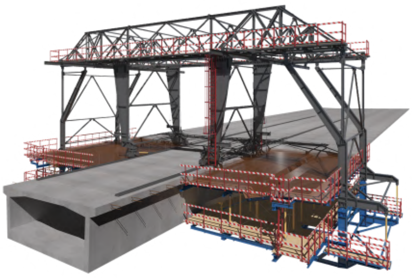
- Service velocity up to 20 mm/sec (10 times higher than for a regular bridge)
- Watertight across the bridge width
- Maintenance free

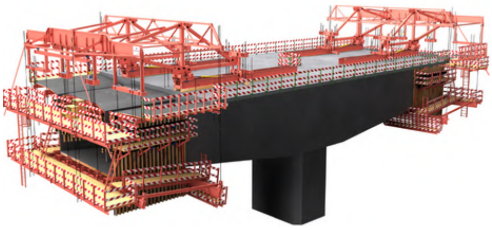
References:

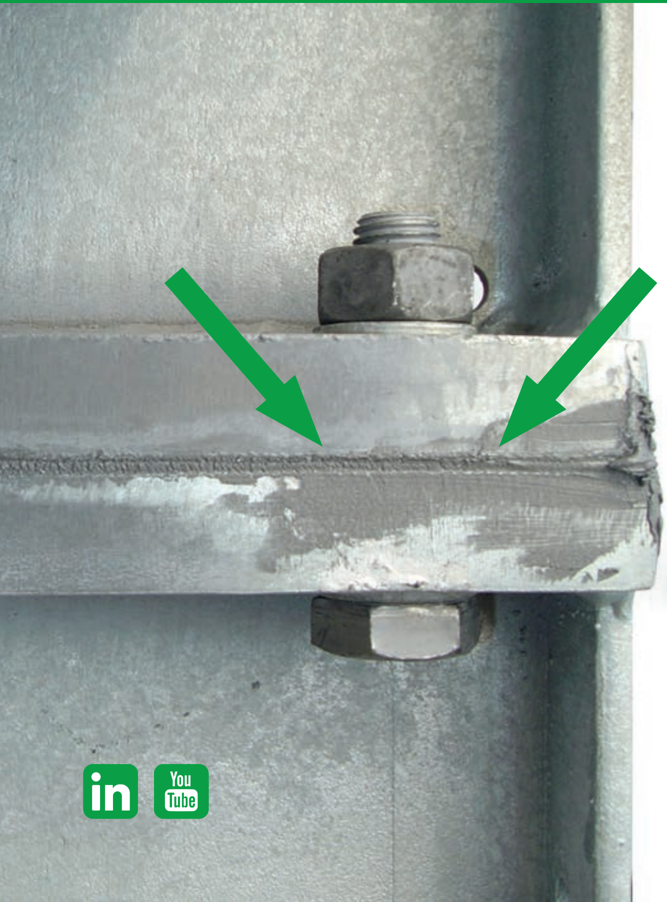
- Bahia de Cadiz, Spain
- Hochmoselübergang, Germany
- Osman Gazi Bridge, Izmit, Turkey
- Mainbrücke Randersacker, Germany
- Millau Viaduct, France
- Rheinbrücke Schierstein, Germany
- Rion Antirion, Greece
- Russky Island Bridge, Vladivostok, Russia
- Tsing Ma, China












DIAMANT POLYMER SOLUTIONS
MM1018
Putty - Component A
#1436A
MM1018
Putty - Component B
#1436B
GERMAN GENERAL BUILDING
AbZ
APPROVAL

Helgeland Bridge, Norway

Photo : Jules van den Doel

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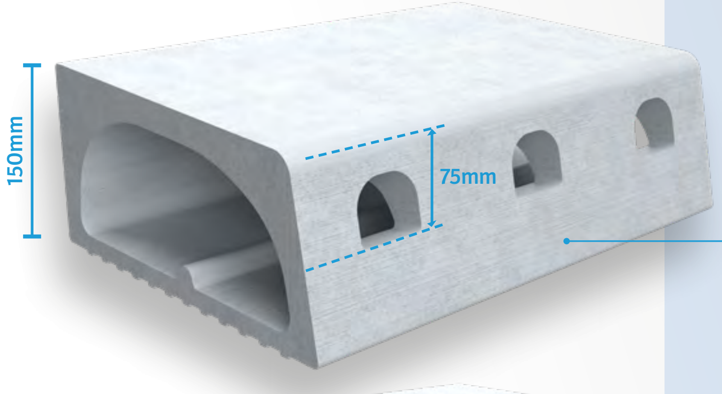
Strong
Connections

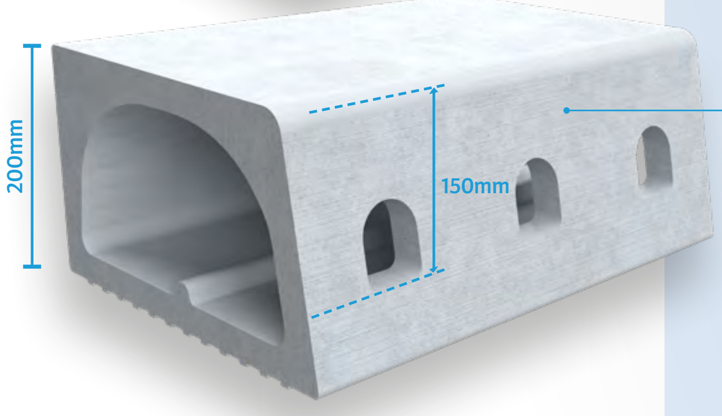
BRIDGE DRAINAGE

Suitable for
75 and 150 mm
Kerb height and
all heights in
between

BRIDGE DRAINAGE UNIT

The bridge drainage channel Type M is designed to collect and discharge surface and structural water from bridges and elevated roads, used by all types of road vehicles.





AVAILABLE HEIGHT OPTIONS

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%
(according to BAST guideline Kap12)

TECHNICAL FEATURES AND ADVANTAGES

The bridge drain elements are made of one material and are moulded monolithically. In other words, they are manufactured in one piece, which ensures a stable structure with high impact resistance.

CUSTOM SOLUTIONS

We specialize in customization. Depending on your requirements, we determine which element best fits your project. We can utilize various production locations, material types, and manufacturing methods to meet your schedule and needs.

CLICK HERE
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American Icon

San Francisco-Oakland Bay Bridge East Span

TYLin

Photo Credit: Thomas Heinser

Bridges to Prosperity

We envision a world where poverty caused by rural isolation no longer exists.

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Each partnership creates a unique experience that promotes teamwork and cross-cultural exchange for our volunteers. Through employee engagement, recruitment and retention, leadership, business development, and marketing, our corporate partners gain a strong return on investment.

Together, we can build more than a bridge; we can build a pathway out of poverty.

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Engineers
in Action

Bridging COMMUNITIES

We Connect Students, Industry Partners, and Communities Through Collaborative **Bridge Building** and **WASH Projects**.

Isolation caused by impassable rivers is a root source of poverty all over the world. Fueled by the passion of University Students, our Industry Partners, and the wisdom of our Local Partners, we build footbridges with isolated communities to ensure they have year-round safe access to essential resources such as education, healthcare, and markets.

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ISSUE 04/2025 DECEMBER