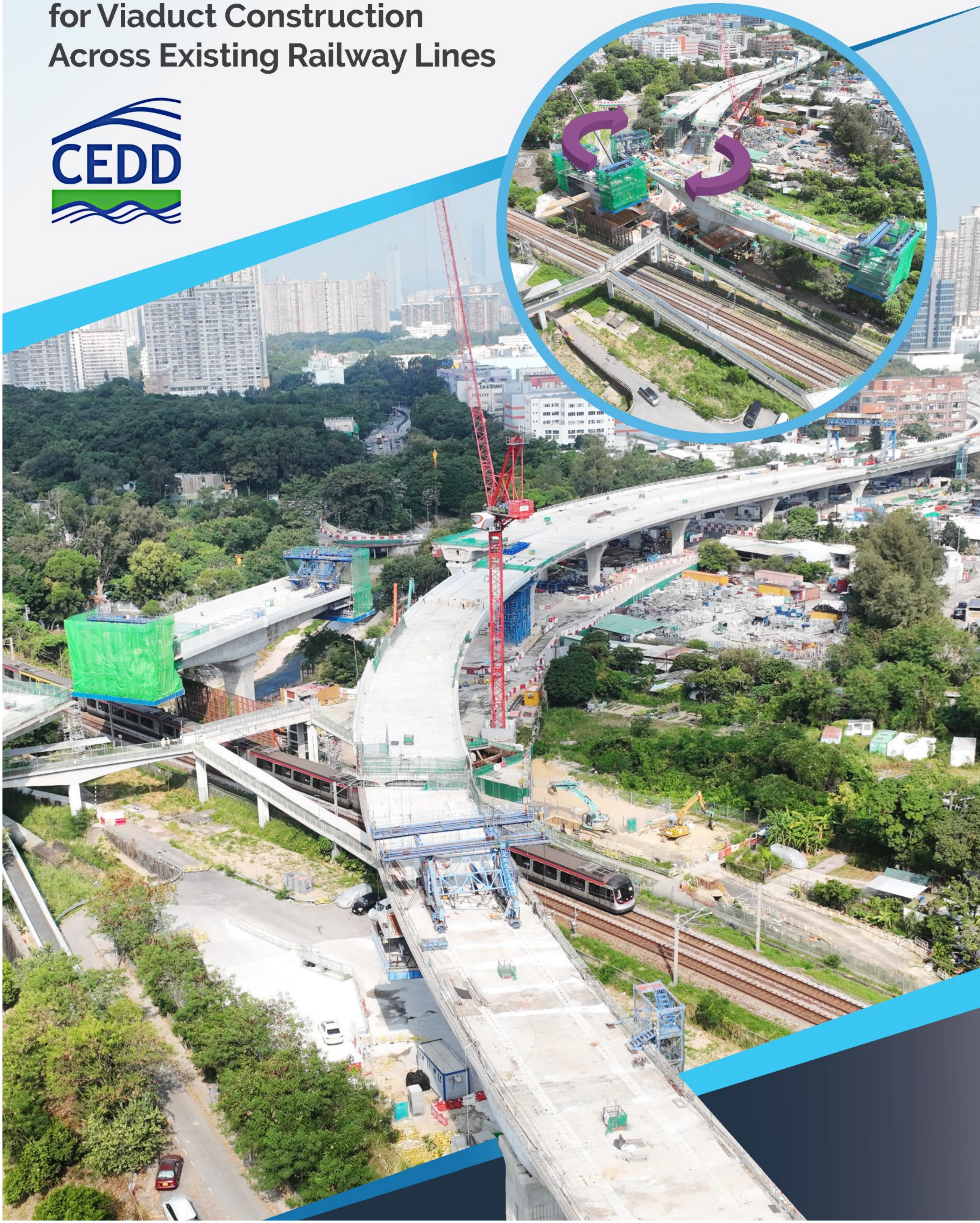
Practice Notes on

Horizontal Bridge Rotation Method

for Viaduct Construction Across Existing Railway Lines

CEDD



Preface

The successful adoption of the "Horizontal Bridge Rotation Method" (HBRM) in the Fanling Bypass Eastern Section project across the East Rail Line represents a significant advancement in bridge construction technology, showcasing how cutting-edge innovative engineering technologies / practices and stringent construction protocols of Mainland and Hong Kong could be synergistically integrated to achieve outstanding results.

I would like to commend the project team for making tremendous efforts in introducing and adapting the Mainland's bridge rotation technology to effectively overcome Hong Kong's complex site constraints, including the presence of the railway line, large-diameter water mains, high-voltage power lines, limited working space, and restricted time slots in midnight after train service hours. The expertise and innovative application of this technology were pivotal in mitigating safety risks above the railway line, ensuring the protection of both railway operations and surrounding communities.

I would also like to express my sincere appreciation for the exemplary spirit of collaboration between the project team and the MTR Corporation Limited (MTR), which was critical to the success of this innovative method. The adoption of this innovative method has not only enhanced construction safety, but also improved programme and cost efficiency, resulting in significant time and cost savings.

As always, CEDD aims to foster innovation and collaboration for driving the delivery of resilient, safe, and sustainable infrastructure in Hong Kong. This document summarises our successful experience in HBRM and is intended to serve as a useful reference for engineers, contractors, and stakeholders planning to adopt HBRM in the construction of viaducts, in particular, across existing railway lines.

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Disclaimer

This Practice Notes is intended solely for informational and experience sharing purposes. They should not be regarded as a mandatory handbook or comprehensive set of procedures. It does not constitute part of the official contractual documentation or mandatory requirements. Users are advised to consult the relevant standards, regulations, and contractual provisions applicable to their specific projects. CEDD assumes no liability for any actions taken or decisions made based on this Practice Notes.

Acknowledgment

CEDD, in partnership with MTR, has successfully applied the ground-breaking Horizontal Bridge Rotation Method in the Fanling Bypass Eastern Section project. CEDD sincerely appreciates MTR for their invaluable insights, unwavering support, and active collaboration, all of which were vital in pioneering the adoption of this innovative approach over existing railway infrastructure.

CEDD also extend heartfelt thanks to AECOM Asia Co. Ltd., the project consultant; the CRCC – Paul Y. Joint Venture, the main contractor; and their dedicated subcontractors, including YWL Engineering Ltd., China Railway 15th Bureau Group, CSSC Sunrui, and Wuhan Tebridge Engineering Consulting. Their expertise in deploying advanced construction techniques and digital technologies was crucial in overcoming the project's challenges. Lastly, we acknowledge the invaluable contributions of all project stakeholders whose collective efforts have been essential to the success of this initiative.

Executive Summary

The FLBP is a crucial part of the strategy to improve connectivity between the Fanling North New Development Area and the existing highway network. The main challenge was to construct two sections of viaduct above the existing MTR East Rail Line while ensuring the railway remained operational without interruptions. Traditional construction methods were unsuitable due to site-specific constraints, including safety risks associated with the active railway, major utilities, limited workspace, proximity to residential areas, and seasonal typhoon threats.

To address these challenges, the project team adopted the Horizontal Bridge Rotation Method (HBRM). This involved construction of two T-shaped bridge segments parallel to the railway and then rotating them into their final position in two nights. This approach provided several benefits: it significantly reduced risks to the railway, minimized disruptions to train services and nearby residents, and allowed construction to proceed during normal daytime hours which the railway service is still operational.

The success of the project depended on careful planning, detailed structural design, and temporary works engineering. The bridge segments were designed as long-span, pre-stressed concrete units with curved alignments to navigate existing site constraints while maintaining structural integrity. The design process incorporated safety standards such as the Ultimate Limit State (ULS) and Serviceability Limit State (SLS), ensuring the long-term durability and reliable performance of the viaduct.

One of the most critical features was the custom-engineered rotation mechanism, designed to ensure safe and precisely controlled movement. The bridge segments were supported throughout rotation by high-capacity spherical bearings made of structural steel, coupled with more than a thousand PTFE sliding pads to enable smooth, friction-managed motion. Structural stability was reinforced by stanchions strategically distributed around the perimeter sliding track. To initiate the rotation, hydraulic strand jacks applied controlled traction forces to bundles of steel strands embedded in and encircling the turntable's periphery.

The installation, monitoring, and removal of temporary works were guided by detailed plans to minimize safety risks and environmental impact. Load sensors and real-time data monitoring enabled continuous supervision of load transfers, allowing the team to make proactive adjustments and ensure performance standards were maintained.

With safety as the paramount guiding principle, strict protocols were implemented and reinforced through regular drills to protect personnel, railway operations, and the surrounding environment. This rigorous safety management contributed to the successful project completion, validating the effectiveness of the HBRM approach.

Overall, the FLBP project highlights the importance of innovative thinking and strong collaboration among engineers and stakeholders in overcoming construction challenges. The successful application of HBRM offers a valuable model for future projects, supporting more sustainable and efficient construction practices. Integral to this success was the collaboration with MTR. Their invaluable expertise, stringent safety oversight, and close involvement in planning and execution were crucial in navigating the railway environment and ensuring minimal disruption to train operations, demonstrating a shared commitment to a safe and efficient outcome.

List of Abbreviation

- **ADMS** - Automatic Deformation Monitoring System
- **Al** - Artificial Intelligence
- **BUGN** - Business Unit General Notice
- **CA** - Corporate Affairs
- **CEDD** - Civil Engineering and Development Department
- **CG** - Center of Gravity
- **DEVB TC(W)** - Development Bureau Technical Circular (Works)
- **EAL** - East Rail Line
- **EDoc** - Engineering Document
- **EQU -** Equilibrium
- **FLBP** - Fanling Bypass Eastern Section
- **GEO -** Geotechnical
- **HBRM** - Horizontal Bridge Rotation Method
- **HyD** – Highways Department
- **LIDAR** - Light Detection and Ranging
- **MTR** - MTR Corporation Limited
- **NTH** - Non-Traffic Hours
- **OPHL** - Operational Project Hazard Log
- **PR** - Public Relations
- **PRU** - Public Relation Unit
- **PTFE** – Polytetrafluoroethylene
- **RP** - Railway Protection
- **RCAC** - Risk Control and Analysis Committee
- **SB** - Security Bureau
- **SDMHR** - Structural Design Manual for Highways and Railways
- **SLS** - Serviceability Limit State
- **STR** - Structural
- **S.W.L** - Safe Working Load
- **ULS** - Ultimate Limit State

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1. Objective of Practice Notes

The objective of this Practice Notes is to provide comprehensive guidelines for application of the Horizontal Bridge Rotation Method (HBRM) in the construction of viaducts spanning existing MTR lines in Hong Kong. This innovative method, designed to effectively minimise construction risks to railway operations, was first introduced in Hong Kong for the construction of two sections of viaduct of FLBP spanning the existing East Rail Line (EAL) under CEDD Contract No. ND/2019/05, achieving highly successful results.

This Practice Notes summarises key considerations in the planning, design and construction of HBRM, aiming to:

- Promote the adoption of HBRM as a safe and efficient construction method for viaduct spanning existing railway lines.
- Provide a guideline for planning, design, and execution of HBRM.
- Highlight the key challenges associated with bridgework in close proximity to MTR premises and outline specific requirements that must be addressed.

2. Background of Bridge Rotation adopted in FLBP

The entire FLBP comprises a 3.3km long viaduct and 0.7km long underpass, undertaken through two CEDD contracts: ND/2019/04 and ND/2019/05. Contract No. ND/2019/05 includes the construction of 2km-long viaduct between Shung Him Tong and Kau Lung Hang. The viaduct alignment meanders across Ma Wat River and runs through the industrial zones and low-density village residential areas. It spans the EAL and finally connects to the existing Fanling Highway.

ND/2019/05 commenced in March 2020 which adopted the NEC3 ECC Option C Target Cost Contract form. Its launch coincided with the outbreak of the COVID-19 pandemic, during which fluctuating public health directives, limited workforce availability, and evolving operational restrictions posed significant challenges to site productivity and effective coordination with MTR.

2.1 Challenging Site Constraints across the EAL under FLBP

Multiple Site Constraints and Construction Challenges

The construction of viaducts spanning the EAL was the most challenging aspect of the project due to complex site constraints. A convergence of severe spatial, logistical, and safety constraints shaped the complex viaduct alignment required for constructing the long-span D2 and E2 overbridges, which span multiple critical infrastructure elements (**Figure 2.1**), including:

- The EAL – a vital commuter artery;
- A densely packed utility corridor featuring underground public utilities, comprising a group of underground 132kV high voltage cables supplying power to Liangtang/ Heung Yuen Wai Boundary Control Point and four sets of large diameter above-ground Dongjiang water mains (ranging from 1.4m to 2.3m in diameter);
- Existing Ma Wat River;
- An adjacent footbridge structure and village access road.

To avoid conflicts with existing utilities and infrastructure, the bridge spans across EAL at Piers D2-01 and E2-01 were designed as long-span prestressed concrete structures, measuring 100m and 128m respectively. Unlike other precast segmental bridge sections which feature a typical 60m span length and uniform structural depth, these spans were supported by single-cell prestressed concrete box girders featuring a haunched profile to ensure adequate structural capacity.

A balanced cantilever method was adopted in the Contractor's alternative design. The depth of T-span at D2-01 (66m long) varied from 6m to 3m, while T-span E2-01 (136m long) ranged from 7.5m to 3m. The T-span at Pier E2-01 also featured a curved alignment, with a radius of curvature of 340m.

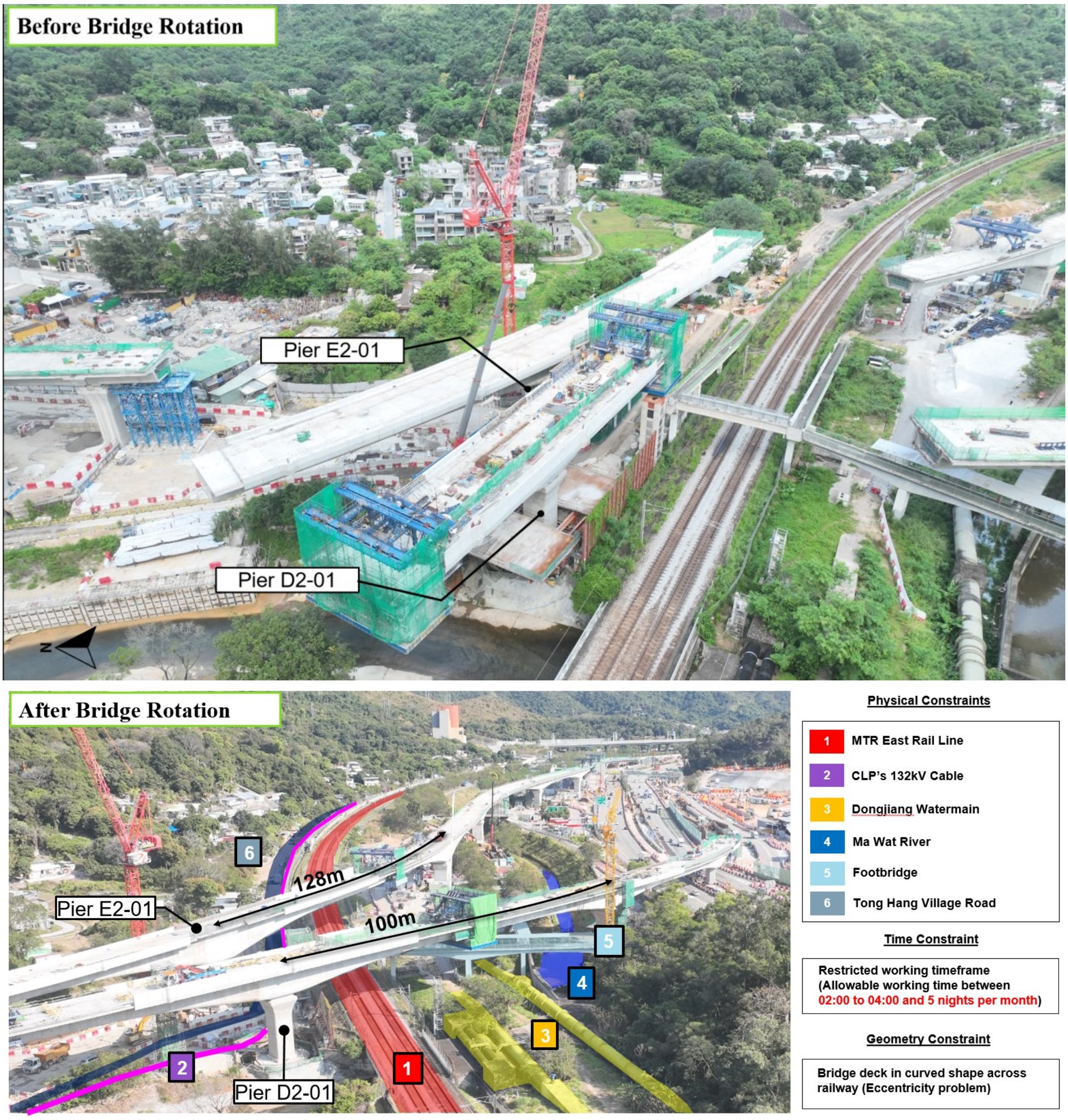


Figure 2.1 - Site Constraints of Bridge Construction

2.2 Selection of Construction Methods

2.2.1 Conventional Methods for Viaduct Construction Across Railways

Due to stringent MTR requirements for work within the Railway Protection Area, bridge superstructures spanning railway lines are typically constructed using precast segments, erected using segment lifters or launching girders, as seen in projects such as the Tuen Mun–Chek Lap Kok Link, Heung Yuen Wai Highway, and Route 8 Ngong Shuen Chau Viaduct.

For local road bridge construction, precast beams with in-situ decks are occasionally used (e.g., Pok Yin Road bridge near Pak Shek Kok). Earlier projects sometimes adopted cast-in-situ methods for deck construction using form-travelers (e.g. Deep Bay Link) or temporary falsework (e.g., Tuen Mun Lung Fu Road flyover across Light Rail Transit and Tsuen Wan Cheung Pei Shan Road Flyover).

Different methods of bridge construction commonly adopted with respect to span length are illustrated in **Figure 2.2**.

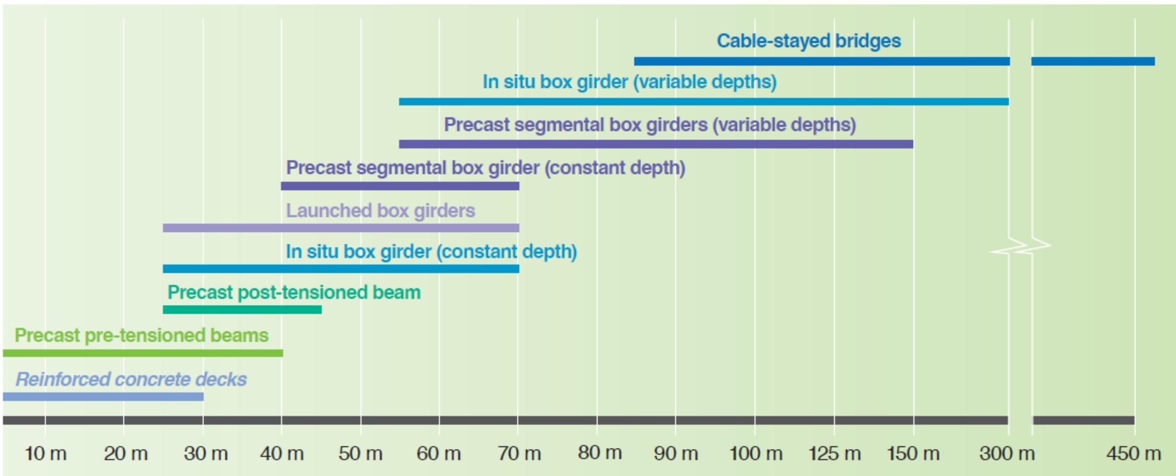


Figure 2.2 - Span ranges for different types of bridge superstructures

[Source: Prestressed Concrete Bridges, 2nd Edition published by ICE, Figure 7.1]

The original construction approach proposed by the contractor for the two viaduct sections spanning the EAL involved the use of segment lifting frames to install precast concrete segments. Due to operational constraints, these activities were limited to designated Non-Traffic Hours (NTH) during the midnight window when train services were halted. Based on maintenance and other works demands, the MTR was anticipated to allocate roughly five NTH per month as a lower bound. Given that the installation of each segment required three separate nights—one for lifting, one for stressing, and one for parapet installation—placing all 40 segments across the two bridge decks would have required a minimum of 120 nights.

As a result, the overall construction timeline was projected to span approximately two years in the worst scenario.

The planning and execution of construction works within the Railway Protection Area must adhere to the requirements stipulated in DEVB TC(W) No. 1/2019**.** Drawing from these guidelines and past project experience, several drawbacks have been identified in using conventional methods for constructing precast segmental bridges over active railway lines:

- The depth and weight of precast segments are constrained by limitations along the transportation route from the precast yard to the installation site.
- Segment erection windows during NTH are both limited and unpredictable, as they must be coordinated around MTR's routine railway maintenance, introducing risks to programme certainty and cost.
- Night-time lifting of heavy segments over live railway tracks poses elevated safety risks to on-site personnel.
- Extensive night works in close proximity to residential areas can lead to significant disturbance to the public.
- A lifting failure during segment installation could cause severe consequences, including service disruption and potential hazards to both workers and the railway system.

2.2.2 Innovative Horizontal Bridge Rotation Method (HBRM)

These challenges were effectively mitigated through the implementation of the HBRM**.** This innovative technique allowed the bridge deck to be constructed using the balanced cantilever method outside the railway protection zone, aligned parallel to the existing railway track, and under normal daytime working conditions. Once the deck was fully constructed in its temporary position, the entire T-shaped span was horizontally rotated into its final alignment during a single midnight operation—dramatically reducing risks to railway operations and minimizing service disruptions.

Compared to conventional construction methods, HBRM offers several key advantages:

- Overcome difficult site constraints and limited working area: The method overcomes difficult site constraints, minimizes the impact on utilities, reduces the workspace needed, and minimizes railway disruptions during construction.
- Minimal Equipment and Simple Operation: The method requires fewer machines and equipment, streamlines the process, and ensures operational safety.
- Structural Rationality and Clear Force Transmission: The method exhibits excellent structural mechanics and performance characteristics.
- Overcoming Difficult Conditions: The rotation method effectively addresses challenges in constructing large-span structures in mountainous valleys, areas with deep, fast-flowing rivers, or navigable waterways. Its advantages are particularly evident for urban interchanges and railway overpasses in high-traffic areas.

- Cost-Effectiveness and Speed: The method is fast, economical, and cost effective.
- Minimal Railway Disruption: Construction proceeds without directly affecting railway operations, requiring only brief periods of track possession for rotation.
- Reduced Night Work: Construction activities such as in-situ casting can be completed during the day, reducing environmental and social impacts.
- Safety Enhancements**:** Controlled rotational movement mitigates risks arising from heavy lifting operations.

2.2.3 Insights from Mainland China on HBRM

HBRM has been extensively adopted in highway infrastructure projects across Mainland China, with numerous successful applications. First introduced in the 1970s, the technique initially gained traction in the south western regions of the country. As the method evolved and its advantages became more apparent—particularly its ability to minimize disruptions to existing transportation networks during construction, it saw broader adoption. Today, HBRM is widely utilized for the construction of bridges spanning rivers, expressways, and, most notably, active railway lines where permissible construction windows are extremely limited.

2.3 Brief Description of Bridge Rotation Mechanism and Components

The bridge rotation mechanism (**Figure 2.3**) incorporated several key components designed to facilitate the controlled horizontal rotation of the T-span structure, ensuring stability and safety throughout the process:

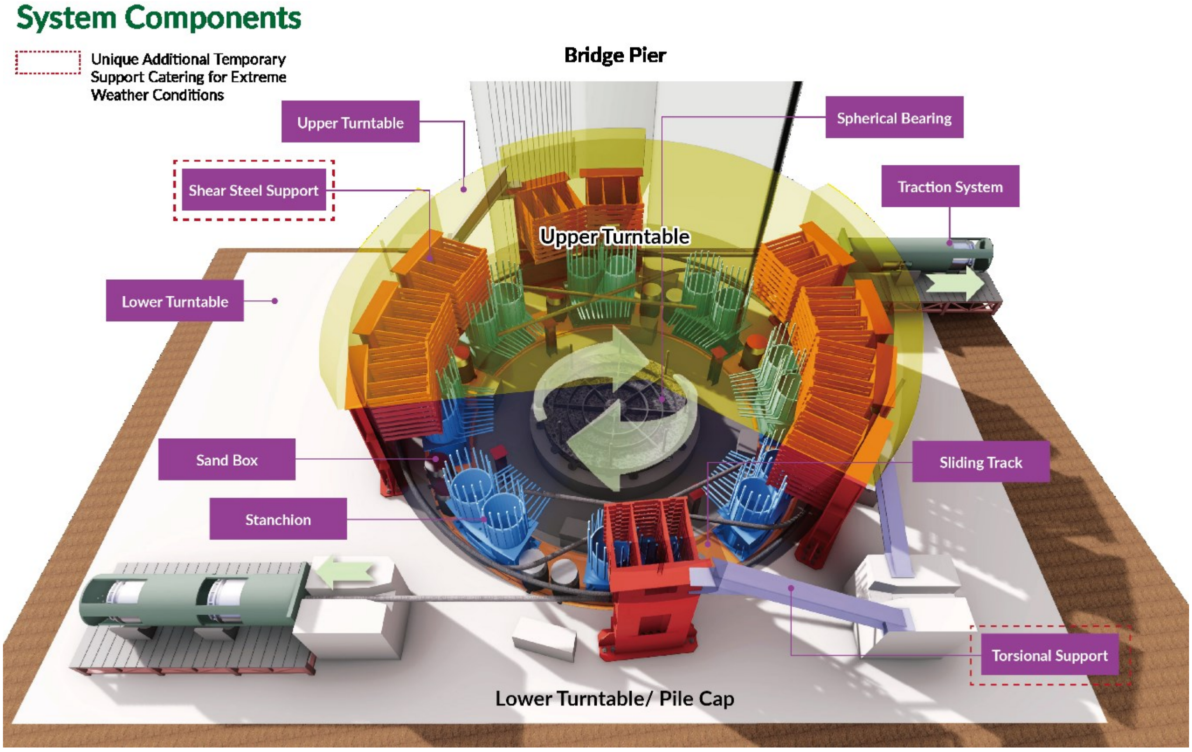


Figure 2.3 - Component and Mechanism of Bridge Rotation

At the core of the system was a high-capacity rotational bearing fabricated from structural steel and incorporating approximately one thousand and fifty-six low-friction PTFE sliding pads, strategically positioned between the upper and lower sections of the spherical bearing. This bespoke assembly was engineered to sustain loads of up to 7,050 tonnes for the T-span structure E2-01, with a Factor of Safety of 2, ensuring robust performance under extreme structural demands.

Encircling the perimeter of the turntable, eight pairs of stanchions offered additional structural support. Each stanchion transferred loads onto a stainless-steel sliding track, which was lined with low-friction PTFE plates featuring a coefficient of friction below 0.03. This configuration significantly improved both the stability and smoothness during rotation.

To generate the required traction, hydraulic strand jacks and cast-in reaction blocks within the upper turntable were employed. Tensioned strand wires transmitted forces to the reaction blocks, enabling precise control over the rotational movement. During rotation, the majority of the structural load was borne by the spherical bearing, with the centre of gravity carefully aligned through weight balancing to maintain equilibrium. The stanchions functioned as secondary supports, counteracting unbalanced forces and providing resistance against overturning.

To ensure structural stability of the T-span structure during the one-year pre-rotation period, a series of temporary stabilization measures were implemented. Notably, seven pairs of preloaded sandboxes were installed between the upper and lower turntables. Once the upper turntable was cast and ready for rotation, the controlled release of sand facilitated the effective transfer of load to the spherical bearing and stanchions.

In addition, ten pairs of robust vertical elements, referred to as shear steel supports, were embedded within the upper turntable and securely bolted to the lower turntable during casting. These supports were specifically designed to resist overturning forces in compliance with the Structural Design Manual for Highways and Railways (SDMHR), thereby enhancing structural stability during rotation.

Subsequent chapters will provide a detailed account of the design rationale and construction procedures, showcasing how each critical component was methodically engineered and assembled to maximize both safety and performance. The discussion will also cover the key quality control measures applied throughout the fabrication and installation phases, ensuring the reliability and effectiveness of the system. These insights will illustrate the meticulous planning and high standards that form the foundation of the bridge rotation success.

3. Structural Design for Viaduct Constructed by Horizontal Bridge Rotation Method

3.1 Preliminary Design Phase

Chapter 2 has outlined the suitability of HBRM for a variety of site conditions. HBRM is recognized as a safe and efficient approach for constructing bridges over sensitive infrastructures such as railway corridors, arterial roadways, and other critical facilities. Its ability to minimize operational disruption makes it particularly advantageous in dense and highly constrained urban settings.

To ensure the method's effectiveness, a comprehensive assessment of site conditions is essential during the preliminary design phase. This assessment involves careful identification and evaluation of key site-specific constraints, including:

- Vertical and horizontal bridge alignment;
- Proximity to existing structures and underground or overhead utilities;
- Ground topography and the extent of temporary works required;
- Available working footprint;
- Local wind patterns and aerodynamics;
- Environmental and regulatory factors affecting constructability and safety.

One of the primary objectives of the preliminary design is to establish a strategic response to these constraints. Developing this strategy early in the design process allows ample time for coordination among all key stakeholders including MTR, utility undertakers, the HyD, and other statutory authorities, thereby facilitating integrated planning and risk mitigation.

Typically, the preliminary design addresses two core aspects of construction:

3.1.1 <u>Geometric Considerations</u>

The first key aspect centers on geometric constraints, particularly the kinematic behavior of the bridge during rotation. The primary objective is to enable a smooth, obstruction-free operation that does not adversely affect adjacent sensitive structures. Where minor obstructions exist within the bridge's rotational path, targeted modifications may be required. For instance, in CEDD Contract No. ND/2019/05, the upper section of a lift shaft for a pedestrian footbridge was trimmed to ensure sufficient clearance for the rotating superstructure. This underscores the importance of early stakeholder engagement to identify and resolve potential conflicts, thereby minimizing delays during construction.

A further geometric concern involves spatial limitations at the pier base. The turntable, permanently embedded within the pile cap, must be accommodated alongside the lower cap and the jacking system, which includes reaction blocks engineered to generate rotational traction forces. Sufficient underground working space must be reserved, and the final elevation of the pile cap relative to the formation level must be agreed upon with stakeholders to avoid clashes with existing underground utilities.

3.1.2 Load Effects on Adjacent Structures

The second major design consideration addresses the bridge's load impact on surrounding structures, during both the rotation phase and long-term service. Typically, the rotation-induced loads are localized and resisted by the permanent bridge components themselves, making the structural behavior of these permanent elements critical in design calculations. However, temporary works—particularly excavation and lateral support (ELS) systems employed for pile cap construction—can also exert influence on neighboring infrastructure, particularly below ground. These impacts must be evaluated to prevent adverse effects on utilities and other sensitive elements.

As such, the preliminary design phase must incorporate a robust analysis of both geometric and structural factors. This includes:

- Kinematic modeling of the rotation process;
- Assessment of spatial clearances and working envelope;
- Analysis of load distribution from both permanent and temporary systems.

3.1.3 Key Deliverables

Outcomes from this stage should include:

- Detailed bridge layout drawings;
- Swept path envelope and horizontal rotation angle;
- Headroom clearance studies relative to adjacent assets;
- Preliminary sizing of the turntable;
- Dimensional and depth requirements for the pier base excavation.

3.2 Structural-Material Integration and Bearing Design Consideration

The design of a rotational bridge necessitates comprehensive structural analysis to ensure seamless motion during construction and dependable performance in long-term service. Central to this process is a detailed understanding of the interaction between the mechanical rotation system and the supporting structural components.

The primary structural elements involved in rotation include:

- The balanced cantilever superstructure;
- The pier;
- The upper segment of the pile cap, which functions as the rotating turntable.

These components must be robustly designed to resist both transient loads encountered during rotation and the sustained service loads acting throughout the bridge's lifespan.

A pivotal mechanical-structural element enabling rotation is the custom-engineered spherical bearing, which serves as the central pivot. This bearing supports the entire self-weight of the T-span and absorbs transient rotational forces. Typically ranging in diameter from 2.5 to 4 meters, its sizing is determined by the specific load demands of the bridge. Situated between the upper (rotating) and lower (fixed) pile caps, the bearing facilitates smooth, controlled rotation and is essential to the mechanism's function.

Upon completion of the rotation, the bearing is grouted and structurally integrated between the turntable and the lower pile cap, forming a cohesive part of the permanent foundation system. This integration ensures both the long-term transfer of vertical and horizontal forces and continuity in load path.

As illustrated in **Figure 3.1**, a typical T-span is shown supported on a fully integrated turntable system, designed to rotate as a single rigid body.

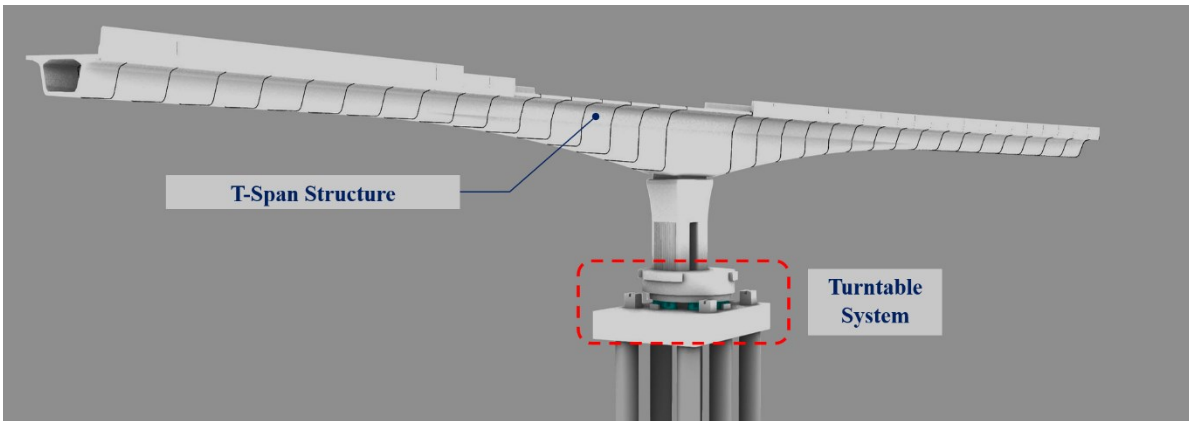


Figure 3.1 - Perspective view of T-span supported on the upper pile cap (turntable)

3.3 Design Requirement of the Spherical Bearing

The spherical bearing is a critical component in the rotational bridge system and must be designed to ensure structural integrity, operational precision, and long-term reliability. The following design criteria shall be satisfied:

1. **Bearing Panel Requirements**

- The steel panel of the bearing shall possess sufficient stiffness and strength, with a minimum thickness of 30 mm.
- Radial and circumferential stiffeners must be incorporated to enhance rigidity.
- The panel beneath the rotating bearing shall be anchored using embedded steel bars or a positioning skeleton, and a fine-tuning mechanism shall be installed to facilitate alignment.

2. **Material Strength Specifications**

- The steel plates forming the upper and lower spherical bearings and the rotary bearing baseplate shall be of grade Q355 or higher.
- The positioning skeleton and the bearing housing shall utilize materials of grade Q235 or higher.

3. **Pin Shaft and Bushing Design**

- The bearing pin shaft may be fabricated from a solid steel rod, preferably using 45# steel or superior alternatives.
- Composite configurations are also acceptable, such as a steel–concrete hybrid shaft comprising a solid steel core or a seamless steel pipe filled with ultra-high-performance concrete.
- The bushing shall be constructed from seamless steel tubing, suitable for construction applications.

4. **Sliding Interface Material**

The rotary bearing's sliding surface shall be made of one of the following:

- Modified PTFE,
- Modified ultra-high molecular weight polyethylene, or
- Filled PTFE composite sandwich materials.

5. **Stress Analysis Requirements**

The design shall include a detailed evaluation of:

- Vertical normal stress on the rotating bearing,
- Normal stress on the sliding interface, and
- Shear stress on the pin shaft.

6. **Stress Limitation**

The applied vertical normal stress on the rotating bearing must not exceed its allowable capacity, as specified by the manufacturer or code-based design limits.

3.4 Design Considerations for Various Construction Stages

A rotation bridge should be designed to satisfy requirements in 3 main construction stages:

- **Stage 1** - initial position where the T-span is built, clear of all obstructions and site constraints. This scenario is illustrated in **Figure 3.2**.
- **Stage 2** - transition positions where the T-span rotates from the initial position to its final position.
- **Stage 3** - final position where the T-span will connect with the rest of the units to form a complete viaduct structure. This configuration is shown in **Figure 3.3**.

The design considerations of the bridge structure at various construction stages are summarized as follows:

1. **Construction of foundation and lower pile cap:** The piles and lower pile caps are constructed in their permanent positions. They are designed to resist the service load scenarios and checked against the transient loads induced by the rotation operation.

2. **Installation of spherical bearing and turntable**: After installing the spherical bearing which supported on the lower pile cap, the turntable together with the associated temporary works for the rotation will be casted on top of the bearing. The turntable is set out in its initial position prior to the rotation. It will be designed to resist the transient loads from the rotation operation, particularly the concentrated load from the spherical bearing. **Figures 3.4 and 3.5** show details of a typical spherical bearing. The turntable will be connected to the lower pile cap by temporary works in order to ensure global stability of the cantilever T-span during construction.

3. **Pier construction**: The pier connecting to the turntable will be constructed in its initial position before the rotation. It will be designed to resist the service loads and checked against the transient loads induced by the rotation operation.

4. **Superstructure construction**: The balanced cantilever T-span will be constructed either by in-situ concreting using a pair of form travellers. It will be formed in the initial position before rotation and designed to resist the service loads and checked against the transient loads induced by the rotation operation which are generally non-critical.

5. **Rotation of T-span**: During rotation of the cantilever T-span, the superstructure, pier and turntable move together as a rigid body from their initial positions to the final permanent positions of the bridge. The design at this stage focuses on the global stability check against transient loads.

6. **Final Integration**: After grouting the turntable and the lower pile cap, the integrated cap is the permanent structure connecting the deck and pier to the pile foundation. Connection of the integrated cap is achieved by reinforcement setting out at the peripheral of the turntable to facilitate easy construction.

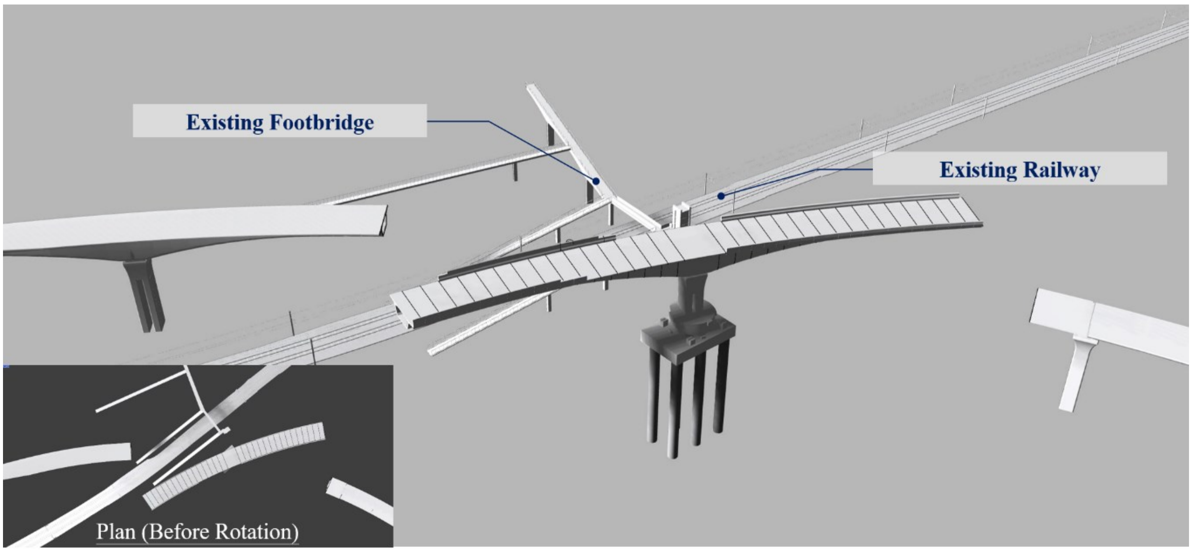


Figure 3.2 - Initial Position of Cantilever Bridge

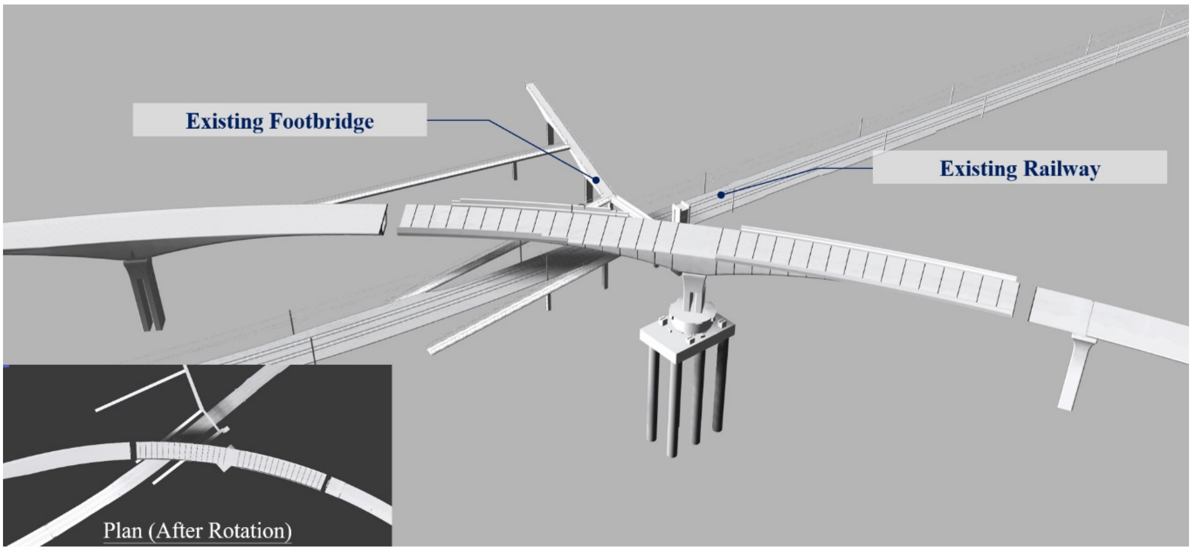


Figure 3.3 - Final Position of Cantilever Bridge

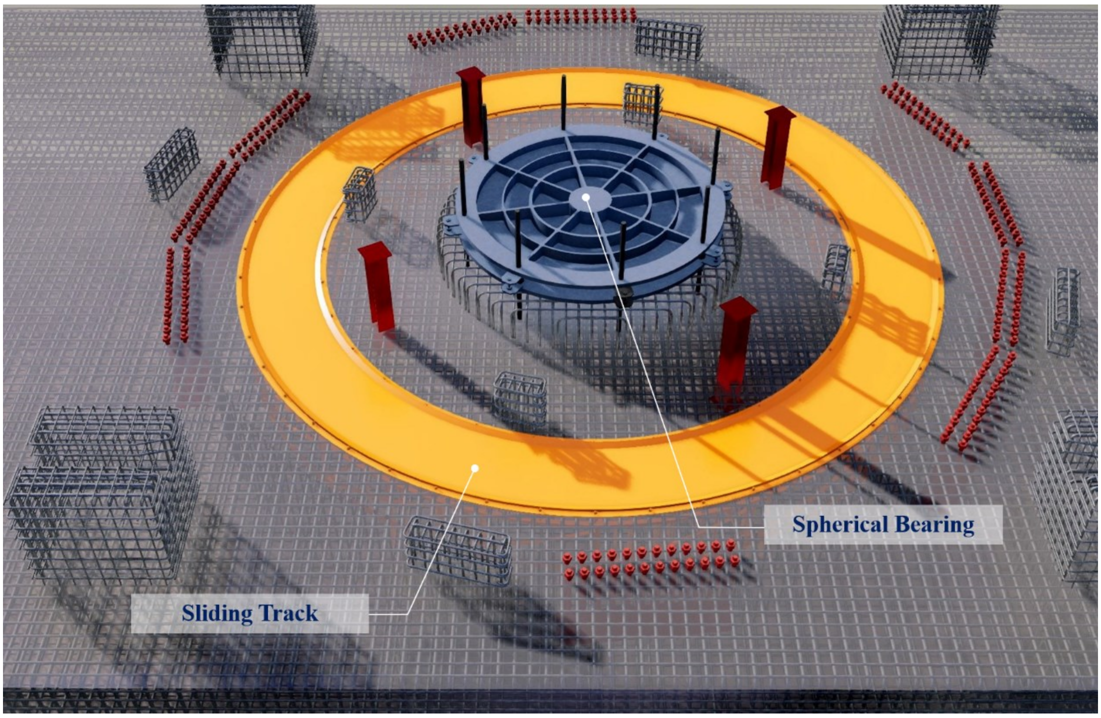


Figure 3.4 - Typical Spherical Bearing and Sliding Track

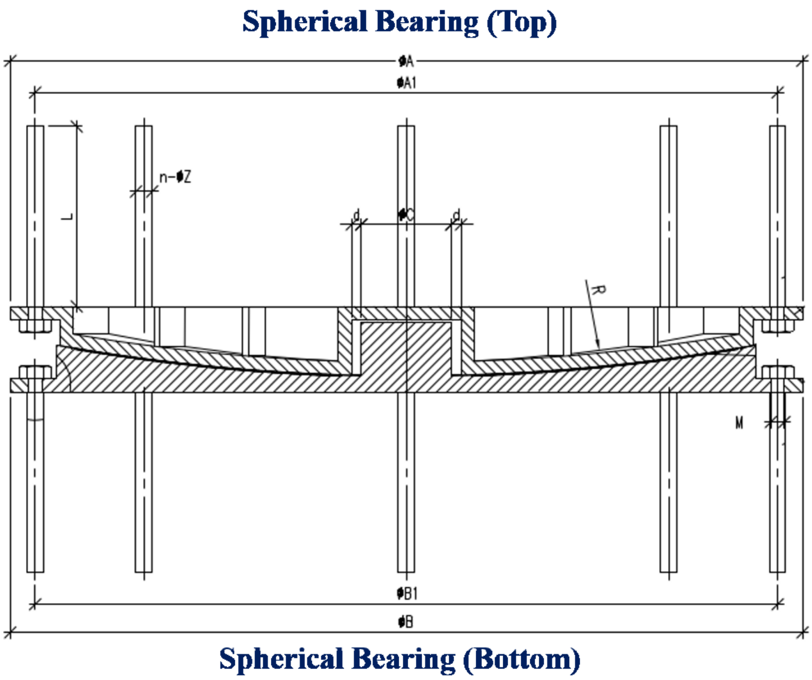


Figure 3.5 - Details of a Spherical Bearing

(Courtesy of Luoyang Shangrui Special Equipment Co Ltd)

3.5 Design Approach and Philosophy

The bridge design shall primarily adopt the limit state philosophy described in Clause 2.1 of BS EN 1990: Eurocode: Basis of Structural Design, which outlines the fundamental principles of structural reliability and design requirements for Ultimate Limit State (ULS) (Clause 6.4) and SLS (Clause 6.5).

The permanent structure shall be designed for the actions and combinations of actions specified in Eurocodes, including: BS EN 1990 : Basis of Structural Design; Eurocode 1, Parts 1 and 2 (BS EN 1991-1 and BS EN 1991-2); Eurocode 8 : Design of Structures for Earthquake Resistance Parts 1 and 2 (BS EN 1998-1 and BS EN 1998-2); and the corresponding UK National Annexes and Published Documents, except where modifications are specified in the Structures Design Manual for Highways and Railways (SDMHR) and its Amendments issued by the HyD. Some key modifications include the accidental and seismic actions, crack width and tensile stress verifications in Appendix B of SDMHR.

3.5.1 ULS Design

To satisfy ULS requirements, the structure shall undergo the following verifications:

- Equilibrium (EQU): Prevent loss of static equilibrium of the structure or any part of it.
- Structural (STR): Prevent internal failure or excessive deformation of the structure or structural members, including deck, pier, pile cap and piles.
- Geotechnical (GEO): Ensure no failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance.

3.5.2 SLS Design

General requirements for SLS design aim to ensure that the structure does not experience unacceptable levels of deformations, vibrations, cracking or other functional impairments. The verification criteria include:

- Characteristic Combination of Actions: Represents a combination of actions with a relatively low probability of being exceeded, typically associated with rare but plausible situations.
- Frequent Combination of Actions: Represents combinations of actions that are likely to occur relatively often within the structure's life but not persist continuously.
- Quasi-Permanent Combination of Actions: Represents actions that are present for the majority of the structure's life, focusing on long-term effects.
- Crack width verification: Control crack width as required by the SDMHR.
- Tensile Stress Verification: Control tensile stresses in prestressed concrete members, a requirement in SDMHR.

The design of most structural components is governed by the requirements for service conditions. Therefore, it is recommended that the bridge be initially designed to meet all service condition requirements. Subsequently, its individual components should be verified against the requirements for other conditions at various construction stages.

Since the objective of this document is to focus on the special considerations relevant to the bridge rotation design, the methodologies and details for designing a typical balanced cantilever concrete bridge under service conditions will not be repeated here.

3.6 Design Considerations for Load Scenarios During Construction and Rotation of the T-Span

When the T-span is constructed in its initial position, clear of obstructions and site constraints, the design considerations—including ULS and SLS verifications—are largely similar to those of a conventional cantilever bridge. The primary distinction is that the T-span is supported on a turntable rather than a permanent pile cap. To ensure stability and adequate structural performance, the turntable have to be restrained using temporary works, which transfer loads to the lower pile cap or other ground supports.

A comprehensive computer model is essential for simulating the global and local behaviour of the integrated system. This model allows accurate capture of load effects on various parts of the structure, ensuring a safe design.

3.6.1 Critical Load Scenarios During Initial Construction

Key Action Effects

- Wind Loads: Includes wind actions determined in accordance with BS EN 1991-1-4, UK NA to EN 1991-1-4 and PD 6688-1-4 together with the specific requirements stipulated in SDMHR Section 3.4.

- Out-of-Balance Cantilever Moment: Arises from:
  - Differences in the self-weight of the two cantilever arms, as per SDMHR Clause 3.2.1(5) and Table 3.3.
  - A potential one segment shortfall in an arm due to unintended non-synchronized casting of the cantilever arms or failure of the erection equipment.

- Construction Live Load: Includes weight of construction personnel and equipment.

ULS-EQU Verification

The imbalance in self-weight creates a substantial longitudinal moment that has to be equilibrated. This is achieved through resistance provided by temporary works, as the connection between the turntable and lower pile cap is via a spherical bearing idealized as a pinned joint.

3.6.2 Critical Load Scenarios During Rotation Operations

During T-span rotation from its initial to final position, the configuration continuously changes. System stability during this stage is ensured by engaging a different set of temporary works, as the restraining temporary works used during T-span casting must be removed to allow rotation.

Action Effects

The imposed actions on the deck and pier remain consistent with those in the initial position. However, the operation will be carefully controlled, and weather conditions closely monitored to ensure that the design wind speed can be confidently achieved. To minimize the structural stability risk, the rotation shall be scheduled in non-typhoon season. Furthermore, wind speed monitoring shall be carried out early in the project to collect sufficient information to verify the wind speed design assumption, which may vary across projects due to different topography or sheltering effects. Generally, a design wind speed of 26m/s will be adequate when the rotation is scheduled in non-typhoon season. Additionally, the continuous variation in the direction of load effects on the lower pile cap as the T-span rotates necessitates verification of the structural performance of both the cap and the piles.

Verification Requirements

Both the upper and lower caps and the piles must be verified under the following conditions:

- ULS-EQU: Prevent loss of static equilibrium of the structure or any part of it.
- ULS-STR: Ensuring sufficient structural strength of the lower pile cap and piles.
- ULS-GEO: Verifying ground stability and resistance against geotechnical failures.
- SLS: Ensuring serviceability performance, such as limiting deformations and stresses under operational loads.

3.6.3 Load Combinations and Partial Factors

The following combinations of actions (Section 3.2, SDMHR) shall be adopted in the design for the T-span during construction stages, as illustrated in **Tables 3.1 and 3.2**:

Table 3.1 - ULS Combinations and Partial Factors

Design Situation	G_k (Unfavourable)	G_k (Favourable)	P	Q_c	$F_{Wk,x}$	$F_{Wk,y}$	$F_{Wk,z}$	A_d
EQU (set A)	1.15	0.85	1.00	1.35	1.55	-	1.55	-
	1.15	0.85	1.00	1.35	-	1.55	1.55	-
STR/GEO (set B)	1.35	0.95	1.00	1.50	1.55	-	1.55	-
	1.35	0.95	1.00	1.50	-	1.55	1.55	-
STR/GEO (set C)	1.00	1.00	1.00	1.30	1.30	-	1.30	-
	1.00	1.00	1.00	1.30	-	1.30	1.30	-

Table 3.2 - SLS Combinations and Partial Factors

Design Situation	G_k (Unfavourable)	G_k (Favourable)	P	Q_c	$F_{Wk,x}$	$F_{Wk,y}$	$F_{Wk,z}$
Characteristic Combination	1.00	1.00	1.00	1.00	1.00	-	1.00
	1.00	1.00	1.00	1.00	-	1.00	1.00

Where

G_k - Dead load and superimposed dead load

P - Prestressing load

$F_{wk,s}$ - Wind load in a specific direction (s), where s can be x, y (horizontal) and z (vertical)

Q_c - Construction live load

A_d - Accidental load

3.6.4 <u>Setting Out of Turntable</u>

The turntable is a critical structural component that determines the success of the rotation operation. For a T-span with a curved horizontal alignment, the centre of gravity (CG) of the deck under construction varies continuously. The turntable must be positioned such that its centre aligns with the CG of the completed cantilever T-span, which should also coincide with the centre of the spherical bearing—the point of rotation.

Minimizing the eccentricity between the T-span's CG and the bearing's rotation axis is essential to ensure a safe and stable rotation operation. While minor adjustments to the T-span's CG can be made using counterweights prior to rotation, the theoretical prediction of the CG must be as accurate as possible. This prediction should account for factors such as the horizontal curve, longitudinal gradient, and transverse gradient of the deck.

In certain situations, the full cantilever may not be completed before rotation, with the remaining segments to be erected or casted after the bridge is rotated. In such cases, temporary works, such as form travellers mounted on the deck, may be required to facilitate segment casting or erection at a later stage. The weight of the temporary works must be accounted for when evaluating the system's centre of gravity (CG).

To avoid introducing additional risks to the sensitive structure after rotation, intrusive construction activities, such as parapet erection, should be completed before rotation. The construction of this portion of the parapet will influence the system's CG and must be included in the CG calculations.

Given the complex geometry and layout of the structural components, it is recommended to use a fine-mesh finite element model to evaluate the theoretical CG of the T-span and improve precision in computation.

3.6.5 Structural Performance and Stability of Turntable

The turntable shall be designed to meet both SLS and ULS requirements for various operational scenarios. Its stability is to be verified against bearing, sliding, and overturning capacities under ULS-EQU, based on the reactions at the column base.

The turntable is supported by the spherical bearing and associated temporary works during different construction stages. Accurate evaluation of load distribution among the structural components is essential to ensure proper design and prevent overloading or damage to the spherical bearing. Since the spherical bearing is almost irreplaceable after installation, special attention must be given to its protection throughout the construction and operation processes.

Horizontal Force Resistance

Before rotation, the sliding (horizontal) resistance of the turntable is determined based on the combined shear capacity of the pin of the spherical bearing and the restraining temporary works between the turntable and the lower pile cap. The design for a proven temporary works system, consisting of structural steel members installed around the perimeter of the turntable, is detailed in Chapter 4. The combined shear capacity is evaluated in accordance with SDMHR and BS-EN 1993-1.

To prevent overstressing the bearing pin, it is recommended that the perimeter steel sections be overdesigned to independently resist the combined actions – the vector sum of the horizontal forces, Fx and Fy, in the x and y directions – without relying on contributions from the bearing pin.

During the bridge rotation, all shear-resisting steel members at the perimeter of the turntable will be removed. At this stage, the shear resistance of the turntable will rely solely on the bearing pin. However, the design shear force during rotation is smaller than that during the construction of the T-span, as the allowable operational wind speed is limited to 26 m/s.

Overturning Moment Resistance
The turntable supported on the spherical bearing has no intrinsic moment resistance. Before rotation, the overturning moment resistance of the turntable is provided by the temporary works, specifically the shear steel support installed around its perimeter. The design out-of-balance moment is counteracted by a compression-tension couple generated by these members. The stability of the T-span shall be verified under ULS-EQU. For a curved T-span, these checks must be performed in both longitudinal and transverse directions.

During rotation, the shear steel support will be removed, and the turntable's overturning moment resistance will rely on another set of temporary works, this system consists of steel stanchions installed at the soffit of the turntable and supported on the top of the lower pile cap. Further details on the stanchion design approach are provided in Chapter 4.

Structural Performance Verification
The structural performance of the turntable is to be verified under both SLS and ULS-STR against the construction stage loadings. The load scenarios include actions from the shear steel support during T-span construction, actions from stanchions during rotation, actions from the spherical bearing for all construction stages, and actions from other temporary works interfacing with the turntable which will be further discussed in Chapter 4.

3.6.6 Final Construction of the T-span

Upon completing the rotation, the T-span reaches its final position under service conditions. Stabilization of the T-span shall be executed immediately by welding the stanchion to the embedded track. Concurrently, the construction of the permanent integrated pile cap should commence.

A potential issue that could delay pile cap construction is difficulty in placing connection reinforcement. To mitigate this, it is crucial to design simple and efficient detailing, ensuring that the reinforcement cage connecting the turntable to the lower pile cap can be installed effectively. Potential reinforcement conflicts and temporary cast-in items should be thoroughly analyzed and resolved to ensure smooth construction. **Figure 3.6** illustrates the connection reinforcement between the turntable and lower pile cap.

The next step involves connecting the T-span to adjacent spans through in-situ stitching joints to form a continuous deck structure. While this is a standard operation in conventional balanced cantilever construction, risks associated with a cantilevered T-span over existing sensitive structures are only fully mitigated when the continuous deck is completed. Therefore, the construction program should prioritize completing this activity as early as possible.

A potential complication during this stage is the risk of geometry mismatch between adjacent spans. Geometry control is critical, not only for successful bridge rotation but also for ensuring seamless T-span integration with adjacent spans, essential in any balanced cantilever construction.

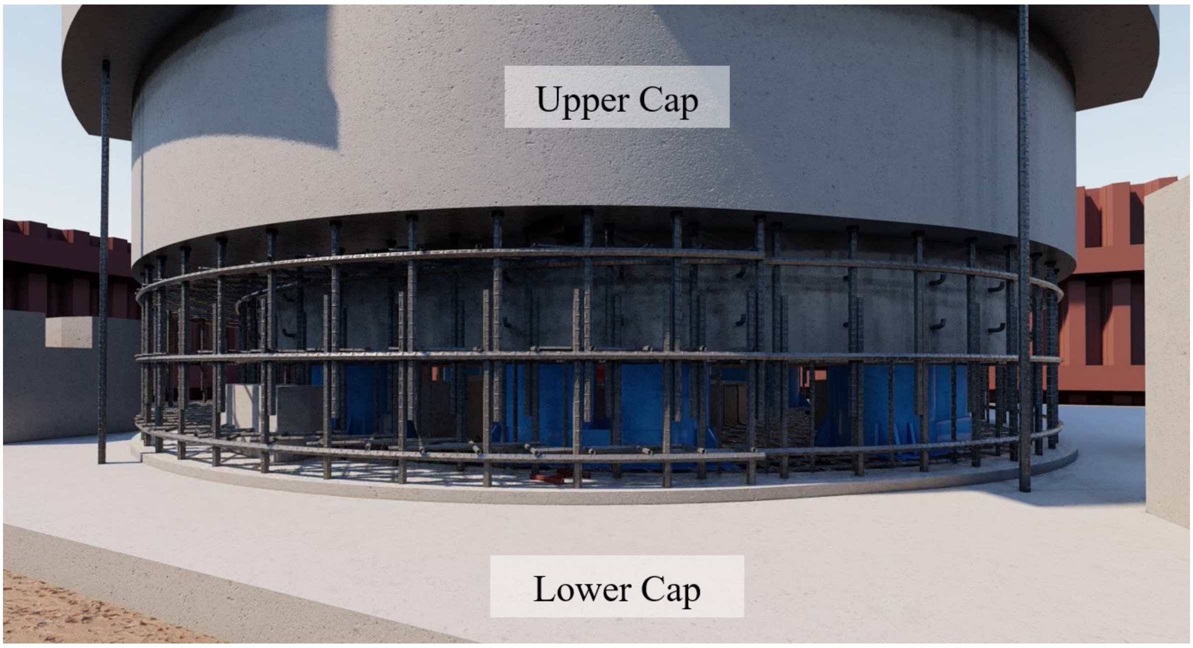


Figure 3.6 - Connection Reinforcement between Turntable and Lower Cap

4. Temporary Works and Works Activities for Horizontal Bridge Rotation Method

4.1 Single-point vs Multi-point Support of Horizontal Rotating System

The designer for the rotating system should thoroughly consider the characteristics of the bridge structure and the site constraints, and reasonably determine the form of the rotating structure, including location of the rotating system, rotating bridge span length, and the construction method.

The horizontal rotating body support form can be selected according to the rotating tonnage and balance requirements. When the rotating bridge can be balanced by counterweight and if conditions permit, it is advisable to adopt a single-point support rotating body. When the rotating structure cannot be balanced by counterweight or the space conditions are limited, it is advisable to use a multi-point support horizontal rotation system.

4.2 Types of Horizontal Rotating Systems (Multi-point Support)

According to the different forms of auxiliary support structure and rotation power, the multi-point support rotation system can be divided into three types: (1) with steel strand traction on the upper turntable, (2) with steel strand traction on the stanchions, and (3) with motor rack and gear-wheeled drive on the stanchions.

- **Multi-point support horizontal rotation system with steel strand traction on the upper turntable** refers to the rotation system in which the stanchion is designed to always be in contact with the sliding track and bear the vertical load, and the steel strands provide traction force to the upper turntable to rotate the bridge.

- **Multi-point support horizontal rotation system with steel strand traction on the stanchion** refers to the rotation system in which the stanchion is designed to always be in contact with the sliding track and bear the vertical load, and the steel strands provide traction force to the stanchion to rotate the bridge.

- **Multi-point support horizontal rotation system of motor rack and gear-wheeled drive on the stanchions** refers to the rotation system in which the stanchion is designed to always be in contact with the sliding track and bear the vertical load, and the motor is integrated on the stanchion, and the gear of the stanchion is driven by the motor to roll along the lateral preset rack meshing and rolling to drive the bridge to rotate.

The design should cater for the strength, stiffness and stability of the bridge structure and the rotating system under each construction stage.

4.2.1 Horizontal Rotation System Adopted in CEDD Contract No. ND/2019/05

CEDD Contract No. ND/2019/05 adopted a multi-point support horizontal rotation system with steel strand traction on the upper turntable, as illustrated in **Figures 4.1 and 4.2**.

The system consists of four main components: (a) the spherical bearing located between the upper and lower turntables, (b) the lower turntable with sliding tracks, (c) the upper turntable equipped with the rotational traction system, and (d) the temporary works that stabilizes the upper and lower turntables during T-span construction stage.

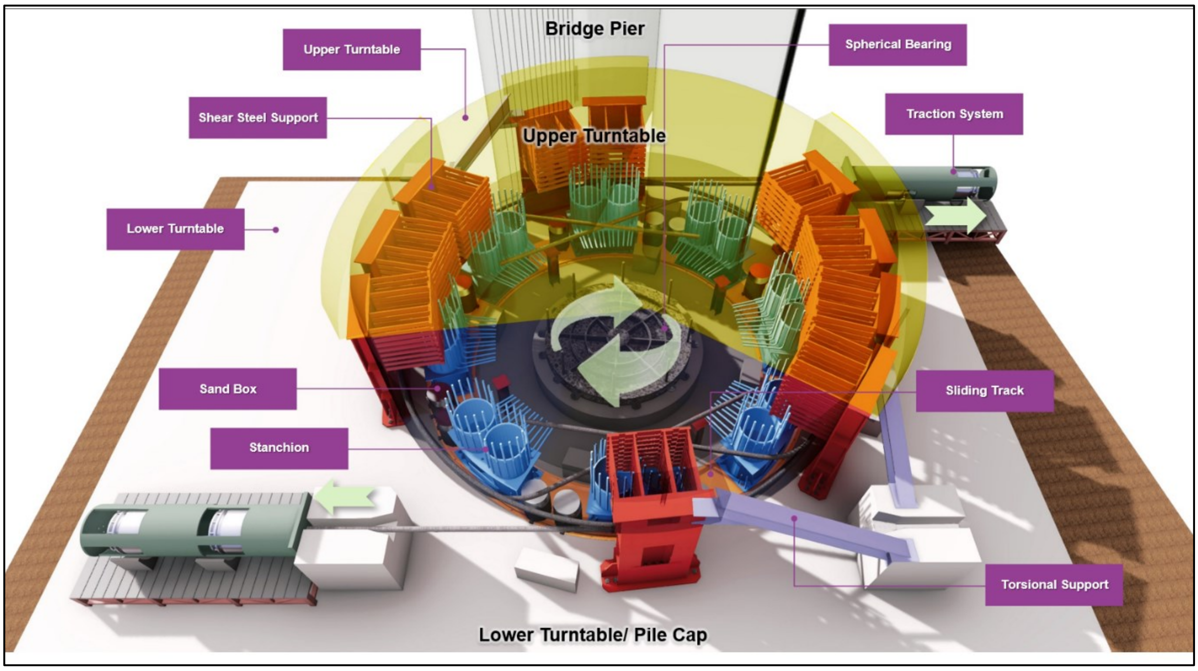


Figure 4.1 - Bridge Rotation System Component

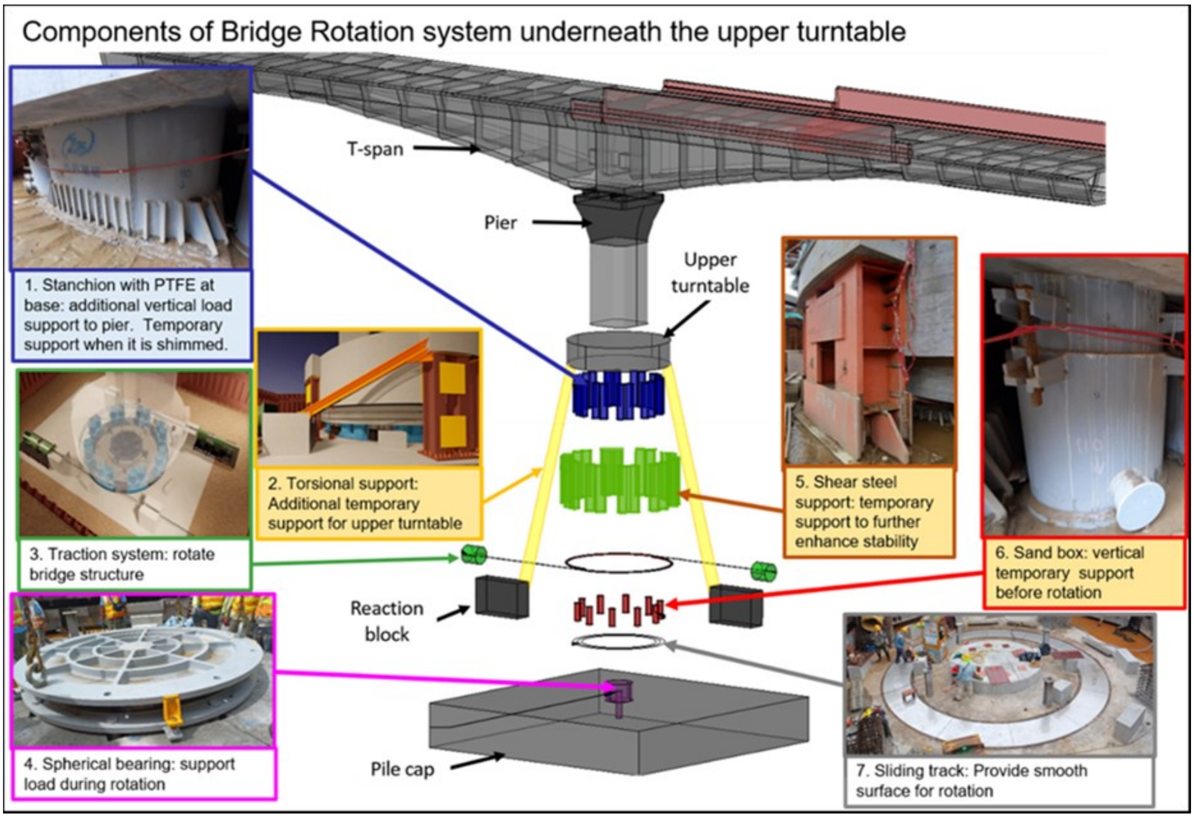


Figure 4.2 - Exploded view diagram for temporary works components of Bridge Rotation System

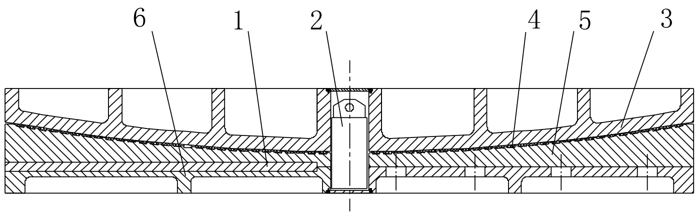
4.3 Spherical Bearing Installed Between the Upper and Lower Turntables

The structural form of the supporting system should be determined according to comprehensive factors such as rotating tonnage, construction method, transportation and installation conditions. According to the structural form, the rotation bearing can be divided into rotating spherical bearing and rotating flat bearing.

According to the material type of the pressure-bearing parts, the rotating spherical bearing is divided into steel spherical bearing and steel-concrete combination spherical bearing, and the steel spherical bearing is divided into ordinary steel spherical bearing, cast steel spherical bearing and rotating body bearing according to the processing method.

The body of the cast steel spherical bearing is generally composed of the upper spherical bearing, the lower spherical bearing, the sliding plate, the pin shaft, the base plate, the shear key and other components, and the upper and lower spherical bearings of the cast steel spherical bearing are generally cast as a whole. Large-tonnage rotating bridges should be provided with a base plate under the lower spherical bearing, and a shear key should be set on the base plate.

The schematic structure of the steel spherical bearing body of the rotating steel spherical bearing at the bottom of the pier is shown in **Figure 4.3**.



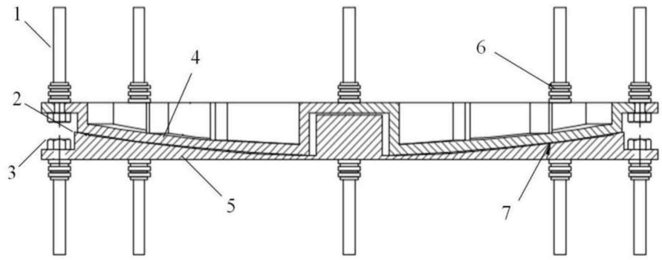
1 - shear key;
2 - pin shaft;
3 - upper spherical bearing;
4 - sliding plate;
5 - lower spherical bearing;
6 - base plate

Figure 4.3 - Schematic diagram of the structure of the rotating steel spherical bearing at the bottom of the cast and formed pier

4.3.1 Anchorage of Spherical Bearing

The rotating body bearing is mainly composed of upper spherical bearing, lower spherical bearing, upper anchor assembly, lower anchor assembly and other components.

The anchor rod rotating support system, as shown in **Figure 4.4**, was adopted in CEDD Contract No. ND/2019/05. The rotation bearing was installed when the lower and upper turntables were cast. Given the long construction period after installation, the rotation bearing was regularly re-inspected before bridge rotation to verify its condition.



1 - anchor rod;
2 - sealing device;
3 - bolt;
4 - upper spherical bearing;
5 - lower spherical bearing;
6 - sleeve;
7 - sliding plate

Figure 4.4 - Schematic diagram of anchor rod rotating support

4.3.2 Rotating Steel Spherical Bearing Adopted in CEDD Contract No. ND/2019/05

The rotating steel spherical bearing was adopted in CEDD Contract No. ND/2019/05. The bearings were prefabricated and tested in fabrication factory before delivery to the site for installation. Technical information is illustrated in **Table 4.1**.

Table 4.1 - Technical Information of Spherical Bearing Adopted in CEDD Contract No. ND/2019/05

	Pier E2-01	**Pier D2-01**
Diameter	3.3 m	2.55 m
Height	0.31 m	0.25 m
Loads during rotation	7050 Tons	4600 Tons
Capacity	14000 Tons (FOS 2.0)	8000 Tons (FOS 1.7)
No. of PTFE sliding pads in the bearing	1056 nos.	603 nos.
PTFE sliding disc design static friction	0.1	0.1
PTFE sliding disc actual static friction	0.015	0.015

4.3.3 Spherical Bearing Fabrication

The spherical bearing, a core component of the rotation system, is made of high-strength ZG250-500 steel. It is produced through precision casting, heat treatment, and machining, resulting in a bearing with a diameter of 3.3m and a thickness of 230mm. It is designed to withstand immense pressure and ensure smooth rotation.

PTFE (polytetrafluoroethylene) sliding plates are laid between the upper and lower spherical bearings as a sliding layer to reduce friction during rotation. These plates undergo compression moulding and sintering tests, are lubricated with tetrafluoro powder as shown in **Figure 4.5** to lower the friction coefficient.

Figure 4.5 - PTFE pads at spherical bearing

4.3.4 Spherical Bearing Anchorage Installation

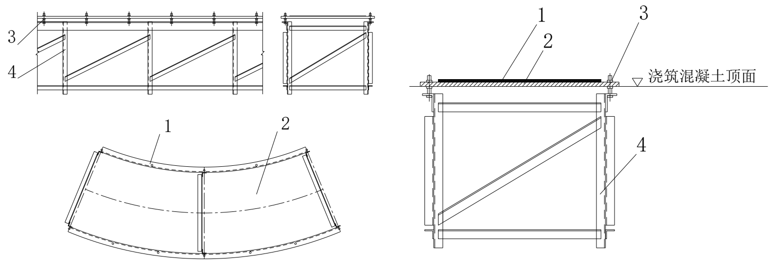
During the casting of the lower turntable and bearing plinth, holding down bolts for temporary supports and anchorage holes for the spherical bearing are reserved.
The prefabricated spherical bearing supports are accurately positioned in the reserved anchor holes of the lower turntable, grouted in place, and embedded during the casting of the upper turntable to ensure structural stability. (**Figure 4.6**)

Figure 4.6 - Spherical Bearing Installation

4.4 Lower Turntable with Sliding Tracks

On top of the bearing plinth supporting the rotation bearing, the lower turntable shall be cast with an integrated sliding track, primary reaction blocks, and secondary reaction blocks. The sliding track shall provide a smooth, continuous surface to support the stanchions, thereby enabling the upper turntable to rotate together with the support stanchions. The sliding track shall be arranged in a circular configuration, with its centerline precisely aligned with the centerline of the stanchions.

The sliding track assembly consists of a stainless steel surface plate, a base steel plate, a positioning skeleton steel frame, adjustable bolts, and other associated components. The positioning skeleton may be fabricated using angle steel and welded to ensure structural integrity. The detailed structure of the sliding track is illustrated in **Figure 4.7**.



1 - stainless steel plate
2 - base steel plate
3 - adjusting bolt
4 - positioning skeleton

Figure 4.7 - Schematic diagram of the sliding track

The base steel plate should be Q235 and above, and can be fully welded with stainless steel plate. The thickness of the stainless-steel plate should not be less than 3mm. A sliding plate should be placed on top of the base steel plate or stainless steel plate, and the slide plate material is made of polytetrafluoroethylene, modified PTFE, or modified ultra-high molecular weight polyethylene.

Table 4.2 - Technical Information of Sliding Track Adopted in CEDD Contract No. ND/2019/05

	Pier E2-01	**Pier D2-01**
Inner diameter	6.6 m	6.2 m
Outer diameter	8.8 m	8.4 m
Design fall tolerance	Less than 1:3000	Less than 1:3000
Actual fall	1:4400	1:4100

4.4.1 <u>Sliding Track Fabrication and Installation Adopted in CEDD Contract No. ND/2019/05</u>

The sliding track framework and circular steel plate are prefabricated in the factory. The sliding track, 1.1m wide and with an outer diameter of 8.8m, is made of a 24mm-thick steel plate overlaid with a 2mm stainless steel plate. The framework is divided into eight sections for prefabrication and delivered to site for installation (**Figures 4.8 and 4.9**).

Figure 4.8 - Preassembled framework

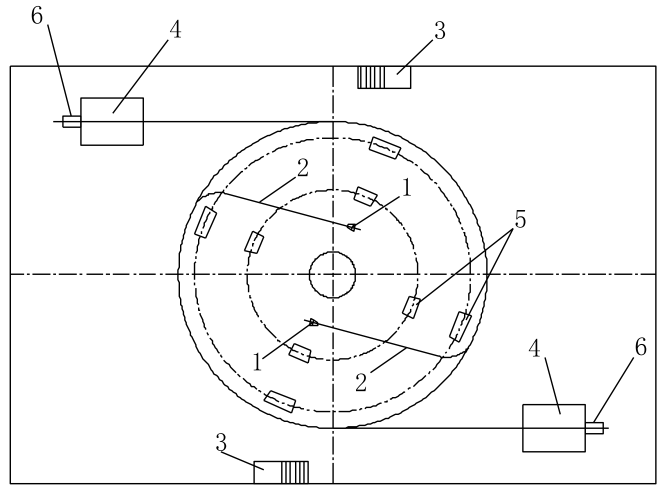
Figure 4.9 - Installation of sliding track

The sliding track framework is hoisted into position at the designated location, welded on-site, and then fitted with the circular sliding track. The stainless-steel sliding track should be installed horizontally within a tolerance of 1:3000.

4.5 Upper Turntable with Rotational Traction System

The traction strands of the traction system compose with prestressed steel strands, and the traction strands should be set in the centre of the symmetrical turntable, and the height of the jack action point should be consistent with the embedded height of the traction strands. The traction system should form a balanced towing force moment, and it is advisable to use 2 groups or 4 groups of strand wire.

The traction system is composed of a pair of traction strands, continuous strand jacks, primary traction reaction blocks, limiting stop blocks, secondary booster reaction blocks, and the structure is schematic as shown in **Figure 4.10**.



1 - traction strand fixed end anchorage;
2 - traction strand;
3 - limiting stop block;
4 - primary traction reaction block;
5 - secondary booster reaction block;
6 - continuous strand jack

Figure 4.10 - Layout of the traction system

The formwork and falsework for the upper turntable are installed with precise alignment to ensure accurate placement of the reinforcement for the upper pier and lower stitching joint, anchorage of the upper portion of the spherical bearing, and installation of other embedded temporary structures required for bridge rotation—namely, shear supports, traction strand anchorages, and stanchions (**Figure 4.11**).

Figure 4.11 - Upper turntable casting

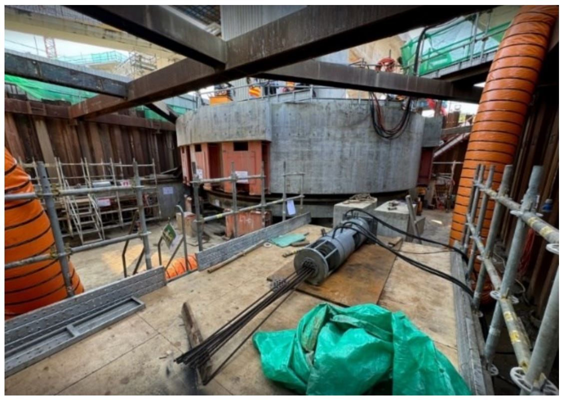


Figure 4.12 - Set-up of continuous strand jack at the primary reaction block

After casting the upper turntable, the pre-embedded traction strands are protected until continuous strand jacks are installed, which occurs immediately prior to initiating the bridge rotation process **(Figure 4.12**).

4.6 Temporary Structure Stabilizing Upper and Lower Turntables

The temporary structures stabilizing upper and lower turntables are namely stanchions, sandboxes, and shear and torsion supports (**Figures 4.13 and 4.14**). Stanchions and sandboxes are typical arrangement for bridge rotation system while the shear and torsional supports are project-specific, designed according to the rotating structure geometry before the rotation.

Stanchions and sandboxes are arranged symmetrically in pairs beneath the upper turntable. These temporary structures bear the construction load, preventing excessive concentrated pressure on the spherical bearing. The sandboxes are filled with dry quartz sand and removed before the rotation. The stanchions act as safety supports during rotation, ensuring stability by maintaining a multi-point support horizontal rotation system.

Shear and torsion supports are temporary structures specially designed to suit the bridge structure arrangement and are installed to enhance factor of safety during the bridge construction stage. The temporary structures resist risks posed by extreme weather and are removed before rotation.

Figure 4.13 - Temporary supports installed on lower turntable prior to the casting of upper turntable

Figure 4.14 - Torsional support installed on upper turntable prior to removal of sandboxes

4.6.1 Stanchions

Support stanchions should be set up in a stable plane, and should be evenly and symmetrically distributed on both sides of the longitudinal axis of the bridge (**Figure 4.15**).

Figure 4.15 - Stanchions before rotation

The stanchion consists of several components, including the walking plate, diagonal brace plate, supporting steel pipe, intermediate plate, oblique vertical plate and other parts. The connection between the brace foot and the upper turntable needs to bear the action of bending moment, shear force and axial force at the stop of the stanchion and sufficient connection strength should be ensured. The stanchion can either be embedded directly into the upper turntable structure as shown in **Figure 4.16** or designed to be detachable.

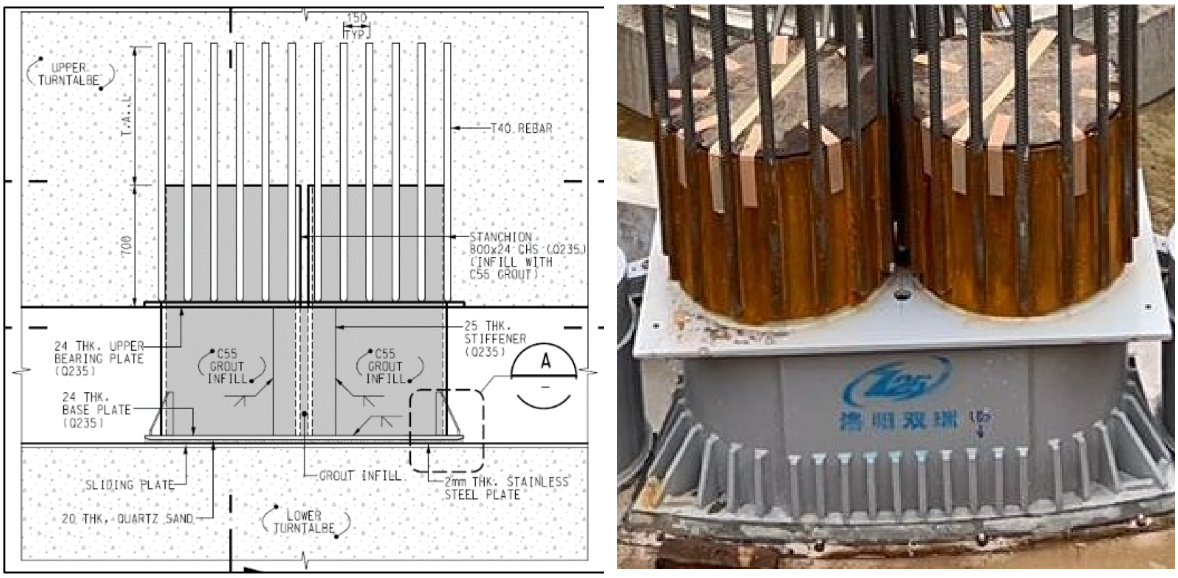


Figure 4.16 - Details of stanchions adopted in CEDD Contract No. ND/2019/05

The stanchions used in CEDD Contract No. ND/2019/05 comprise 8 sets of circular hollow steel sections, each with a diameter of 800 mm and a height of 770 mm. These stanchions are positioned atop the sliding track, with quartz sand infill placed between them as temporary support. The quartz sand will be removed prior to the bridge rotation to allow for the insertion of PTFE sliding plates.

After survey verification, the stanchions are to be filled with grout possessing a compressive strength of 55 MPa. The anchorage bars must be adjusted to accommodate the rebar fixing arrangement of the upper turntable. The technical information of stanchions adopted in CEDD Contract No. ND/2019/05 is illustrated in **Table 4.3**.

Table 4.3 - Technical Information of Stanchions Adopted in CEDD Contract No. ND/2019/05

	Pier E2-01	**Pier D2-01**
Diameter	0.8 m	0.8 m
Height	0.77m	0.77 m
No. of Stanchions	8 Pair	8 Pair
Loads during Rotation (Each Pair)	1000 Tons	1000 Tons
Capacity	4800 Tons (FOS 4.8)	4800 Tons (FOS 4.8)
PTFE underneath Stanchions Design static friction	0.1	0.1
PTFE underneath Stanchions Actual static friction	0.003	0.003

The gap between the support stanchion and the sliding track shall be determined based on several factors, including:

- The compression deformation of the spherical bearing
- The allowable deflection angle between the bearing pin shaft and the shaft sleeve
- The spatial requirements for counterweight installation

The compressive deformation should be estimated through theoretical calculations. Upon completion of the bridge structure, the final gap between the base of the support stanchion and the top surface of the sliding track should be maintained at 10–20 mm. For initial construction purposes, the gap may be set at 25–30 mm to accommodate uncertainties during alignment and settlement.

The gap must be carefully controlled—neither too large nor too small:

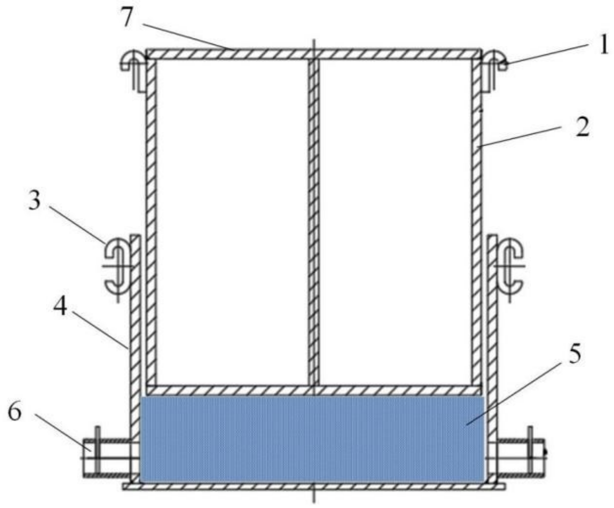
- Excessive Clearance: May result in insufficient stabilization during imbalance, and could lead to jamming of the pin shaft by the shaft sleeve.
- Insufficient Clearance: In the event of deviations between actual and theoretical geometry, this may cause unintended loads to transfer through the support stanchion onto the sliding track, potentially resulting in deformation of the track or interference with rotational performance.

As a general guideline, once temporary structures are dismantled, a residual clearance of approximately 15 mm between the support stanchion and sliding track is required to maintain safe and stable operation during bridge rotation.

4.6.2 Sandboxes

The temporary sandbox serves as a safeguard within the anti-overturning system during the T-span structure construction phase. However, its contribution to overturning resistance shall not be included in the structural design calculations.

The sand box should be composed of an inner cylinder, an outer cylinder and a sand discharge hole, as shown in **Figure 4.17**.



1 - upper hanging hook;
2 - outer cylinder;
3 - lower hook;
4 - inner cylinder;
5 - sand;
6 - sand discharge hole;
7 - cover plate

Figure 4.17- Schematic diagram of the sandbox

The height and quantity of the sand box should meet the requirements of the rotating structure and weight, and the sand box should be evenly arranged between the stanchions. The sand box should be installed synchronously with the stanchion as shown in **Figure 4.18** and should be removed prior to rotation preparation.

Figure 4.18 - Pre-load of the sandbox

Figure 4.19 - Pre-load of the sandbox in Factory

The upper support of the sandbox may be constructed using a steel pipe, which shall be filled with compensating shrinkage concrete to ensure dimensional stability. The interior of the sandbox is to be filled with dry quartz sand, and a sand discharge hole shall be provided at the base to allow for controlled removal prior to bridge rotation.

The sandbox shall possess adequate bearing capacity and stiffness to support temporary loads during construction. Each unit must undergo preloading, either welded or bolted, at the fabrication stage, tested to 1.1 times the design load, as illustrated in **Figure 4.19**. The deformation of the sandbox under this applied load shall be measured and recorded to verify compliance with structural tolerances.

Technical specifications for the sandboxes used in CEDD Contract No. ND/2019/05 are detailed in **Table 4.4**.

Table 4.4 - Technical Information of Sandboxes Adopted in CEDD Contract No. ND/2019/05

	Pier E2-01	**Pier D2-01**
Diameter	0.55 m	0.55 m
Height	0.8 m	0.8 m
No. of Sandboxes	14 nos.	14 nos.
Loads during Rotation	300 Tons	300 Tons
Capacity	600 Tons (FOS 2)	600 Tons (FOS 2)

4.6.3 Shear Support and Torsional Support Adopted in Contract No. ND/2019/05

As the spherical bearing and support stanchions are not intended to resist unbalanced forces during the pre-rotation construction phase, dedicated shear supports are designed by the bridge engineer in accordance with the applied construction loads to satisfy stability checks. Additionally, torsional supports are installed to counteract rotational torque induced by wind loading before the rotation begins, particularly after the removal of shear supports and sandboxes.

As depicted in **Figures 4.20 and 4.21**, the outer shear supports consist of eight pairs of steel girders fabricated from 356×406×393UC sections in S355 grade steel. These are positioned along the outer perimeter of the sliding track to connect the upper and lower turntables. The inner shear supports comprise four members of 203×203×46UC sections in Q235 grade steel, located at the inner perimeter of the sliding track.

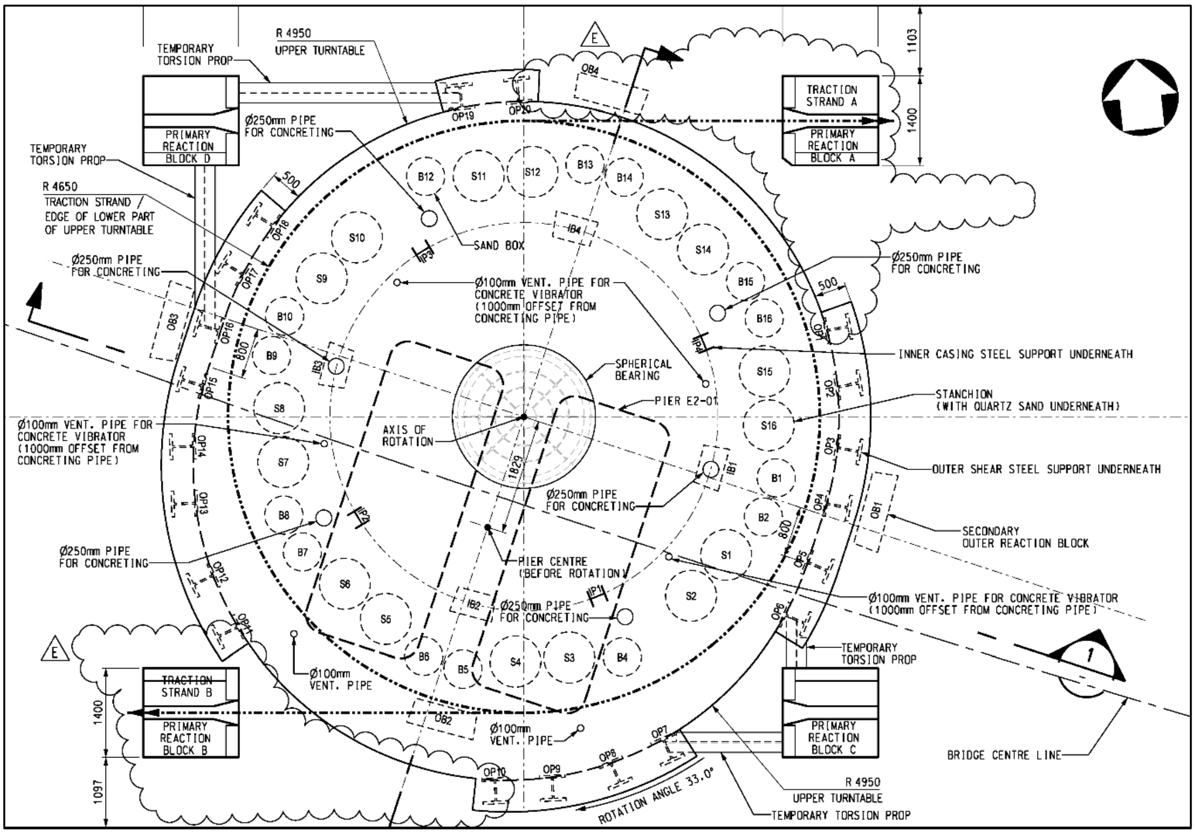


Figure 4.20 - Plan of turntable showing the inner and outer shear support

Figure 4.21 - Photos of turntable showing the inner and outer shear support

The lower ends of the outer shear supports are fixed to the lower turntable using hold-down bolts and nuts, while the upper ends are embedded into the upper turntable during the concrete casting process to ensure structural continuity. Technical specifications and material properties of the shear support system are detailed in **Table 4.5**.

Table 4.5 - Technical Information of Shear Steel Supports Adopted in CEDD Contract No. ND/2019/05

	Pier E2-01	Pier D2-01
Dimensions	1.85m (L) x 0.6m (W)	1.65m (L) x 0.6m (W)
Height	3 m	3 m
Quantity	10 pairs (20 nos.)	6 pairs (12 nos.)
Loading during rotation	900 Tons	700 Tons
Capacity	1700 Tons (FOS 1.8)	1100 Tons (FOS 1.6)

4.7 Works Activities for Bridge Rotation

Prior to initiating the bridge rotation process, the temporary stabilization structures supporting the upper and lower turntables (except stanchions) shall be dismantled. Upon their removal, strand jacks are installed at designated anchorage points. A controlled traction force is then applied through the rotational traction system, thereby enabling the bridge deck to pivot smoothly into its final alignment.

The workflow adopted by the construction crew for this operation, specific to CEDD Contract No. ND/2019/05, is presented in **Figure 4.22**. A detailed breakdown of the pre-rotation activities is provided in the following section.

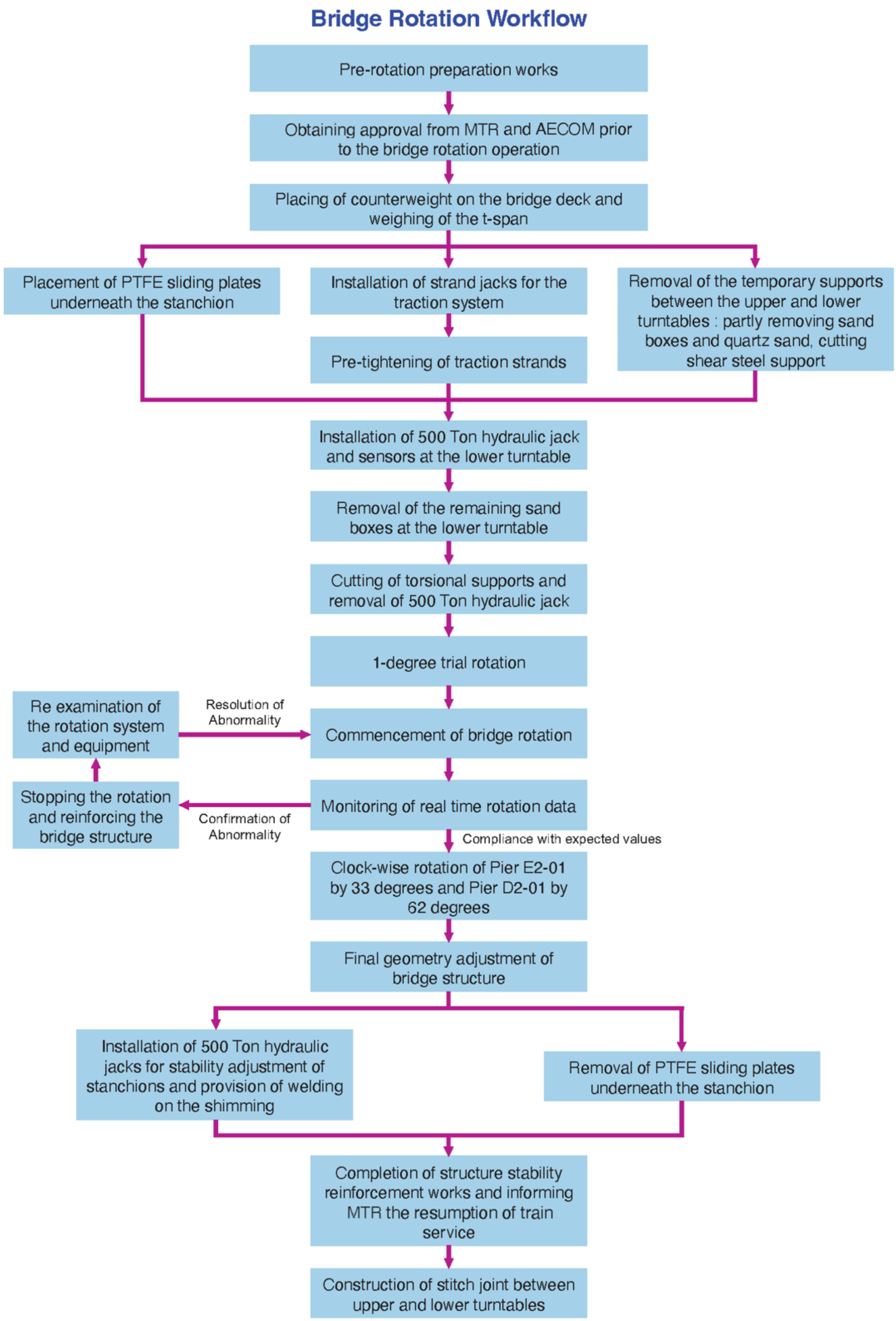


Figure 4.22 - Workflow for Bridge Rotation in CEDD Contract No. ND/2019/05

4.7.1 Detailed pre-rotation activities

1) Installation of traction system
2) Installation of PTFE at bridge rotation system
3) Placing of counterweight on bridge deck
4) Installation of temporary works at bridge rotation system
5) Weight balancing by load cells of hydraulic jack system
6) Installation of remaining PTFE and prepare pre-rotation bridge configuration
7) Installation of hydraulic jacks at bridge rotation system
8) Installation of temporary works at bridge rotation system
9) Trial rotation by 1 degree
10) Bridge rotation to final position
11) Installation of hydraulic jacks at bridge rotation system
12) Final adjustment of bridge structure by hydraulic jacks
13) Adding shims at stanchions at bridge rotation system
14) Temporary works installation at bridge rotation system
15) Installation of clamping beam at connection between Piers E1-04 and E2-01
16) Removal of traction system at bridge rotation system
17) Grout of temporary works at bridge rotation system
18) Construction of stitch joint between upper and lower turntables

4.7.2 Simulation and Site Rehearsal

Prior to the actual bridge rotation, the site team shall conduct simulation exercises to verify the estimated time required for the operation. Due to the limited working space between the upper and lower turntables, these simulations are especially critical for activities such as hydraulic jack installation and welding operations (see **Figures 4.23 and 4.24**).

Figure 4.23 - 500 Ton Jack Installation

Figure 4.24 - Shimming and Spot Welding at Stanchion

A full-scale site rehearsal shall begin no less than two weeks before the scheduled rotation day, typically spanning 3 to 5 days. This rehearsal allows for refinements to the operation, identification of risks, and resolution of logistical challenges. All contractors and site supervision personnel must become thoroughly familiar with the rotation workflow. Detailed time allocations, task sequences, and inspection checkpoints should be reviewed and validated. Under CEDD Contract No. ND/2019/05, a comprehensive rehearsal involving over 50 contractor workers and 20 supervisory staff was carried out to ensure the entire team was fully acquainted with the operation procedure (**Figure 4.25**).

Figure 4.25 - Site Rehearsal before Bridge Rotation

During the site rehearsal, all primary and auxiliary equipment, including backup plant systems, shall be fully tested to verify operational readiness. A comprehensive emergency response plan shall be established to identify potential failure scenarios and outline immediate corrective measures. Backup plants must be readily deployable to ensure uninterrupted execution of critical works in the event of primary system malfunction.

Spherical bearing stress shall be continuously monitored via a dedicated bridge monitoring system. A designated monitoring team shall be present throughout the rehearsal period to supervise the monitoring interface, validate the accuracy of real-time sensor readings, and ensure system reliability.

In parallel, the site team shall conduct detailed inspections of all highly stressed components within the rotating structure during the construction of temporary works. Any anomalies, such as material deformation, misalignment, or unusual stress patterns, shall be addressed promptly and documented in accordance with quality assurance protocols.

4.7.3 Resources Plan

Based on operational experience from CEDD Contract No. ND/2019/05, the successful execution of the bridge rotation procedure requires the deployment of seven dedicated teams, each responsible for a critical aspect of the operation.

To ensure a coordinated and timely execution, a comprehensive resource allocation plan shall be developed. This plan will detail the personnel assignments, activity durations, and interdependencies across all stages of the bridge rotation. An example layout of the team structure and corresponding activity breakdown is provided in **Table 4.6**, while the operational flow and resource interaction are illustrated in **Figure 4.26**.

Table 4.6 - Team Grouping in Resources Plan

Team Grouping	Number of People	Responsibility
Command Team	4	Contact and communicate with Project Manager to confirm the start time. Control the implementation of the rotation, issue the rotation operation command, lead the bridge deck geometry adjustment.
Traction Team	6	Install and debug the rotating equipment, carry out the rotating traction operation according to the instructions, and cooperate with the bridge deck geometry adjustment.
Monitoring and Quality Assurance Team	5	Responsible for verifying rotation progress and system performance. Report the rotation situation in a timely manner, issue early warning signals, put forward operation suggestions, and cooperate with bridge deck geometry adjustment.
Survey Team	11	Installation and commissioning of survey equipment, arrangement of survey control points, implementation of rotation retest, and bridge deck adjustment suggestions
Welders Team	10	Welding stanchions and sliding track, cutting torsional supports
Support and Emergency Team	13	Install and disassemble jacks according to command instructions, install temporary support measures, and assist in bridge deck geometry adjustment. Arrange emergency rescue according to contingency plan.
Temporary Works Installation Team	6	Install the anchorage bars for upper turntable, install the support tower top jack

Specialist's Rotation Team (3 ppl.)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0130	30 mins	Entre work area and take position
0130-0200	30 mins	Test hydraulic system and communication signal
0200-0245	45 mins	Stressing traction strands
0245-0315	30 mins	Communicate real-time monitoring data
0315-0400	45mins	Final geometry adjustment
0400-0415	15mins	Lock 500T jack
0415-0430	15mins	Final check

Specialist's Adjustment Team (3 ppl.)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0130	30 mins	Entre work area and take position
0130-0200	30 mins	Test communication signal
0200-0245	45 mins	Support the removal of sliding plate
0245-0315	30 mins	Install 1 nr. 500T jack and jack steel plate
0315-0400	45mins	Final geometry adjustment
0400-0415	15mins	Lock 500T jack
0415-0430	15mins	Final check

Main Contractor's Rotation Equipment Support Team (5 ppl.)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0130	30 mins	Entre work area and take position
0130-0200	30 mins	Test communication signal
0200-0245	45 mins	Remove jack and steel beam after rotation started
0245-0315	30 mins	Install 1 nr. 500T jack
0315-0330	15 mins	Remove PTFE sliding plates
0330-0400	30 mins	Stanchion wedge shims standby
0400-0415	15 mins	Install wedge shims at the gap between stanchions and sliding track (3 sides)
0415-0430	15 mins	Install remaining wedge shims (inner side)

Main Contractor's Operation Support Team (8 ppl.)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0130	30 mins	Entre work area and take position
0130-0200	30 mins	Test communication signal
0200-0245	45 mins	Remove jack and steel beam after rotation started
0245-0315	30 mins	Assist installation of jack steel plate
0315-0330	15 mins	Remove PTFE sliding plates
0330-0400	30 mins	Stanchion wedge shims standby
0400-0415	15mins	Install wedge shims at the gap between stanchions and sliding track (3 sides)
0415-0430	15 mins	Install remaining wedge shims (inner side)

Welder's Team (8 ppl.)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0245	1.75 hours	Standby at waiting area
0245-0330	45 mins	Final inspection of the welding machine and wearing of protective clothing
0330-0345	15 mins	Entre work position
0345-0400	15 mins	In position for welding
0400-0415	15 mins	Spot weld for wedge shims (3 sides)
0415-0430	15 mins	Final check

Subcontractor (Team A)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0215	1.25 hours	Standby at waiting area
0215-0245	30 mins	Entre work area
0245-0315	30 mins	Install 1 nr. 500T jack and steel plate
0315-0345	30 mins	Entre work area at the top of support tower
0345-0415	30 mins	Install steel plate for jacking
0415-0430	15 mins	Jacking up the jack

Subcontractor (Team B)

Time	Duration	Task
0000-0100	1 hour	Detailed workflow briefing
0100-0215	1.25 hours	Standby at waiting area
0215-0245	30 mins	Entre work area
0245-0315	30 mins	Install 1 nr. 500T jack and steel plate
0315-0345	30 mins	Entre E2-01 work area uing the access route via Bridge E1
0345-0400	15 mins	Install 2 nr. M32 anchor bolts
0400-0415	15 mins	Tighten 2 nr. M32 anchor bolts
0415-0430	15 mins	Install clamping beam

Independent Checking Engineer (ICE)

Time	Task
0000-0100	Detailed workflow briefing
0130-0400	Standby at waiting area
0400-0415	Entre work area at the lower turntable
0415-0430	Issue ICE Certificate (ICE CERT 15)

MTR Resume Traffic

Specialist's Rotation Team (3 ppl.)

Time	Duration	Task
0430-0500	30 mins	Move 500T jack
0500-0630	1.5 hours	Install steel strands for reverse rotation system

Specialist's Adjustment Team (3 ppl.)

Time	Duration	Task
0430-0500	30 mins	Move 500T jack
0500-0630	1.5 hours	Install steel strands for reverse rotation system

Main Contractor's Rotation Equipment Support Team (5 ppl.)

Time	Duration	Task
0430-0500	30 mins	Take break and change tools
0500-0600	1 hour	Cut steel plates underneath stanchion
0600-0700	1 hour	

Main Contractor's Operation Support Team (8 ppl.)

Time	Duration	Task
0430-0500	30 mins	Take break and change tools
0500-0600	1 hour	Cut steel plates underneath stanchion
0600-0700	1 hour	

Welder's Team (8 ppl.)

Time	Duration	Task
0430-0500	30mins	Spot weld for wedge shims (inner side)
0500-0530	30 min	Take break
0530-2359	18 hour	Fillet weld for stanchion wedge shims

Subcontractor (Team A)

Time	Duration	Task
0430-0500	30 mins	Dismantling 1 nr. steel support using crane lorry
0500-0530	30 mins	Dismantling 1 nr. steel support using crane lorry
0530-0600	30 mins	Dismantling 1 nr. steel support using crane lorry
0600-0700	1 hour	

Subcontractor (Team B)

Time	Duration	Task
0430-0500	30 mins	Install 2 nr. M40 anchor bolt at clamping beam
0500-0530	30 mins	Install 4 nr. M40 anchor bolt at E2-01 turntable
0530-0630	1 hour	Install steel strands for reverse rotation system

Independent Checking Engineer (ICE)

Time	Task
0430-0500	Issue ICE Certificate (ICE CERT 16 & 17)
0500-0530	Issue ICE Certificate (ICE CERT 19)
0530-0600	Issue ICE Certificate (ICE CERT 18)
0600-0700	

Main Contractor's Construction Team Leader (Operation Commander)

Main Contractor's Senior Enginer (Sub-team Commander A)		Main Contractor's Section Agent (Sub-team Commander B)					Main Contractor's Design Manager Independent Checking Engineer
Staff: 1. Worker 1 (Group leader) 2. Worker 2 (Operator at the hydraulic pump station) 3. Worker 3 (Technician)	Staff: 1. Worker 4 (Operator at the hydraulic pump station) 2. Worker 5 (Technician) 3. Worker 6 (Technician)	Staff: 1. Worker 7 (Group Team) 2. Worker 8 (Stanchion S7 & S8) 3. Worker 9 (Stanchion S3 & S4) 4. Worker 10 5. Worker 11	Staff: 1. Worker 11 (Group leader) 2. Worker 12 (Stanchion S5 & S6) - North Entrance 3. Worker 13(Stanchion S11 & S12) - North Entrance 4. Worker 14 (Stanchion S9 & S10)- North Entrance 5. Worker 15 (Stanchion S1 & S2) - North Entrance East Entrance: 6. Worker 16 (Group leader) 7. Worker 17 (Stanchion S13 & S14) 8. Worker 18 (Stanchion S15 & S16)	Staff: 1. Worker 19 (Group leader) 2. Worker 20 (Stanchion S7 & S8) 3. Worker 21 (Stanchion S3 & S4) 4. Worker 22 5. Worker 23	Staff: 1. Worker 24 (Group leader) 2. Worker 25 (Technician) 3. Worker 26 (Technician) 4. Worker 27 (Technician)	Staff: 1. Worker 28 (Group leader) 2. Worker 29 (Technician) 3. Worker 30 (Technician)	

Figure 4.26 - Resources Plan for Bridge Rotation

4.7.4 <u>Survey Plan</u>

Survey monitoring procedures shall be established to ensure continuous tracking of critical reference points before, during, and after the bridge rotation process (**Figures 4.27 and 4.28**). Given the importance of maintaining tight tolerances for final alignment, robust geometry control is essential throughout all phases of rotation.

To achieve uninterrupted observation, a system of 360-degree survey prisms and an automatic monitoring total station shall be employed to continuously record deck geometry in real time. This live data stream will enable rapid assessment and adjustment during the final positioning phase, particularly under the time constraints often present in night-time operations.

Furthermore, hydraulic jacking displacements beneath the upper turntable shall be closely coordinated with the monitored positional data at the deck's end tip. Integration of survey and jacking data ensures synchronized movement and facilitates precise geometric correction during the final alignment process.

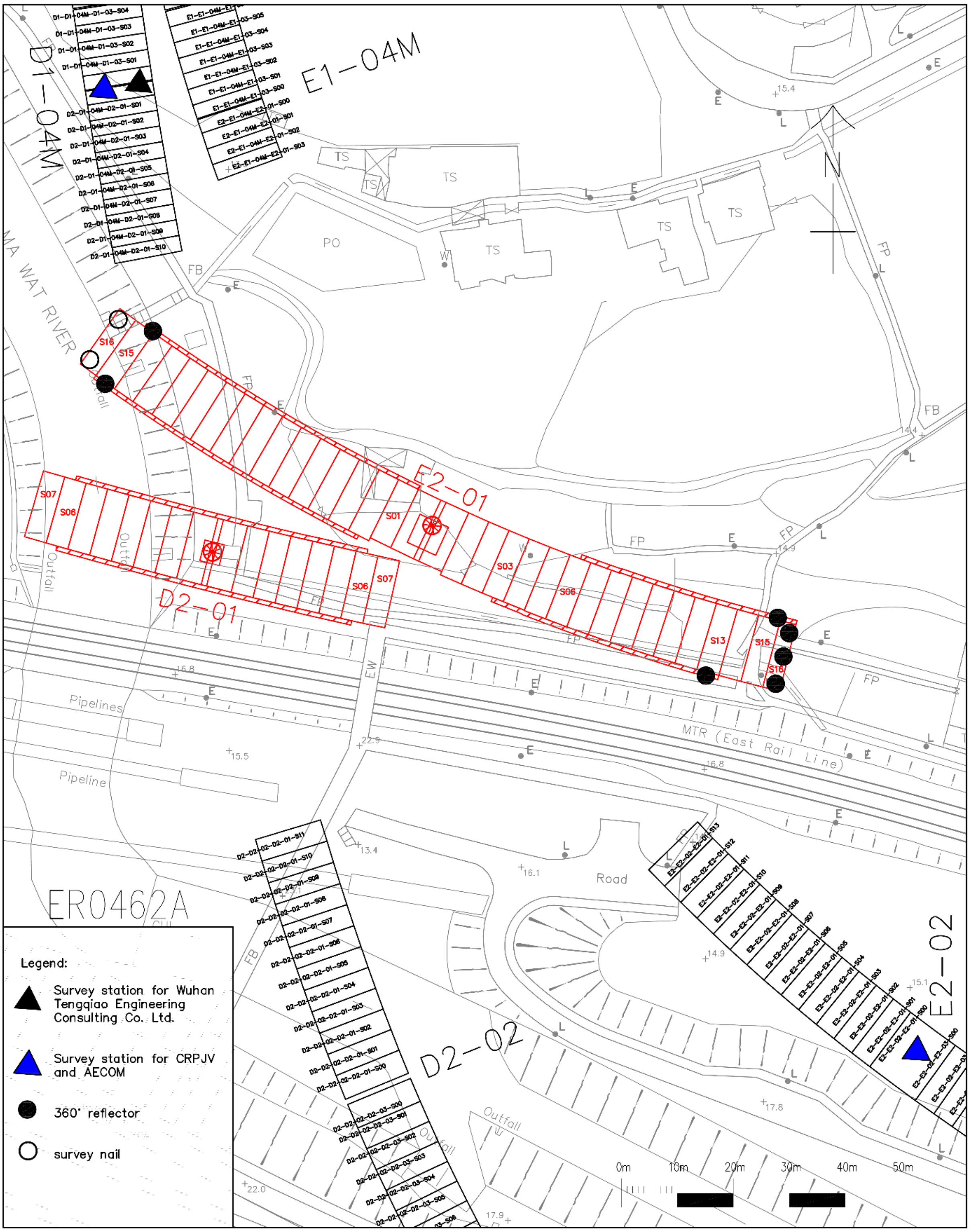


Figure 4.27 - Survey Plan of Pier E2-01

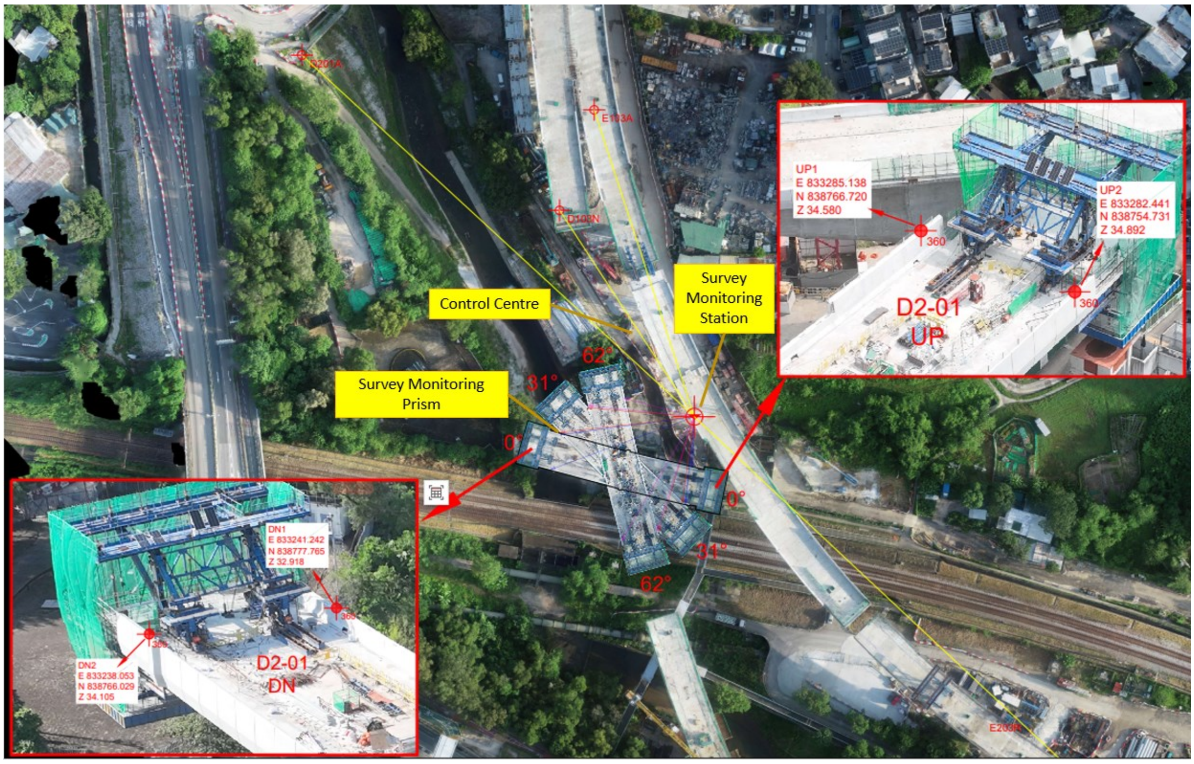


Figure 4.28 - Illustration of survey monitoring at Pier D2-01

4.7.5 Equipment Preparation

Prior to the commencement of bridge rotation, all designated equipment shall be checked to verify both quantity and operational functionality. A comprehensive equipment checklist, as extracted in **Figure 4.29**, shall be used for verification. Backup equipment must also be available on-site, and the spatial arrangement for each item shall be clearly identified in the site layout plan (**Figure 4.30**).

Equipment Checklist for Bridge Rotation Operation – Luoyang Shuangrui + Dr. Che's Team						
No.	Equipment	Model	Quantity on Site	Quantity in Use	Spare Quantity	Photo
1	Rotation control cabinet (Luoyang Shuangrui)	LYND-016	2	1	1	
2	Rotation hydraulic power unit (Luoyang Shuangrui)	ZLYZ200E-11/X2x15	4	2	2	
3	Rotation jack (Luoyang Shuangrui)	LEHY2-200T-LXD 1800X460	5	2	3	
4	Strand transfer device (Luoyang Shuangrui)	N/A	2	2	Non-critical mechanical device, no spare needed	
5	PTFE sliding plates (Luoyang Shuangrui)	N/A	32	16	16	

Figure 4.29 - Equipment checklist (Capture)

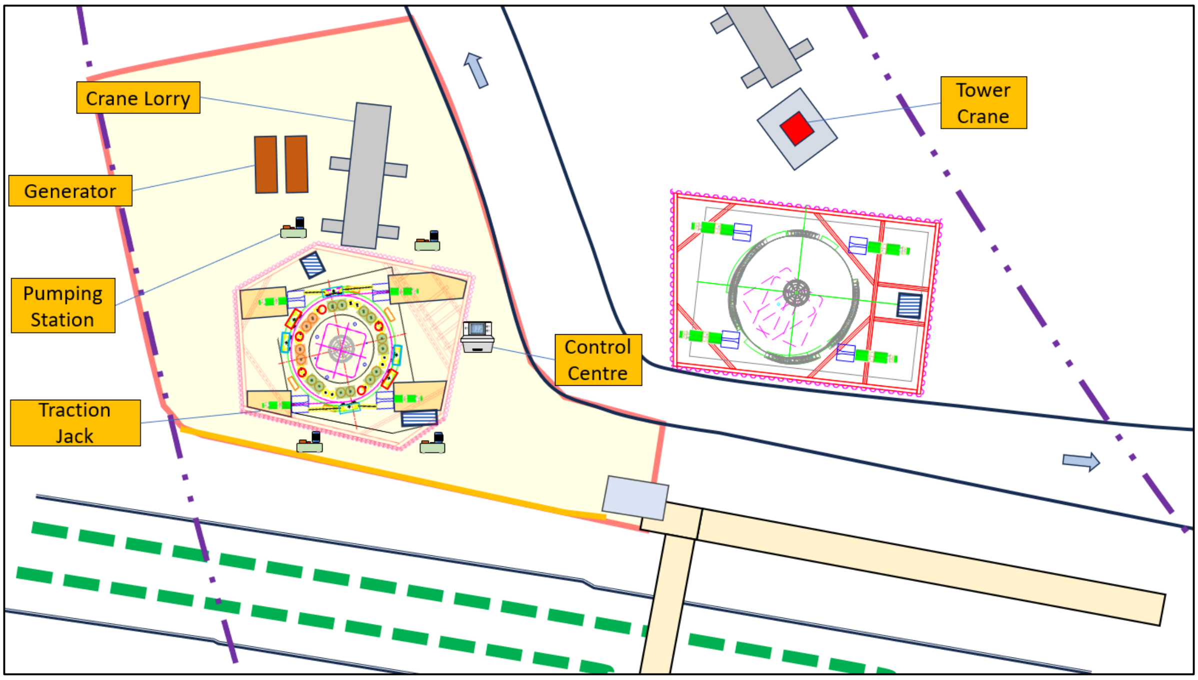


Figure 4.30 - Layout of equipment placement

The major equipment for the weight balancing are the displacement gauge, load cells with hydraulic jacks, and computer for data-logging and analysis of the displacement verse force. (**Figures 4.31 to 4.33**).

The bridge rotation operation should also be equiped with the equipment with examples in **Figures 4.34 to 4.40**. Arc length and angle observation scales should be set on the turntable, and a horizontal laser marker should be used as a pointer to observe the angle or arc length of the turntable.

Figure 4.31 - Displacement gauge

Figure 4.32 - Load cell on the hydraulic jacks

Figure 4.33 - Analysis software

Figure 4.34 - Strand jack and guide frame

Figure 4.35 - Wind speed gauge

Figure 4.36 - Survey total station

Figure 4.37 - PTFE sliding plate and the horizontal lazer marker

Figure 4.38 - Control station for hydraulic strand jacks

Figure 4.39 - Backup mono-jack

Figure 4.40 - Hydraulic pump for strand jack

4.7.6 Temporary Works Removal and Installation

The timeframe for dismantling temporary works shall be carefully scheduled in alignment with the bridge rotation sequence and the time previously required for their installation (**Figure 4.41**). Adequate buffer time must be allocated for site clearance activities in the vicinity of the turntable to facilitate a smooth and delay-free rotation process.

- Preparatory measures shall include:
- Surface improvement of the sliding track
- Pre-loosening of bolts and nuts on shear supports
- Pre-loosening of sandboxes to ease removal
- Installation of working platforms for hydraulic jack deployment

In addition, safe and efficient access and egress routes must be established, along with adequate lighting and ventilation systems to support operations, particularly if conducted during night shifts.

Preparation Works before Bridge Rotation
Outside railway track (From D-8 to D-1)

** NTH: Non-traffic hour
TH: Traffic hour
D: The Day of Bridge Rotation

Day	Time	Duration	Work	Allowable Gust Wind Speed
D-10 to D-8	08:00 - 18:00	3 days	Install traction system	/
D-7	08:00 – 18:00	1 day	Install PTFE at Bridge Rotation system (underneath the turntable)	/
D-6	08:00 – 18:00	1 day	Place counterweight on bridge deck (*)	/
D-5 to D-3	08:00 – 18:00	3 day	Temporary works installation at Bridge Rotation system (*)	26m/s (94 km/hr)
D-2	08:00 – 13:00	5 hrs	Weight balancing by load cells of hydraulic jack system (*)	26m/s (94 km/hr)
	13:00 – 16:30	3.5 hrs	Install remaining PTFE and prepare pre-rotation bridge configuration (*)	
	16:30 – 18:00	1.5 hr	Install hydraulic jacks at Bridge Rotation System (*)	
D-1	08:00 – 10:00	2 hrs	Temporary works installation at Bridge Rotation System (*)	26m/s (94 km/hr)
	10:00 – 14:00	4 hrs	Trial rotation by 1 degree (outside railway track) (*) [ICE loading certificate for the bridge structure with grouted tendons and counterweight will be issued prior to the trial rotation to confirm that the bridge structure is ready for rotation]	
	14:00 - 24:00	10 hrs	Data analysis of trial rotation result	
	Total	10 days	Remark: tentative rundown, subject to actual site progress	

(*): ICE loading certificate with hold-point checklist would be provided after completion of activity

Figure 4.41 - Bridge rotation preparation work

The strand jack should be installed and tightened with traction strands around the turntable by preload jack as shown in **Figure 4.42**. The strands should be smooth with no knots. The jacks are horizontally, parallel and symmetrically located on reaction block posts on both sides of the turntable. The center line of the jacks is tangent to the outer circle of the upper turntable and is level with the center line of the traction strand embedded in the upper turntable.

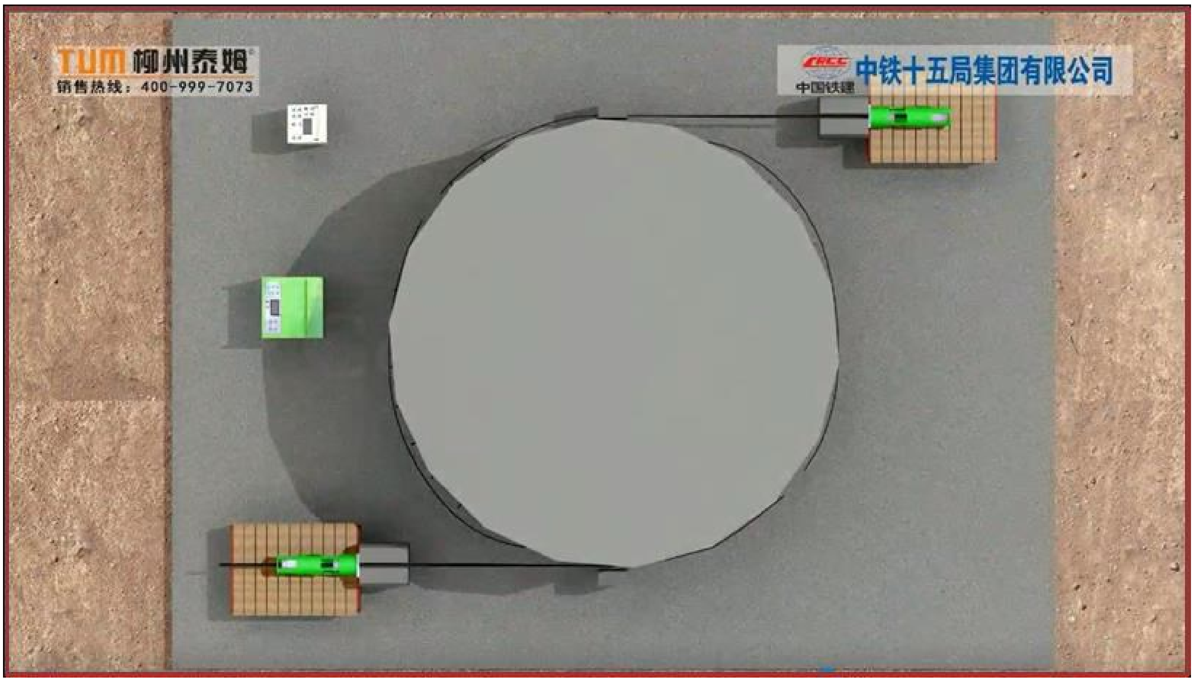


Figure 4.42 - Pre-tightening the traction strand

The quartz sand beneath the support stanchions shall be fully removed to allow the placement of the PTFE sliding plates. In addition, the temporary torsional supports must be installed in advance of severing the temporary external shear supports to preserve structural stability during load transfer.

The external shear steel supports are then flame-cut and detached between the upper and lower turntables, as illustrated in **Figure 4.43**. The removal of these temporary structures shall be conducted symmetrically, in strict accordance with the construction sequence specified by the designer, to ensure proper and balanced load transfer to the spherical bearing and support stanchions.

Following the structural release, the **traction strands** shall be tensioned, fixed, and neatly organized around the perimeter of the upper turntable (see **Figure 4.44**) to facilitate the upcoming rotation procedure.

Figure 4.43 - Cutting of shear supports

Figure 4.44 - Fixing traction strands

The sandboxes are unloaded by removing the quartz sand inside the circular hollow section **(Figure 4.45**). Hydraulic jacks with load sensors are installed at the specified location for weight balancing (**Figure 4.46**).

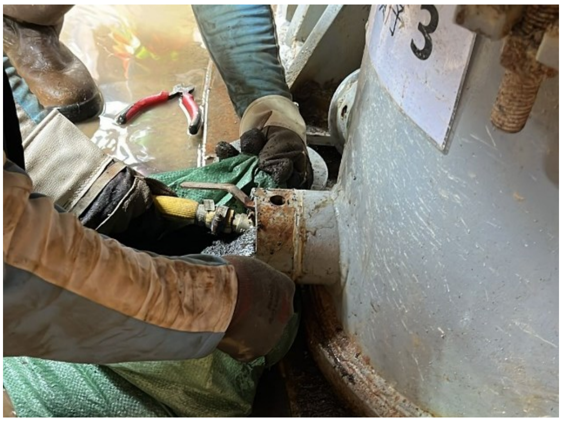


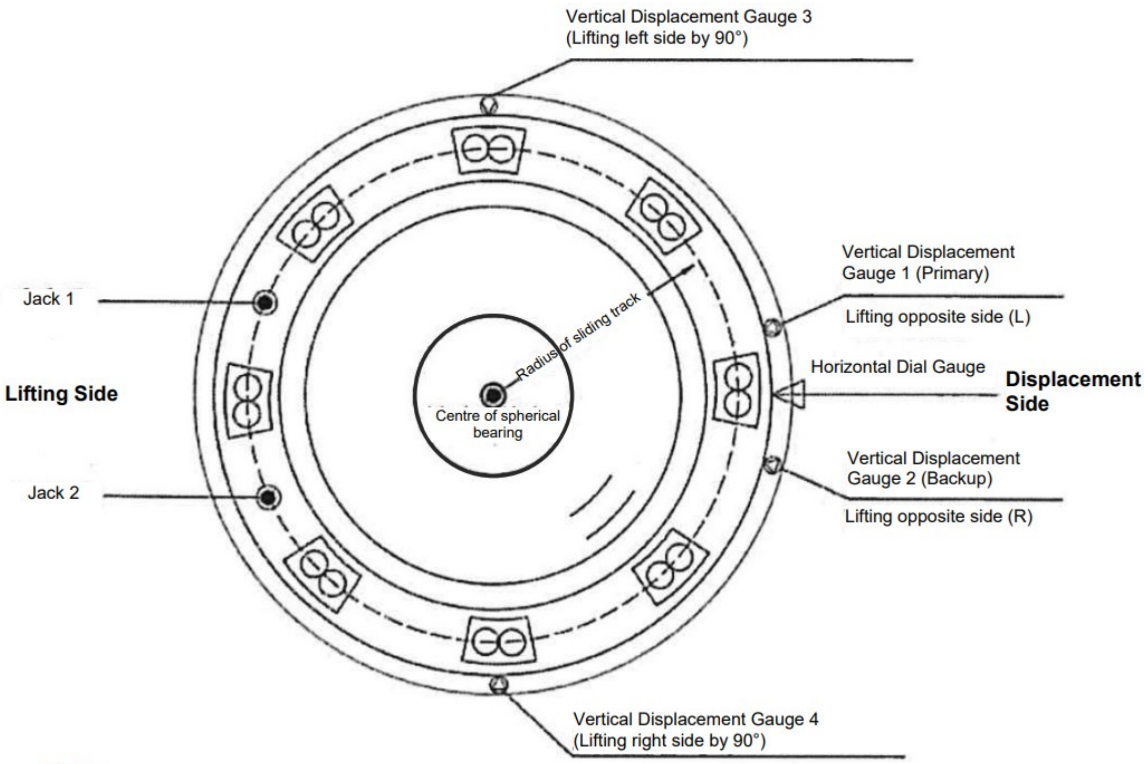
Figure 4.45 - Removing the quartz sand

Figure 4.46 - Sandboxes and hydraulic jacks

4.7.7 Weight Balancing

Weight balancing will be conducted during the pre-rotation stage, following the completion of the bridge structure and the removal of temporary components associated with the rotating system, including shear supports and sandboxes. Before use, all weighing equipment and instruments must be calibrated to ensure accuracy.

Hydraulic jacks will then be installed along the sliding track to raise and lower the upper turntable, as shown in **Figure 4.47**. This creates an unbalanced moment in the rotating bridge structure, allowing the weighing process to proceed. The jacking force and displacement values, recorded during the test and illustrated in **Figure 4.48,** will be used to determine the overall weight balance. Based on the structure's eccentricity, the required counterweight will be calculated. The process will also include calculating the friction torque and friction coefficient of the rotating spherical bearing, with all findings compiled into a comprehensive weight balancing report.



Notes:

1. This schematic applies to longitudinal and transverse bridge weighing tests
2. If the unbalanced moment > friction moment, the lifting side is the side where the stanchions contact the sliding track
3. If the unbalanced moment < friction moment, both sides must be lifted separately in symmetrical setup

Figure 4.47 - Hydraulic Jack Arrangement

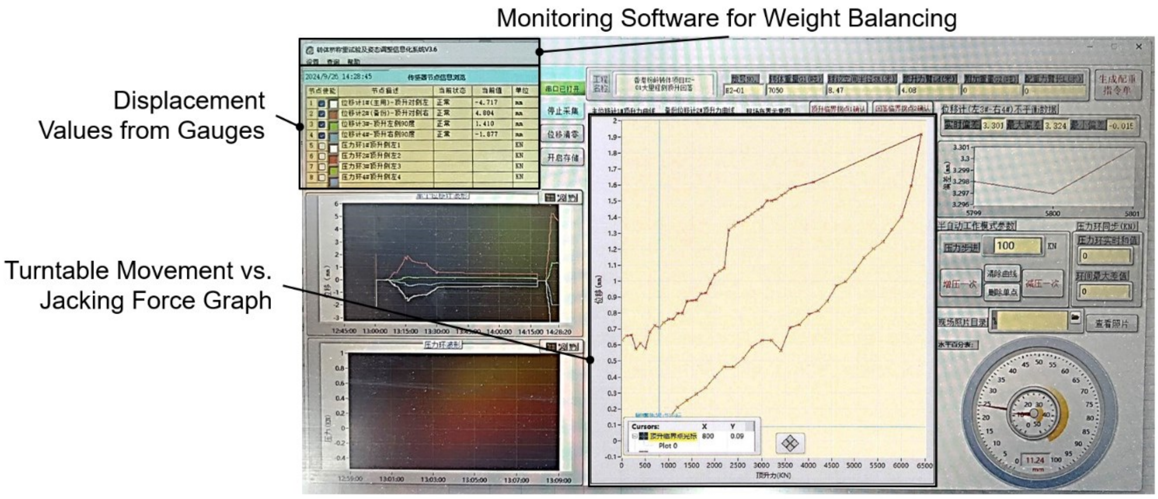


Figure 4.48 - Turntable Movement vs. Jacking Force

During this procedure, the stability, eccentricity, and traction of the structure will be carefully assessed. It is essential to keep the longitudinal eccentricity between 0.05 m and 0.15 m. If it is confirmed to be below 0.15 m, no counterweights will be placed on the bridge deck. Transverse weight balancing will not be required.

4.7.7.1 **Application of Counterweights in Bridge Rotation**

To ensure structural stability during bridge rotation, it is essential to eliminate any unbalanced bending moment. This can be achieved either by installing stanchions or by symmetrically placing counterweights at both ends of the bridge deck. Once installed, these counterweights must be securely fixed to the structure. Following the application of counterweights, the resulting structural eccentricity must not exceed 0.15 m.

A practical example of eccentricity control is demonstrated in CEDD Contract No. ND/2019/05 at Pier E2-01. During pre-rotation monitoring, as detailed in **Table 4.7**, a longitudinal eccentricity of 0.282 m was observed—well above the specified limit. Although the theoretical design value of 0.195 m indicated the structure remained safe from an overturning perspective, the weight-balancing process was restricted by the 500-tonne capacity of the hydraulic jacks.

To rectify the imbalance, 48.4 tonnes of counterweights were placed 30.5 m from the centre of gravity based on design calculations. Subsequently, an additional 17.6 tonnes of counterweights were added following the initial weight-balancing test. This successfully reduced the eccentricity to 0.01 m (see **Figure 4.49**).

Table 4.7 - Theoretical Moment Design Values

Moment and Eccentricity at Final Stage	Theoretical Value	Deduced Value from Strain Gauge Measurement	Moment Allowance
Total Longitudinal Moment	13,412 kNm	19,358 kNm	158,076 kNm
Total Longitudinal Moment	0.195 m	0.282m	2.298 m
Total Transverse Moment	-2,885 kNm	-1,605 kNm	169,797 kNm
Total Transverse Eccentricity	-0.042 m	-0.023 m	2.471 m

Figure 4.49 - Counterweight Concrete Blocks for Weight Balancing

4.7.8 1-Degree Trial Rotation and Functionality Test

A 1-degree trial rotation shall be carried out prior to the formal bridge rotation to verify the functionality of the rotating structure and equipment, and to collect experimental data for the upcoming rotation operation. The trial rotation shall be conducted on the day preceding the formal bridge rotation. During this trial, both the static and kinetic traction forces generated by the strand jacks, as well as the movement of the structure during predefined jacking intervals, will be carefully recorded. A sample record of the trial rotation is illustrated in **Figure 4.50**.

Trial Rotation Procedure:

1. All power and monitoring equipment shall be installed and debugged in accordance with the formal rotation requirements, ensuring normal operation.

2. Temporary torsional supports shall be removed.

3. The structure shall be gradually loaded until movement is initiated, and the static starting traction force and kinetic rotational traction force shall be recorded.

4. The rotation speed shall be adjusted by comparing measured results with calculated design values, and the final trial rotation speed shall match the formal design specification.

5. A series of jacking intervals (e.g., 4 × 5 seconds, 4 × 3 seconds, 2 × 2 seconds, and 3 × 10 seconds) shall simulate the "inching" process required for the final stages of rotation.

The trial rotation shall be deemed satisfactory if the required jacking force and movement data are successfully obtained. The data from the trial rotation shall inform the final "inching" process during the last stages of the formal bridge rotation. The entire procedure, including data analysis, is expected to take approximately 1 - 2 hours. Upon completion, the structure will be temporarily secured to prevent unintended movement.

Trial Rotation Data Analysis

E2-01 转体桥 试转数据分析表

	序号	测试项目	x	y	已转动角度（°）	已转弧长（m）	本次转动弧长（m）	本次转动角度（°）
		记录内容（其中：360度棱镜设置在纵桥向 小 里程梁端位置；实际天窗点:2024年 9月28日 10：02 至 10：31						
Static Traction Force/ Design Value	1	初始牵引力/设计值			180 KN/ 679.3 KN			
Kinetic Traction Force/ Design Value	2	匀速牵引力/设计值			160 KN/ 407.6 KN			
Angular/ Arc Length Rotation Speed	3	匀速转动角速度/梁端线速度			____(度/分钟) ____ (m/分钟)			
Rotated Angle (°)and Arc Length (m)	4	转体操作工况	x	y	已转动角度（°）	已转弧长（m）	本次转动弧长（m）	本次转动角度（°）
Trial Rotation Initial Value	5	试转前初始值			0.179	0.21		
Inching Initial Value	6	点动初始值			0.180	0.21		
2nd time 5s	7	第2次5s			0.184	0.23	0.02	
…	8	第3次5s			0.251	0.30	0.07	
…	9	第4次5s			0.282	0.34	0.04	
…	10	第5次5s			0.317	0.38	0.04	
1st time 3s	11	第1次3s			0.342	0.41	0.03	
…	12	第2次3s			0.361	0.43	0.02	
…	13	第3次3s			0.382	0.46	0.03	
…	14	第4次3s			0.398	0.48	0.02	
…	15	第5次3s			0.412	0.49	0.01	
1st time 2s	16	第1次2s			0.417	0.50	0.01	
…	17	第2次2s			0.424	0.51	0.01	
1st time 10s	18	第1次10s			0.452	0.54.	0.03	
…	19	第2次10s			0.480	0.57	0.03	
…	20	第3次10s			0.509	0.61	0.04	
	21	第__次__s						

1- Accumulated Trial Rotation Angle
2- Accumulated Rotated Arc Length
3- Elevation Difference
4- Bridge Deck Level Changes

数据统计情况： 1-累计试转角度：0.812 2-累计已转弧长值：0.97 3-平面姿态偏差： 4-梁端标高变化：-0.048m

记录人员：Record 复核人员：Countersigned

Figure 4.50 - Record of Trial Rotation

4.7.9 Bridge Rotation

The bridge rotation operation shall only proceed upon successful completion and verification of the 1-degree trial rotation. All designated personnel are required to be on-site at least two hours prior to the scheduled rotation to attend pre-work briefings and conduct final checks on equipment (**Figure 4.51**). During this preparation period, the hydraulic system must be pre-heated to ensure operational readiness. The formal bridge rotation will commence only under the instruction of the Project Manager and upon receipt of track possession notification from MTR, scheduled for 2 a.m. during the NTH.

Figure 4.51 - Pre-work briefing for workers

In the case of CEDD Contract No. ND/2019/05, once the command from the construction team leader is received, the bridge rotation operation commenced with the control station operating the hydraulic system for the strand jack to pull traction strand at a uniform rate of 1.8 °/min, rotating the bridge clock-wise. The two strand jacks were jacking synchronously under real-time monitoring.

When the bridge was rotated to 3° away from its final position, the construction team leader instructed the control station to reduce the rotation speed to around 1.08 °/min. Simultaneously, the hydraulic system adjusted to 60% traction force to gradually decelerate the bridge's angular momentum.

As the bridge approached its final position, rotation was halted when it reached approximately 1° from the target orientation—corresponding to an arc length of around 700 mm at Pier D2-01. The team leader issued the stop command, allowing the structure to decelerate and come to rest through inertia.

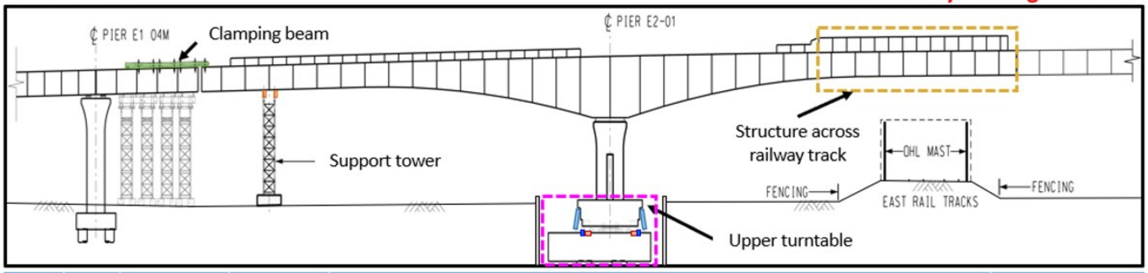
Immediately afterward, the survey team measured and confirmed the actual rotated angle and remaining arc length. Once the data was verified, the construction team leader authorized the commencement of the "inching" process, using the hydraulic jacks for fine alignment adjustments.

The final alignment, including inching, was successfully completed within 30 minutes, with an additional 15-minute float time reserved (refer to **Figure 4.52**).

Day of Bridge Rotation

D (NTH)

** NTH: Non-traffic hour
TH: Traffic hour
D: The Day of Bridge Rotation



Item	Day	Time	Duration	Work	Allowable Gust Wind Speed
1	D (NTH) **	02:00 – 02:45	45 mins #	Rotate T-span (# anticipated 30 mins for completion, allowing 15 mins float time) [Strands will be cut after confirmed completion of rotation and the bridge structure itself is structurally stable at all time]	26m/s (94 km/hr)
2		02:45 – 03:00	15 mins	Install hydraulic jacks and horizontal secondary jacks at Bridge Rotation system (underneath the turntable)	
3		03:00 – 04:00	1hr	Final adjustment of bridge structure by jacks	
4		04:00 – 04:30	30 mins	Add shims at stanchions at Bridge Rotation system (underneath the turntable)	
5		04:30	-	**Finishing Point** – Issue ICE certificate (**)	

Control Point:

i. Should not commence if later than 02:15

ii. Should stop and install temporary works 1-3 if cannot complete by 02:45

[dashed magenta box] Key activities were demonstrated satisfactorily on site to MTR on 27 May 2024

(*): ICE loading certificate with hold-point checklist would be provided after completion of activity

Figure 4.52 - Timeframe for Bridge Rotation Works

The whole process was monitored in real-time by the monitoring team. In addition to the established real-time monitoring system, the monitoring team should verify the monitoring data and report to the construction team leader regularly, say in every 5 degrees for a total rotation of 31 degrees for Pier E2-01. The '3A' value was set in the system as illustrated in **Table 4.8**, if any value exceeds the limitation, monitoring system will alarm and corresponding measures will be taken.

Table 4.8 - Alert, Alarm, Action Value in Bridge Rotation Monitoring System

Critical Parameters	Alert	Alarm	Action
Concrete Stress under Bearing (Bearing ULS Design Capacity: 16Mpa; Concrete Stress Limit: 60Mpa)	≥ 11.2Mpa	≥ 12.8Mpa	≥ 14.4Mpa
	Closely monitor rotation speed	Slow down rotation (Slow down 20%, <1.2°/min – E2-01; <1.8 °/min – D2-01)	Suspend rotation for investigation
Rotation Speed (Operation Limit: 1.5°/min for E2-01; 2.25°/min for D2-01)	≥ 1.20°/min (E2-01); ≥ 1.80°/min (D2-01)	≥1.33°/min (E2-01); ≥ 2°/min (D2-01)	≥ 1.46°/min (E2-01); ≥ 2.15°/min (D2-01)
	Closely monitor rotation speed	Slow down rotation (Slow down 20%, <1.2°/min – E2-01; <1.8 °/min – D2-01)	Further reduce rotation speed, restart rotation system if rotation speed not decreased
Wind speed (Operation Limit: 26m/s)	≥ 20.8m/s	≥ 23.4m/s	≥ 26m/s
	Closely monitor rotation speed	Slow down rotation (Slow down 20%, <1.2°/min – E2-01; <1.8 °/min – D2-01)	Suspend rotation, restart after wind speed decreased

4.7.10 "Inching" Process and Final Bridge Adjustment

Once the construction team leader authorizes the start of the "inching" process, the control station shall operate the traction system in short intervals of 2, 3, 5, or 10 seconds, as previously validated during the 1-degree trial rotation. Throughout each jacking interval, the horizontal arc length movement and the corresponding rotational angle of the bridge should be carefully recorded. Continuous monitoring of the remaining arc length is critical to ensure that the bridge deck stays within the transverse tolerance, which typically ranges from 50 to 100 mm.

After the bridge reaches its intended final alignment, the survey team shall verify the transverse, vertical, and longitudinal offsets at the centre of the T-span and report their findings to the construction team leader. The equipment team will then install temporary jacks beneath the upper turntable to adjust the end-tip level within the maximum allowable deviation of 150 mm. The effect of each 1 mm vertical movement of the hydraulic jack on the upper turntable, pre-calculated based on the bridge's geometry, is used to guide this adjustment. For example, at Pier D2-01, a 1 mm vertical jack movement corresponds to an end-tip level change of approximately 9.04 mm, as illustrated in **Figure 4.53**. The final alignment process is deemed complete when the transverse and vertical offsets at the bridge end-tip, along with the pier centre eccentricity, fall within the tolerances specified by the designer.

Steel strand radius 鋼絞線半徑	4450	mm
Sliding track radius 滑軌半徑	3650	mm
Eccentricity (C.L. Pier – C.L. Rotation) 偏心距離（柱中-轉心）	153	mm
Eccentricity (C.L. Span – C.L. Rotation) 偏心距離（橋中-轉心）	0	mm
Stanchion in contact with ground Ref. No. 著地撐腳編號	9/10 & 11/12	
Pierhead elevation 柱頂標高	32.27	m
Top of pile cap elevation 樁帽標高	9.2	m
Difference in elevation between pierhead and pile cap top 相對高差	23.07	m
Elevation of C.G. to turntable 重心高差	20	m
Cantilever span length 懸臂長度	32.9973	m
Self-weight 自重	4250	T
Traction force 轉動牽引力	120	T
Shift of C.G. after tilting 傾斜之後，重心偏移	109.59	mm
Friction to be overcome by 500T jack 500T頂升克服摩擦力	146.30	T
Eccentric gravity to be overcome by 500T jack 500T頂升克服偏心重力	127.60	T
Equivalent centreline changes by 1mm traction jacking 牽引1mm影響中線	7.42	mm
Equivalent bridge deck tip level changes by 1mm hydraulic jacking 頂升1mm影響高程	9.04	mm
Equivalent pierhead level changes by 1mm hydraulic jacking 頂升1mm影響柱頂	6.32	mm
Ratio of level change of end-tip to pierhead 高差與柱頂受影響程度	1.43	times
Rotation angle 轉動角度	62	degree
Trial rotation angle 試轉角度	1	degree
Level difference 高差	23.070	m
Longitudinal displacement after tilting 傾斜之後縱向位移	126.41	mm
Elevation change after tilting 傾斜之後高程變化	180.81	mm
Theoretical rotation speed 理論轉動速度	1.8	degree/min
Displacement per 1° rotation 每轉動1°偏移值	0.576	m
Displacement at 62° rotation 轉動62°偏移值	35.688	m
Displacement per 1s of inching 點動1s偏移值	11.03	mm
Displacement per 3s of inching 點動3s偏移值	33.10	mm
Displacement per 5s of inching 點動5s偏移值	55.16	mm
Displacement per 10s of inching 點動10s偏移值	110.33	mm
Extension of steel strand per 1° rotation 每轉動1°鋼絞線伸長值	77.67	mm
Total extension of steel strand at 62° rotation 62°總共伸長	4815.36	mm

Rotation for D2-01 with Fully Enclosed Form Traveller

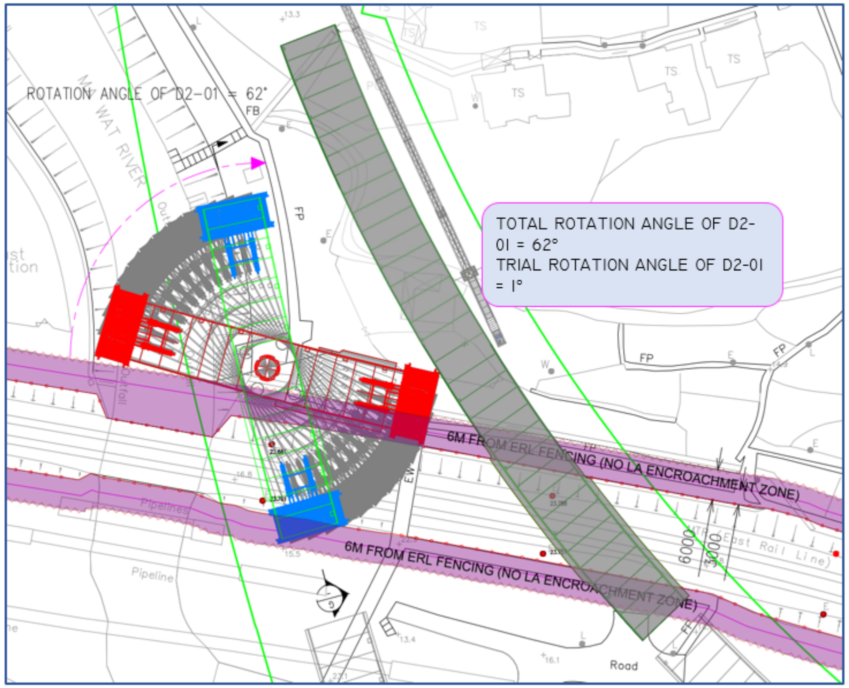


Figure 4.53 - Pre-calculation Technical Data for Bridge Rotation

Once the final adjustment is complete, the rotating bridge structure shall be temporarily secured using designated temporary works. The PTFE sliding plate located between the stanchion and the sliding track must be removed, after which the resulting gap shall be shimmed with steel plates and fully welded to ensure structural stability. All temporary works must be completed within the designated timeframe. Following a thorough track inspection, the line-clear certificate shall be signed by MTR to authorize the resumption of railway traffic.

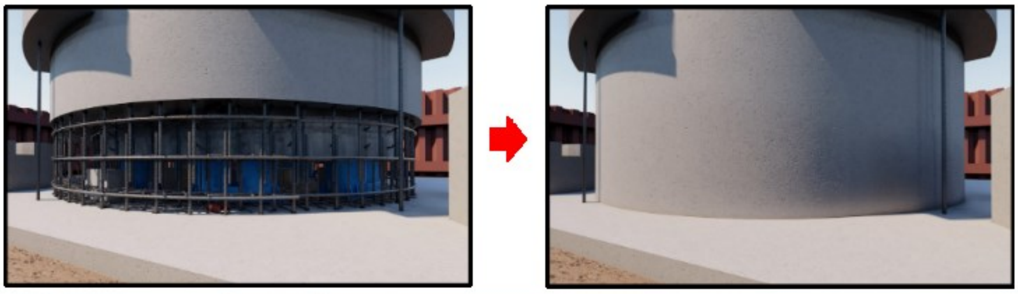
4.7.11 Post-Rotation Works

Following the completion of the bridge rotation, temporary support systems must be installed to stabilize the structure. These include the temporary torsional steel support and the temporary tie-down system. A clamping beam should be secured at the tip of the down-change to provide additional reinforcement. The gap between the stanchion and the sliding track is to be filled with non-shrink grout to ensure proper load transfer and prevent movement.

Subsequently, the traction strand and the temporary torsional steel support shall be removed to allow for rebar fixing at the stitch zone between the upper and lower turntables (**Figure 4.54**). Once the concrete placed at the stitch has attained the required strength **(Figures 4.55 and 4.56)**, the counterweights used during rotation can be safely removed. The pile cap area may then be backfilled, and the remainder of the bridge construction shall continue in accordance with the prescribed sequence outlined in the bridge design documentation.

Stitching Work after Bridge Rotation
(From D+1 to D+9)

** NTH: Non-traffic hour
TH: Traffic hour
D: The Day of Bridge Rotation



Day	Time	Duration	Work
D (TH) **	04:30 – 24:00	19.5 hrs	Temporary works (temporary supports, shims underneath stanchion and tie down bars) installation at Bridge Rotation system (*)
	04:00 – 08:00	4 hrs	Install clamping beam at connection between Piers E1-04 and E2-01 (*)
	08:30 – 18:00	9.5 hrs	Remove traction system at Bridge Rotation system
D+1	08:00 – 18:00	1 day	Grout of temporary works at Bridge Rotation system
D+2 to D+5		4 days	Rebar fixing of stitch between upper and lower turntables
D+6 to D+8		3 days	Formwork erection for stitch between upper and lower turntables
D+9		1 day	Concrete casting of stitch between upper and lower turntables
	Total	10 days	

(*): KE loading certificate with hold-point checklist would be provided after completion of activity

Figure 4.54 - Stitching Work after Bridge Rotation

Figure 4.55 - Concreting for Stitch

Figure 4.56 - Post-concreting condition of the stitch

5. Monitoring System

5.1 Smart Monitoring for Bridge Rotation Works

During bridge rotation construction, smart monitoring technologies should be utilized to capture real-time data on site conditions and the structural behaviour of the bridge deck. This continuous data stream not only ensures construction safety and precision but also provides valuable insights for engineering research and future innovation. Key monitoring systems include the bridge rotation monitoring system, Automatic Deformation Monitoring System (ADMS), LiDAR-based scanning, AI-enabled CCTV for intelligent visual tracking, strain gauges for stress measurement, inclinometers for tilt detection, and anemometers for wind monitoring.

5.1.1 <u>Bridge rotation monitoring system</u>

The bridge rotation monitoring system serves as an integrated management dashboard (**Figure 5.1**) designed to oversee stress levels and control the performance of the rotational system. It provides real-time tracking of several critical parameters throughout the bridge rotation process, including bridge alignment, rotational speed, and wind speed. Sensors installed beneath the spherical bearing—on the bearing plinth of the lower turntable foundation—monitor concrete stress levels continuously. A three-level alert mechanism is embedded within the system, which automatically triggers alarms and adjusts construction speed whenever pre-set thresholds for stress, rotation rate, or wind speed are exceeded. To ensure precision and safety, 360-degree surveying prisms are deployed to monitor bridge alignment throughout rotation. The system also verifies the balance status of the rotating structure in real time, helping to mitigate risks from external disturbances and ensuring the operation proceeds smoothly and securely.

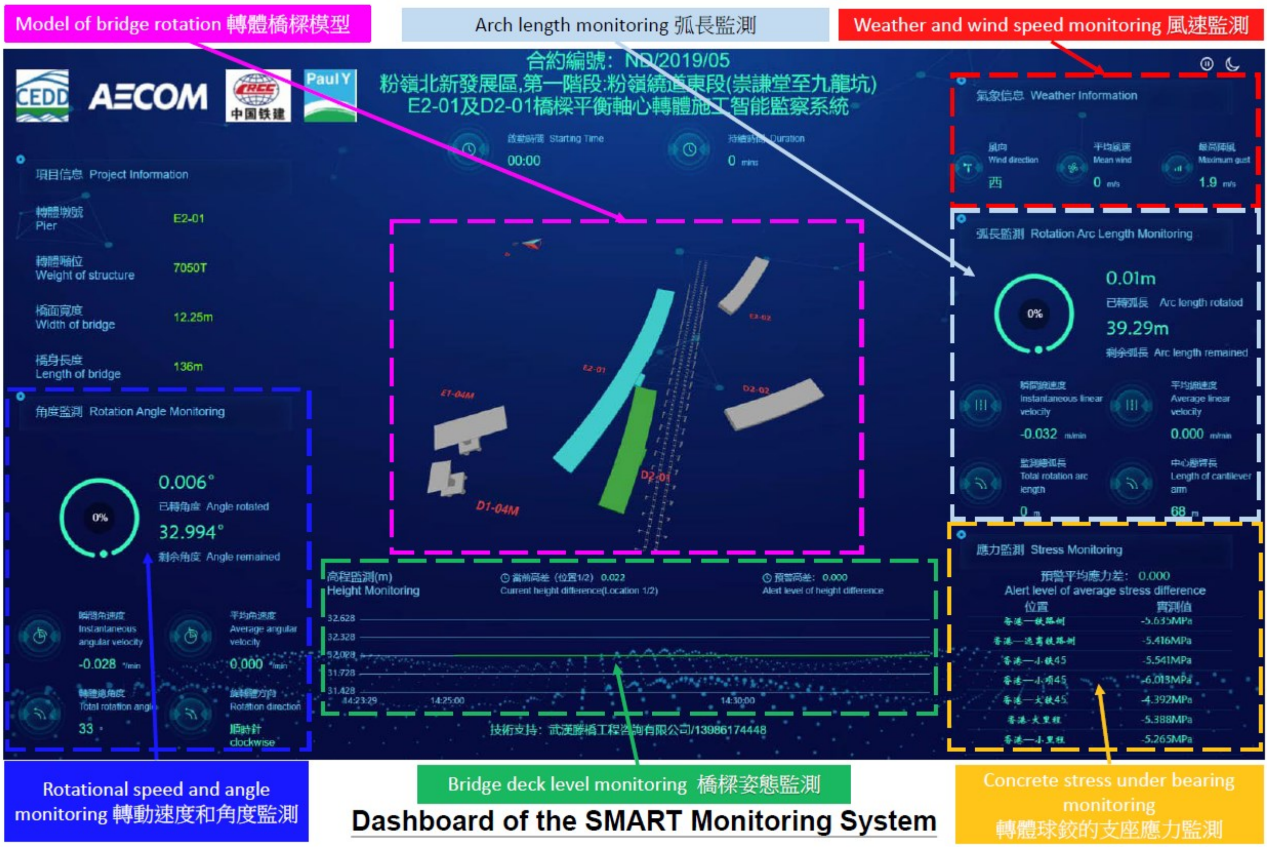


Figure 5.1 - Dashboard of the Bridge Rotation Monitoring System

5.1.2 Automatic Deformation Monitoring System (ADMS)

The Automatic Deformation Monitoring System (ADMS) plays a critical role in safeguarding railway infrastructure during piling and excavation works carried out in close proximity to existing tracks. Its core function is to ensure the structural integrity and safety of railway assets, particularly MTR facilities, throughout operations such as bored pile installation and subsequent construction activities.

The ADMS comprises trackside total stations (**Figure 5.2**) and reflective prisms mounted on railway sleepers. To complement this, inclinometers equipped with real-time data loggers should be installed along the Excavation and Lateral Support (ELS) system. All sensor locations and installation methods must be submitted for MTR approval to ensure compatibility with operational safety requirements. The system continuously monitors key settlement indicators, including differential settlement, cumulative displacement, and structural tilting. Upon reaching predefined thresholds categorized as alert, alarm, or action levels, automatic notifications are triggered. These require prompt implementation of a detailed mitigation plan in accordance with the established response protocol.

Given that the bridge rotation mechanism is generally located below ground atop the pile cap, the surrounding excavated shaft and associated ELS system must remain fully functional and undisturbed for the entire construction duration—from initial piling through to post-rotation stitching. This period may extend beyond two years, making long-term integrity of the monitoring system essential.

To ensure safety compliance, sufficient engineering and survey resources must be allocated to monitor railway track subsidence effectively. Regular reports should be submitted to MTR's Railway Protection & Land Survey Section to maintain ongoing communication and proactive risk management.

Figure 5.2 - Total Station along the railway track

5.1.3 LiDAR Intrusion Detection and AI Camera System

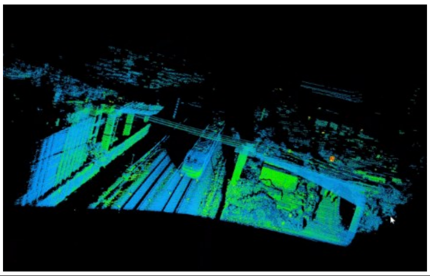
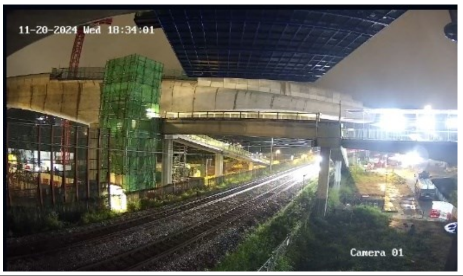
To enhance site supervision and ensure railway safety, Artificial Intelligence (AI) cameras were installed to monitor both the railway track area and ongoing bridge construction activities. These AI-enabled surveillance systems offer continuous 7-day video recording and are capable of issuing real-time alerts to mobile devices when intrusions into the railway zone or unsafe working behaviours within the site are detected.

As an additional layer of protection, a LiDAR-based railway intrusion detection system was implemented along the track in the works area (**Figure 5.3**). This system serves as a second line of defence, and any unauthorized entry into the track zone will trigger immediate alerts in accordance with the established emergency reporting protocol.

A comparative analysis between the AI Camera and LiDAR intrusion detection systems is presented in **Table 5.1**.

Figure 5.3 - LiDAR device along the railway track

Table 5.1 - Technology comparison (LiDAR vs. AI Camera)

Criteria	LiDAR	AI Camera
Image	3D Point Cloud Model 	2D Video 
Frame Rate	50fps detection per second without shutter	25fps, object might blur when fast-moving due to shutter
Accuracy	2M number of points is detected every second to capture the surrounding environment for real-time analysis. Detection is not limited by the object class.	Image recognition accuracy highly depends on the number of pixels and camera resolution. Objects might be omitted if they cannot be classified.
Weather	Able to work under adverse weather, e.g., foggy, heavy rain	Adverse weather with low visibility affects accuracy and detection distance.
Distance	Object size is precisely detected using mass laser scanning	Small objects near the camera and large objects far from the camera appear the same from the camera's perspective.
Angle	Wide range of choice from 120° to 360°	Common range is from 60° to 110°.
Technology	The modern state-of-the-art for object detection. Widely used in industry production (e.g., Tesla, iPhone, drone scanning, aviation, ship, voyage).	Traditional technology for image recognition. Suitable for small investment projects, scattered monitoring, or flexible precision requirements.

In the event that an abnormal situation is detected, the monitoring system will instantly issue alert notifications to both the engineering team and the MTR. These alerts prompt immediate follow-up actions and the initiation of appropriate contingency measures to ensure safety and minimize operational impact. The full sequence of the response mechanism is illustrated in the detailed flowchart provided in **Figure 5.4**.

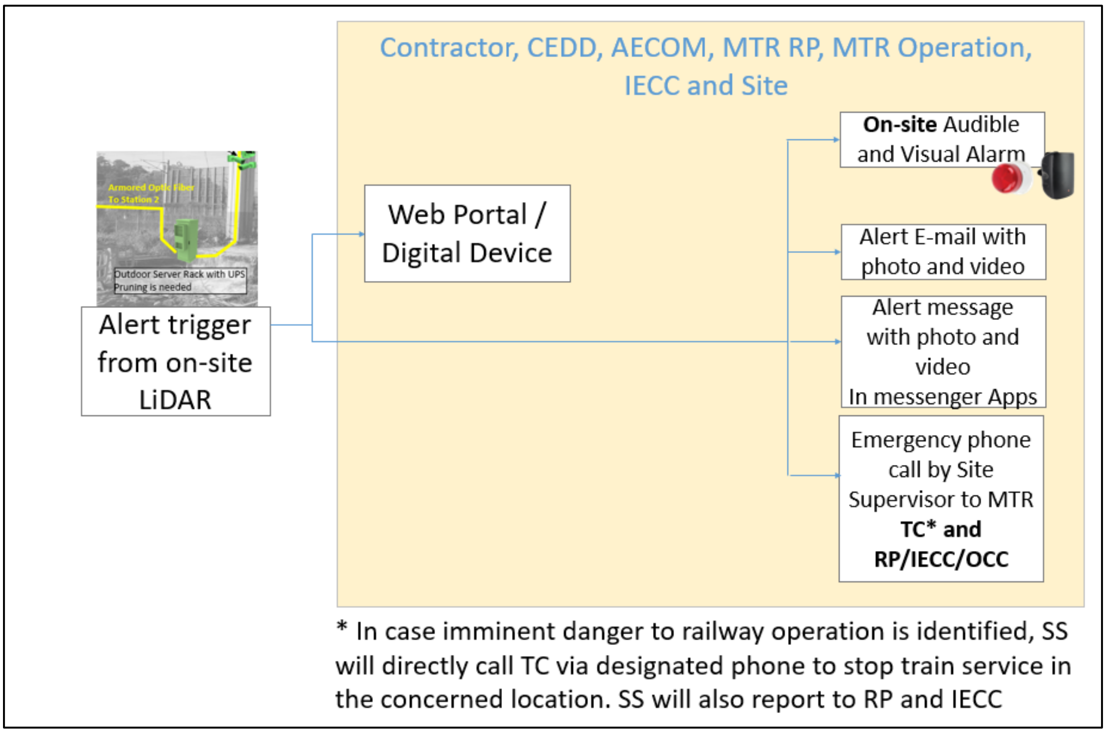


Figure 5.4 - Detailed flowchart for alert delivery by LiDAR and AI camera

5.1.4 Structural Monitoring of Temporary Works

5.1.4.1 **Form Traveller**

During the construction of the cast-in-situ bridge deck, form travellers are employed to facilitate the sequential casting of bridge segments. These travellers consist of a structural frame that supports the segment formworks and are temporarily suspended using high-strength steel bars and anchorage systems.

Given their complexity and structural significance, smart monitoring technology is implemented to assess the performance of key form traveller components in real time. This proactive approach enables early detection of potential issues within the temporary works, thereby improving both safety and construction efficiency (**Figures 5.5 and 5.6**).

Strain gauges are integrated into the monitoring system to measure tension and compression forces acting on critical structural elements. These forces are recorded in microstrain units, where elongation of the gauge indicates tensile strain (positive trend), and shortening indicates compressive strain (negative trend). An automated alert system notifies the project supervisor when recorded strain levels exceed the allowable limits derived from the design working stress, ensuring timely corrective action when needed. This real-time monitoring framework significantly enhances construction control and helps mitigate structural risks associated with temporary works.

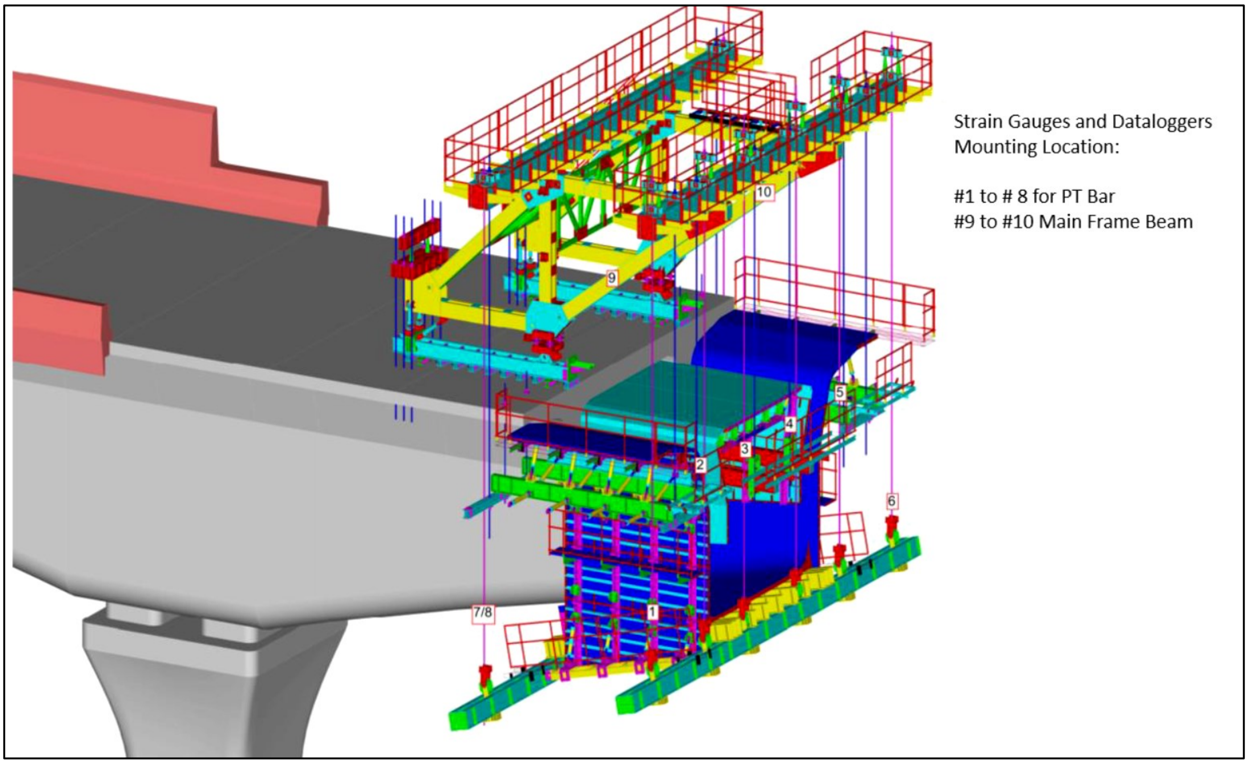


Figure 5.5 - Location of structural monitoring points

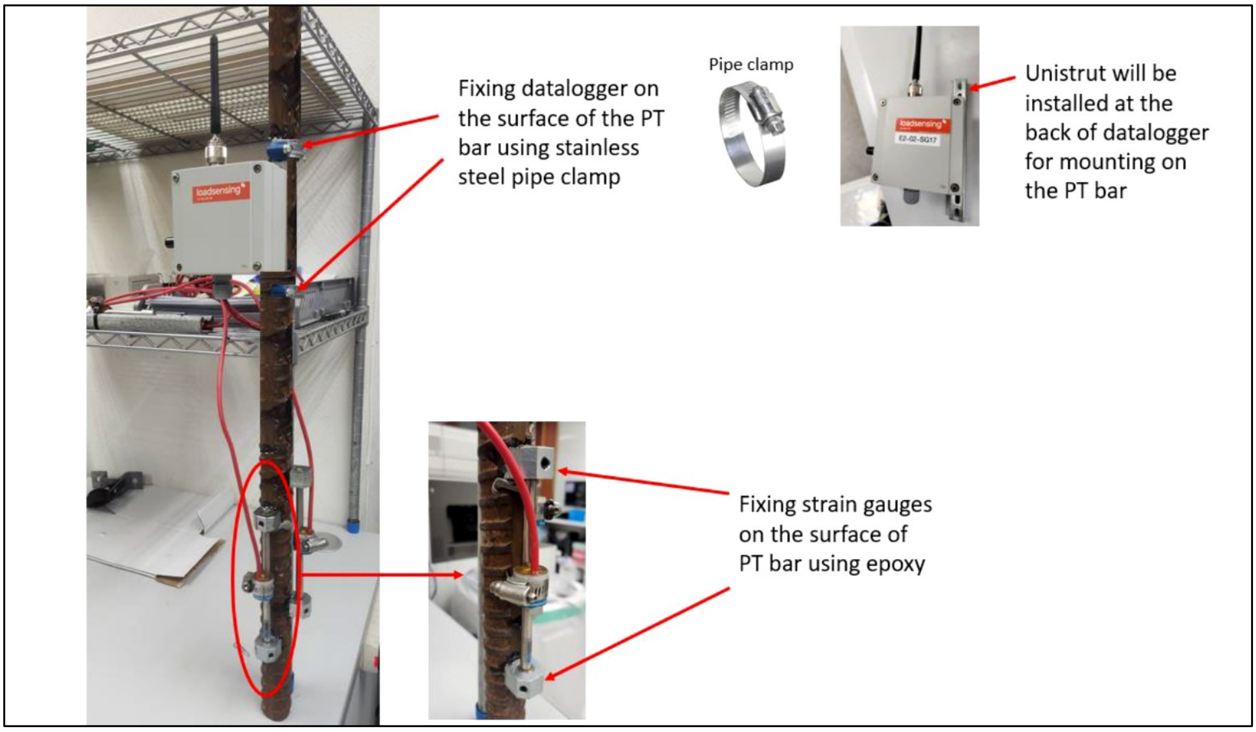


Figure 5.6 - Connection of strain gauges to the high strength bar

5.1.4.2 **Bridge Rotation Turntable Structure**

During the construction stage, the pre-rotation bridge structure was assembled atop the upper turntable, which was primarily supported by temporary works and the central rotational bearing. To ensure safe execution and operational integrity, a suite of sensors and an instrumentation monitoring system was deployed to continuously track load distribution between the superstructure and its temporary supports, as illustrated in **Figures 5.7 and 5.8**.

The monitoring system was specifically configured to measure actual stress levels within the temporary connecting structures between the upper and lower turntables. These measurements were vital for verifying load-balancing conditions and for monitoring the development of overturning moments throughout construction. The system also played a critical role in validating the adequacy of counterweights and confirming that any out-of-eccentricity moments remained within safe limits. This ensured that the bridge rotation process could proceed smoothly without introducing excessive stress to the structure. By delivering real-time data, the monitoring system supported informed decision-making and reinforced the structural integrity of the entire pre-rotation configuration.

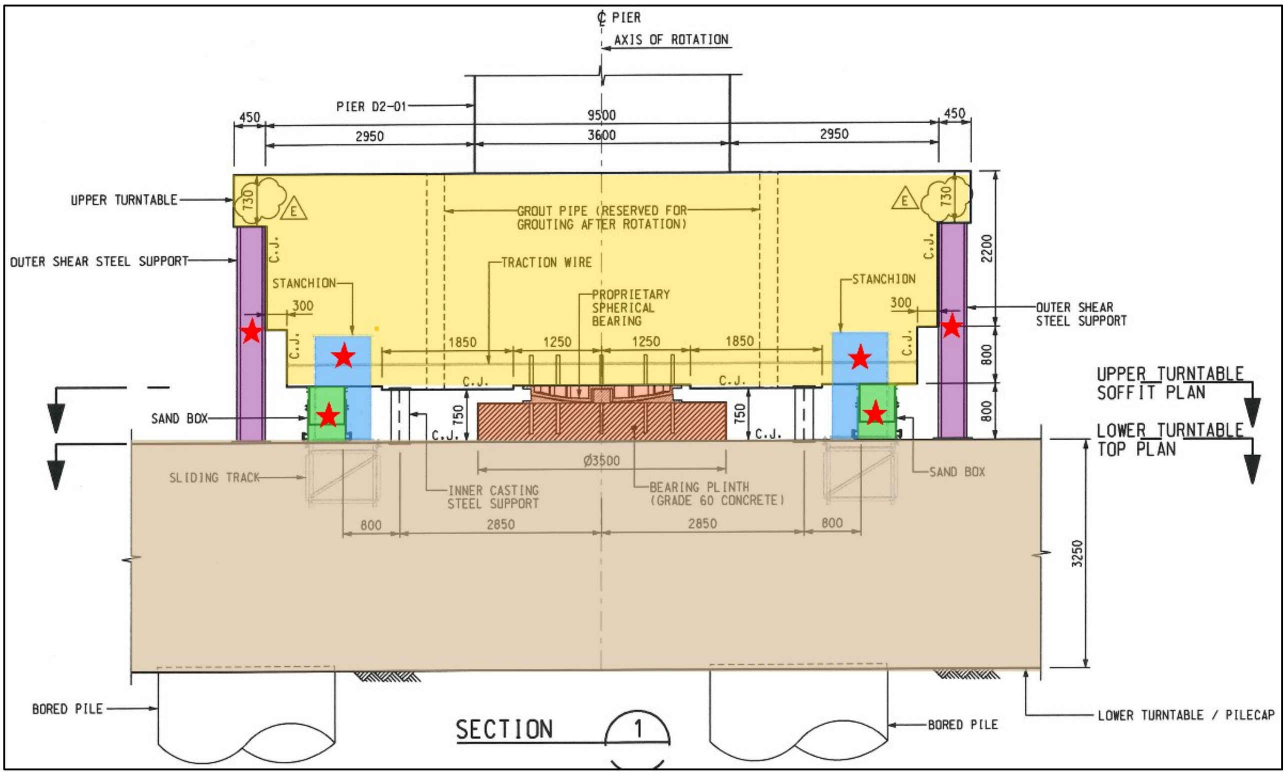


Figure 5.7 - Location of structural monitoring points

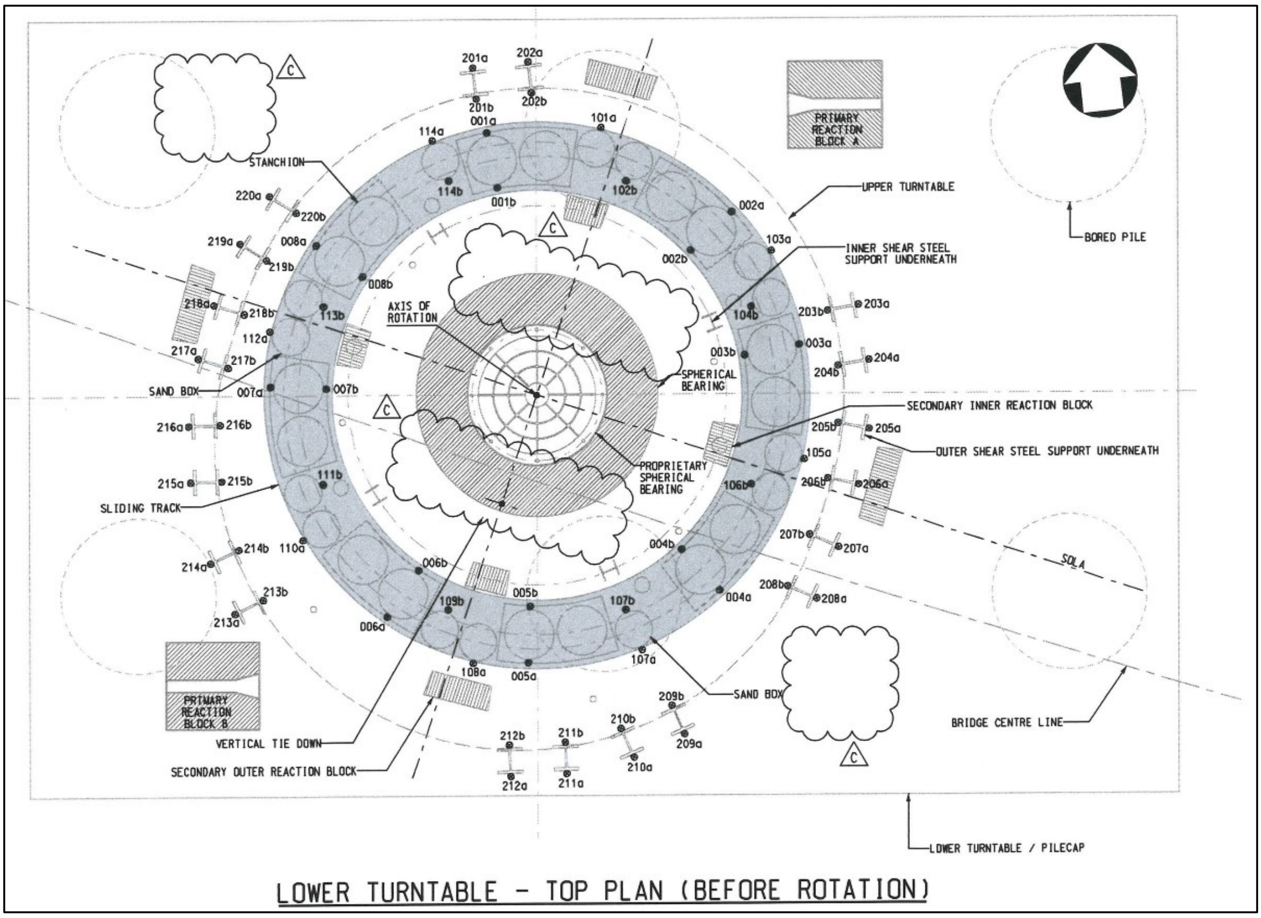


Figure 5.8 - Location plan of structural monitoring points

6. Collaboration with MTR

6.1 MTR Requirements for Bridge Rotation Works in the Railway Protection Area

The construction works for bridge rotation system in the Railway Protection Area must comply with Technical Circular (Works) No. 1/2019 Railway Protection issued by the Development Bureau.

For any proposed works within the Area, Works Departments shall liaise with MTR to minimise any potential/possible interference of the proposed works to railway operation. Where necessary, Works Departments shall consult MTR on various issues such as details of works proposals, protective measures, construction methods, monitoring mechanisms and maintenance requirements. In designing any structure spanning over a railway, Works Departments shall take account of the relevant requirements in the "Structures Design Manual for Highways and Railways" issued by the Highways Department. Consultation with MTR should be commenced as early as possible to ensure key protection measures can be incorporated in the design and construction method.

To cope with MTR year-round operations and over 19 hours daily railway services, the construction time can only be carried out within the two-hour golden window of NTH. The risks duration posed to railway operations will be inevitably prolonged with the traditional bridge construction methods involve numerous complex procedures carried out above the railway. Bridge rotation construction method can complete most of the construction works outside the railway area in advance. The bridge is then rotated into position above the railway. This significantly lowers the related risks. The construction works should also strictly comply with the method statement agreed by MTR and any MTR's internal documents applicable to the works, e.g. **Operational Project Hazard Log (OPHL)**, **Business Unit General Notice (BUGN)**, and **Engineering Document (EDoc)**, etc.

6.2 Enhanced Requirements Encountered During Construction

Due to the nature of bridge construction and rotation operations near the railway, enhanced requirements were implemented based on MTR's feedback during method statement reviews. Key points include:

6.2.1 General Railway Safety Requirements

- Restricted Crane Operations: Lifting appliance swings must not encroach within 6m of the railway area. The lifting plan of the lifting appliances, including but not limited to the swing path, direction of jib, material storage zone, jib failure collapse path, should be agreed with MTR before the setup of the lifting appliances.

- Utilization of all lifting appliances shall be limited to a maximum of 80% of Safe Working Load (S.W.L.).

- Any works within this non-lifting zone were conducted during NTH, typically from 01:30 to 04:30. Activities required traction power supply isolation may further restricted from 02:00 to 04:00.

- If the machinery failure path may intrude into the operating railway, rigid physical barriers shall be provided to separate the works area and to resist the impact load due to the undesirable movement of plants with its design certified by Independent Checking Engineer (ICE).

- For deep excavation works to be carried out, a detailed methodology, works sequence, design, and construction impact assessment to assess all cumulative construction effects in terms of stress change, settlement, and vibration induced by the proposed works to the existing MTR structures certified by Independent Checking Engineer (ICE) should be submitted to MTR for comment and agreement.

- Should there be any anticipated impact brought by the proposed works, such as movement, vibration, stress changes, etc., monitoring proposal including the action plans when the Alert, Alarm and Action values are reached shall also be submitted. Refer to the establishment of Communication and Announcement Mechanism on Public Works within Railway Protection Area in August 2018, such monitoring proposal shall be agreed with the Works Departments and MTR before commencement of works.

- The contractor should coordinate to provide the activities schedule which forecasts the NTH works at least three weeks in advance to MTR.

6.2.2 <u>Special Modifications and Design Considerations</u>

Temporary structures and permanent structures were required to be modified or adjusted upon MTR's request. The general requirements include:

- Temporary ties added to parapet skins on top of push-pull props and kicker concrete before the full parapet structure was cast.

- Installation of additional wire mesh atop the 1.8m high L4 containment barriers to address concerns over falling objects into the railway.

- Scaffolding design catered for wind speed up to Typhoon no. 8 or above according to Hong Kong Wind Code 2019.

- No soffit access openings or external pipes drain of bridge shall be constructed above the railway.

- Street furniture (e.g. lighting pole, fire hydrant, road signage, etc.) should be located away from railway area as far as practicable to minimize future maintenance works above tracks and falling object risks.

6.2.3 <u>Special Requirements for the Bridge Rotation System</u>

- The bridge rotation operation, along with its temporary stabilization works, was required to be conducted during NTH, following the isolation of traction power supply, typically starting at 02:00. The line-clear certificate needed to be signed no later than 04:30, ensuring railway traffic can be resumed. The pre-rotation schedule had to be agreed upon with MTR, with particular emphasis on not removing temporary supports prematurely. A nine-day weather forecast was mandatory, requiring the project team to liaise directly with the Hong Kong Observatory for detailed predictions on rainfall and wind speed during the pre- and post-rotation periods.

- A reverse rotation mechanism was integrated into the bridge rotation system, necessitating the construction of an additional pair of reaction blocks and traction strands. This required enlarging the ELS shaft to accommodate the reverse rotation system. During the pre-rotation stage, the structure was not permitted to encroach into the railway area, limiting the trial bridge rotation operation to a mere 1-degree rotation. This was deemed sufficient to gather essential technical data on the traction force required to overcome static and kinetic friction during rotation, as well as the kinetic behaviour of the system throughout the operation.
- Before bridge rotation, the bridge structure should be design for tilted in such a way that the centre of gravity C.G. is moved away from the trackside to avoid overturning to railway track.

6.2.4 Enhanced Safety and Monitoring Measures

There were enhanced safety and monitoring safeguard required to mitigate the risks:

- Full enclosure of form travellers with fire-resistant safety nets, maintained throughout construction.

- Soffit platform should be enclosed with fire, UV and water resistant material, and water tightness testing should be conducted for form travellers before concreting.

- Installation of 2m tall protective fences with safety nets on the constructed bridge deck.

- Controlled worker access to the deck, including barbed wire installation at access gates, steel corrugated hoarding on access towers and application of facial recognition system and smart pad lock for authorized access.

- Protective wrapping for concrete pump pipe joints to prevent spillage.

- Daily checklists for temporary works and bridge deck housekeeping, verified by the contractor's and supervisor's representatives.

- Site demonstrations for key activities, including tendon stressing, parapet concreting and bridge rotation procedures.

- Installation of Automatic Deformation and Monitoring System (ADMS) and other monitoring instruments, inclinometer and vibration within existing EAL railway tracks with the provisions of a web-based monitoring data management system and carrying out monitoring works.

- Provision of an Intrusion Detection System by LiDAR and CCTV during the construction period.

- Bi-weekly manual survey monitoring of the railway track.

- Full time supervision during daytime by MTR's competent persons for high-risk operations, e.g. rebar fixing, concrete casting, tendons stress, and etc., when the form traveller intruded ahead the railway operation area.

6.2.5 Specific NTH Work Requirements and Protective Measures

Examples of construction activities within 6m of the railway area that could only be carried out during NTH:

- Installation of a 9m tall protective fence with sandwich netting adjacent to the railway before foundation works, providing a rigid physical barrier to prevent plant collapse into the railway operation area.
- Installation and subsequent decommissioning of ADMS towers and LiDAR towers.
- Erection and dismantling of scaffolding and formwork for pier segments.
- Assembly and disassembly of steel platforms for form traveller installation.
- Erection and dismantling of working platforms for lift tower modifications.
- Removal and reinstatement of affected lift towers using cranes, including concreting operations with skips.
- Setting back protective fencing on the bridge deck.
- Lifting and concreting operations for parapet installation using cranes and skips.
- Installation of L3 railing and light poles.
- Launching form travellers.
- Grouting of span tendons across the railway track.
- Bridge rotation operation.

6.3 Preparation and Timeline for MTR Internal Documents

To facilitate coordination with MTR's in-house stakeholders for critical site activities, the project team must work closely with MTR's Railway Protection & Land Survey Section to prepare and submit internal documents. These include the OPHL, BUGN, and EDoc. This process, as illustrated in the workflow (**Figure 6.1**), is suggested to initiate at least half-year prior to first submission to allow sufficient time for review and endorsement by MTR. The project team is responsible for providing relevant method statements covering the entire timeline of bridge rotation operations, from pre-rotation bridge construction to rotation and subsequent bridge activities. The method statements and relevant protective measures should be agreed in principle by Railway Protection & Land Survey Section prior to the processing the MTR in-house procedure. The documentation should be divided into batches aligned with the construction timeline to accommodate the endorsement process.

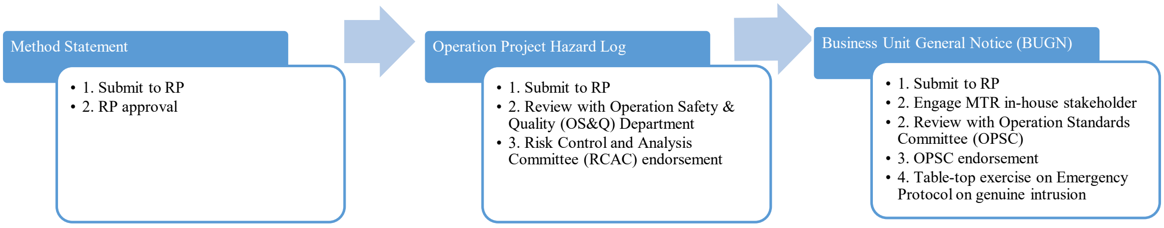


Figure 6.1 - Flowchart for Document Submission

6.3.1 OPHL Preparation and Submission

The process begins with the submission of all relevant method statements to the Railway Protection & Land Survey Section for initial review and comment. The project team must prepare a preliminary OPHL that identifies specific risks (e.g., operational risks affecting future operations and maintenance, risks arising from construction activities, project-specific construction risks, and general site safety risks). The OPHL should propose safeguard measures encompassing design, construction, testing, commissioning, and operations to mitigate risks to acceptable residual levels (R3 or R4, as shown in the risk matrix in **Figure 6.2**). The submission should include a cover checklist and a briefing pack to provide a clear presentation for MTR's stakeholders.

Following the initial review, the OPHL will be assessed and approved during the Risk Control and Analysis Committee (RCAC) meeting, scheduled for the earliest available date in the subsequent month. The overall timeline for OPHL approval is approximately 2.5 months from the first submission.

			CONSEQUENCE						
			7	6	5	4	3	2	1
			Trivial	Negligible	Marginal	Serious	Critical	Catastrophic	Disastrous
Staff/Contractor Safety	Fatality						<5	5 or more	
	Major Injury					<5	5 or more		
	Minor Injury	with ^{3} 3 days sick leave			<5	5 or more			
		with < 3 days sick leave		<5	5 or more				
Passenger/Public Safety	Fatality						<5	5-50	51-500
	Major Injury					<5	5-50	51-500	501 - 5000
	Minor Injury				<5	5-50	51-500	501 - 5000	>5000
Service	Heavy Rail	Line Disruption	<5 min	5<8 min	8<20 min	20-60 min	>60 min	1 day	1 week
		Station Disruption	<20 min	few hours	1 day	1 week	1 month	few months	1 year
	Light Rail	Line Disruption	5<8 min	8<20 min	20-60 min	> 60 min	1 day	1 week	1 month
		Station Disruption	Few hours	1 day	1 week	1 month	few months	1 year	> 1 year
FREQUENCY A	Few times per week or more	^{3} 100 /year	R3	**R1**	**R1**	**R1**	**R1**	**R1**	**R1**
B	Few times per month	^{3} 10 - <100 /year	R4	**R2**	**R1**	**R1**	**R1**	**R1**	**R1**
C	Few times per year	^{3} 1 - <10 /year	R4	**R2**	**R2**	**R1**	**R1**	**R1**	**R1**
D	Few times in 10 years	^{3} 0.1 - <1 /year	R4	R3	**R2**	**R1**	**R1**	**R1**	**R1**
E	Once since operation	^{3} 1E-2 - <1E-1 /year	R4	R3	R3	**R2**	**R1**	**R1**	**R1**
F	Unlikely to occur	^{3} 1E-3 - <1E-2 /year	R4	R4	R3	R3	**R2**	**R1**	**R1**
G	Very unlikely to occur	^{3} 1E-4 - <1E-3 /year	R4	R4	R4	R3	R3	**R2**	**R1**
H	Remote	^{3} 1E-5 - <1E-4 /year	R4	R4	R4	R4	R3	R3	**R2**
I	Improbable	^{3} 1E-6 - <1E-5 /year	R4	R4	R4	R4	R4	R3	R3
J	Incredible	< 1E-6 /year	R4	R4	R4	R4	R4	R4	R3

*26 Oct 01 : SAFCOM - Cells B6 and C5 change from R1 to R2.

DEFINITIONS OF RISK INDICES

R1 Risk must be reduced save in exceptional circumstances.

R2 Risk must be reduced if it is reasonably practicable to do so.
R3 Risk is tolerable but should be further reduced if it is cost effective to do so.
R4 Risk is acceptable.

Note 1: Only SAFCOM has the authority to grant concessions to R1 hazards for which no practicable risk reduction measures have been identified. In general, only high frequency-low consequence R1 hazards, such as slips and trips, would be given consideration. The decision rationale must be documented.

Note 2: RCAC (for Operations) and POSSC (for new extensions) have the authority to grant concessions to R2 hazards if risk reduction is not practicable or cost of risk reduction is grossly disproportionate to improvement gained. The decision rationale must be documented.

DEFINITIONS OF INJURY:

Major Injury:
- Fracture of any bone (but not a bone in the hand or foot)
- Amputation of hand or foot, or complete severance of a finger or toe
- Penetrating injury or burn to an eye or loss of sight
- Electric shock requiring immediate medical treatment
- Loss of consciousness resulting from lack of oxygen
- Inhalation or ingestion through the skin of any substance leading to acute illness or requirement for medical treatment
- Medical treatment resulting from exposure to a pathogen
- Any other injury requiring admittance to hospital for more than 24 hours

Minor Injury: - Any personal injury which is not a major injury

Figure 6.2 - Risk Matrix extracted from OPHL

6.3.2 <u>BUGN Preparation and Submission</u>

Concurrently, the project team must prepare the draft BUGN, incorporating the risks and safeguard measures identified in the OPHL. The BUGN should detail the working area, scope, general sequence, and safety arrangements. Specific activities requiring execution during NTH must be highlighted, along with contingency and recovery plans for railway operations. In order to plan for the worst, the Railway Protection & Land Survey Section will coordinate with MTR's internal stakeholders to finalize the traffic contingency plan and site recovery plan for the worst-cast scenario before circulating the BUGN formally.
The BUGN will be reviewed and endorsed by the Operation Standards Committee. Assuming no significant amendments, the BUGN approval process is expected to follow approximately one month after OPHL endorsement.

The entire MTR in-house endorsement process is closely linked to the quality of submission by the project team, which affects the Railway Protection & Land Survey Section's ability to provide timely agreement on the method statements that may potentially impact the project's construction progress. Therefore, maintaining close and proactive coordination with the Railway Protection & Land Survey Section is crucial to ensuring smooth project execution.

6.3.3 <u>Minute-by-Minute Programme for Bridge Rotation</u>

Bridge rotation operations differ significantly from other general construction activities such as lifting, installation, dismantling, and concreting, which can typically be suspended if necessary. In contrast, bridge rotation is a time-sensitive operation requiring meticulous coordination. In cases where the rotation cannot commence as scheduled or be completed within the allotted timeframe, detailed arrangements must be discussed with MTR.

To ensure precise execution, the project team must develop a minute-by-minute programme in collaboration with MTR, clearly outlining the allowable float time for each activity (**Figure 6.3)**. Whenever possible, site demonstrations should be conducted to provide accurate time estimates for each task. Since full trial rotations of the bridge structure are generally infeasible, insights from similar bridge rotation operations should be referenced, and site visits could be arranged to enhance confidence in time management.

Contingency plans should be developed in collaboration with the Railway Protection & Land Survey Section for each critical control point in the rotation process, aligning with the railway operation perspective. These measures help mitigate risks and ensure the operation's success despite potential uncertainties or delays.

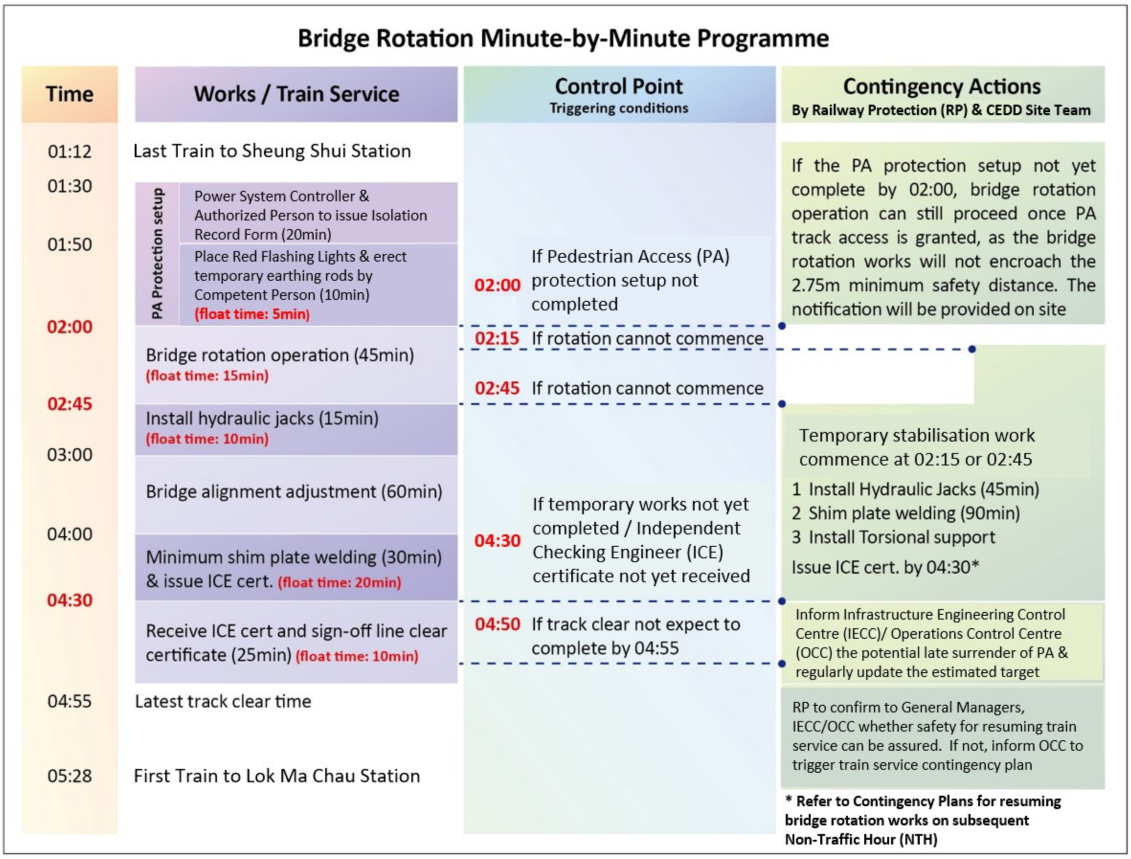


Figure 6.3 - Bridge Rotation Minute-by-Minute Programme

6.3.4 Emergency Preparedness

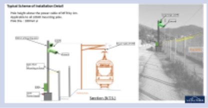
On top of the minute-by-minute programme and contingency plans developed to ensure a smooth bridge rotation operation as well as to prepared for incidental event, table-top exercises would be arranged with the MTR's operation team by the Railway Protection & Land Survey Section for all relevant parties upon BUGN endorsement. Difference incident scenarios would be simulated during the table-top drills.

6.3.4.1 **Emergency Preparedness during Bridge Rotation Operation**

The risk of falling objects during the bridge rotation operation is considered minimal, as illustrated in **Figure 6.4**. However, through discussions with representatives of MTR, it was agreed that the worst-case scenario to be accounted for is the collapse of the rotated T-span onto the railway tracks during or after the rotation.

In this scenario, the contractor must estimate the recovery time required by the site team to clear the debris from the concrete bridge and prepare a detailed recovery plan specifying the necessary plants and equipment. An Emergency Response Unit with standby equipment is to be mobilized within 30 minutes of receiving instructions from MTR.

MTR will assess the time needed to reinstate the affected railway facilities, including the Permanent Way, Civil, Power Distribution and Signalling, and resume train operations. Furthermore, the MTR operations team will implement a traffic contingency plan in which train services will be suspended, and shuttle bus operations will be arranged as an alternative mode of transportation for affected passengers.

Stage	Falling Object Risks	Implemented / Proposed Safeguards
Before Rotation Pre-Rotation (after removal of all sheer supports, i.e. D-3)	Minimal as the bridge structure fall outside the footprint of railway area (including after 1° trial rotation)	Intrusion Detection System (IDS) was established before the construction of pier structures  
During Rotation Post-Rotation (until pier stitch joints reached 7-day strength, i.e. D+16)	Minimal* as no construction works will be carried out above the bridge deck except inspection & monitoring, etc	• IDS will be maintained • Prior & regular inspections of bridge deck to ensure no loose objects • Enhance security control to prevent trespassing to pier and bridge deck above track area
Remaining Works (D+16 onward)	Low (for E2-01) as all permanent structures (incl. parapet) were constructed before rotation Medium (for D2-01) as bridge deck construction to be continued	• Previous safeguards will be maintained • For D2-01, stringent railway protection requirements for construction works will be stipulated (like other constructions above track) • NTH working will be required if falling object risk cannot be eliminated for any works.

* Although extremely unlikely, recovery plan worst scenario of bridge collapse was developed (refer to next page)

Figure 6.4 - Risk of falling object during bridge rotation

6.3.4.2 **Emergency Preparedness for Other Construction Activities**

In case of falling object or object intrusion during other construction activities or subsequence activities after the bridge rotation operation, the reporting protocol in **Figure 6.5** should be followed. In case of imminent danger where stopping train is required, the site supervisor should call directly the railway protection team, Infrastructure Engineering Control Centre and Operations Control Centre via designated call device to report the intrusion. The Traffic Controller will immediately suspend the train service so as to minimize the impact to the smallest. For other intrusion without imminent danger, the site supervisor should report to the railway protection team for arranging earliest work schedule to rectify the intrusion object.

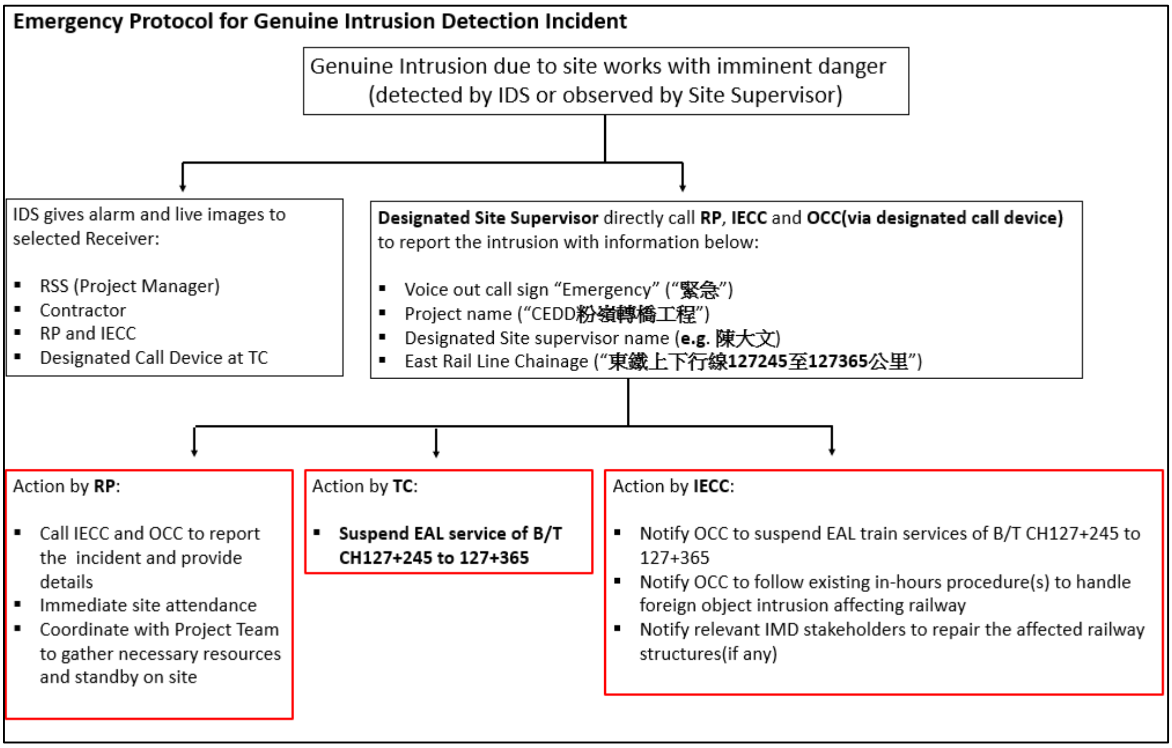


Figure 6.5 - Emergency protocol for genuine intrusion detection incident

6.4 Stakeholders Engagement and Communication Plan

To ensure the smooth execution of the bridge rotation operation, a robust stakeholder engagement and communication plan is essential. The plan involves collaboration across various key parties to address operational, safety, and public concerns effectively.

6.4.1 Coordination with MTR's Corporate Affairs Team and WD's PR Unit

The project public relations (PR) team should work in coordination with the MTR's corporate affairs (CA) team and Works Department's public relation unit (PRU) to develop a comprehensive communication plan. This includes preparing line-to-take and public announcements. The line-to-take for worst case scenario should be prepared. When necessary, an MTR spokesperson will be identified to represent the railway's position and manage public and media communications.

6.4.2 Liaison with Government Departments for Worst-Case Scenarios

In preparation for potential worst-case scenarios, such as operational disruptions or emergencies during the bridge rotation, the project team should inform relevant government departments, including but not limited to Regional Division and Railway Monitoring Division of the Transport Department, Railway Operation & Services Section of Transport and

Logistics Bureau, Police Community Relations Office and Road Management Office of Hong Kong Police Force and Railways Branch of Electrical & Mechanical Services Department.

As the train service disruption affect the cross-boundary passenger management, the Security Bureau (SB) should be informed. The selection of the key date for bridge rotation should be reviewed against the cross-boundary traffic prediction in order to avoid major interruption. The Government Department should be informed about the risks, recovery plans, and their potential roles in mitigating disruptions to public safety and transport operations.

6.5 Good Practices for Stakeholder Engagement with MTR

6.5.1 Site Visit During Construction Stage

To foster a deeper understanding of the construction progress and cutting-edge technology involved in the HBRM among MTR stakeholders, site visits have proven to be a highly effective tool. These visits not only bolstered confidence in the construction works but also promoted valuable information exchange and experience sharing. This collaborative engagement facilitated more informed discussions during the endorsement of method statements and other internal documentation.

Given that full-scale trial rotations of the bridge structure were generally impractical, leveraging similar reference projects and technical visits offered meaningful insights into operational logistics and time management. Under CEDD Contract No. ND/2019/05, a series of site visits were organized to showcase the development of the Fanling New Development Areas to MTR staff. Most notably, two technical visits to mainland China were arranged for the railway protection management team, including:

- 中鐵五局瑤田路上跨廣汕鐵路轉體橋 in Guangzhou
- 湖北襄陽小河港區疏港鐵路專用綫跨焦柳鐵路轉體橋 in Hubei (**Figures 6.6 to 6.9**)

These visits significantly strengthened collaboration and trust among all key stakeholders, including MTR, the Works Department, the Consultant, and the Contractor, reinforcing a shared commitment to excellence in project delivery.

Figure 6.6 - Rotated bridge in Guangzhou

Figure 6.7 - Rotated bridge in Hubei

Figure 6.8 - Group photo in Guangzhou

Figure 6.9 - Group photo in Hubei

6.5.2 Establishment of a Dedicated Railway Protection Team

Drawing from the experience of past projects where incidents arose due to non-compliance on protection measures and potential delays related to manpower and seeking agreement with MTR, establishing a dedicated railway protection team is immensely advantageous for the critical railway protection projects. The team, composing senior railway protection engineer or manager and railway protection inspection staff.

Senior railway protection engineer, or manager should provide engineering advice on submissions, including but not limited to construction proposals, method statements, and monitoring plans, from a railway protection perspective. This role also involves coordinating with MTR in-house stakeholders for critical site activities. They should attend critical site works, site meetings, and demonstrations. This streamline process enhances compliance of safety standards and reduce the potential setbacks during the project execution.

Railway protection inspection staff of dedicated team should monitor site activities closely and ensuring adherence to safety measures. Where appropriate, also act as a Competent Person (Track) to attend critical site works to verify and ensure all activities comply with railway safety requirements. This proactive approach can guarantee the request of manpower and help minimizes the safety risks to railway area throughout the project cycles.

Having sufficient manpower from the MTR Railway Protection & Land Survey Section is essential to ensure the project runs smoothly without delays. This includes timely document processing, comprensive reviews, and multiple tiers of endorsement from MTR, as well as availability for site supervision. The team colllectively contributes to efficiciency and cost-effective completion without delay caused by the document prepareation and endorsemnet, or incident. The manpower cost for MTR to setup the dedicated railway protection team should be borne by the project.

6.5.3 Bi-weekly Progress Meetings and Senior Management Meetings

During the construction period, numerous method statements outlining the construction methods and sequences must be submitted to MTR for review. Any delay in obtaining timely agreement on these method statements could result in significant time and cost implications. Given the operational focus of MTR's railway protection team, they may not always be fully aware of the detailed timelines for the construction activities.

To address this, bi-weekly progress meetings have been found effective in enhancing communication between the project team and MTR. These meetings provide an opportunity to exchange updates on site progress, elaborate on the method statements, and address MTR's comments directly through face-to-face or online discussions.

For critical issues that remain unresolved in the bi-weekly meetings, senior management meetings can be convened to involve higher-level decision-makers. These include General Managers from MTR and the Project Manager from the client department, ensuring that key decisions are made efficiently and effectively.

In CEDD Contract No. ND/2019/05, bi-weekly progress meetings were conducted with engineering representatives from AECOM, CRCC-PY JV, CEDD and MTR's Railway Protection & Land Survey Section. Additionally, senior management meetings were held quarterly in the lead-up to the bridge rotation to address and resolve critical matters.

6.5.4 Compliance and Coordination

The submission of the OPHL and BUGN is critical for securing necessary approvals from MTR. These documents ensure that safety measures and operational risks are thoroughly identified, assessed, and addressed. Early engagement with MTR to review and align on these submissions is essential to streamline the approval process and mitigate potential delays.

Proactive collaboration with MTR helps establish a shared understanding of safety expectations and requirements, facilitating compliance and more efficient project coordination. It is also important for the project supervisor to be well-versed in the details of the endorsed BUGN, ensuring that any non-compliance by the contractor is promptly identified and reported to MTR for appropriate action.

6.5.5 Resource Allocation

Adequate resource allocation is vital for maintaining effective communication and coordination. Given the diverse expectations of various stakeholders involved in railway protection, discrepancies between MTR's requirements and the original proposals are often unavoidable. To address this, additional resources should be allocated proactively to adapt to evolving requirements. The project team may compensate the contractor whenever necessary. By ensuring the availability of dedicated teams from both the project team and the railway protection team from MTR to handle unforeseen changes and align with MTR specific requirements, the project execution process can remain uninterrupted and efficient.

6.5.6 BIM Visualization

The BIM model of the staged construction process, encompassing pre-rotation, rotation, and post-rotation phases, was developed to visualize the detailed construction sequence and site constraints throughout the project.

In CEDD Contract No. ND/2019/05, various BIM applications were effectively utilized, including 3D Coordination (**Figure 6.10**), Existing Conditions Modelling (**Figure 6.11**), Phase Planning with 4D Modelling (**Figure 6.12**), and Site Utilization Planning (**Figure 6.13**). These tools proved invaluable for coordination with MTR.

MTR maintains a strong focus on ensuring adequate vertical and horizontal clearances for both temporary works and permanent structures, as well as assessing potential collapse paths of equipment in proximity to railway assets. These concerns are particularly critical within the designated railway protection zone, where spatial constraints pose complex challenges.

To address these requirements effectively, the project team adopted BIM applications. This digital approach enabled early detection and resolution of clearance conflicts, significantly enhancing spatial planning and risk mitigation. By leveraging BIM's visual simulation and clash detection capabilities, the team was able to optimize the layout and execution of works within the confined site area, while ensuring compliance with MTR's stringent safety standards.

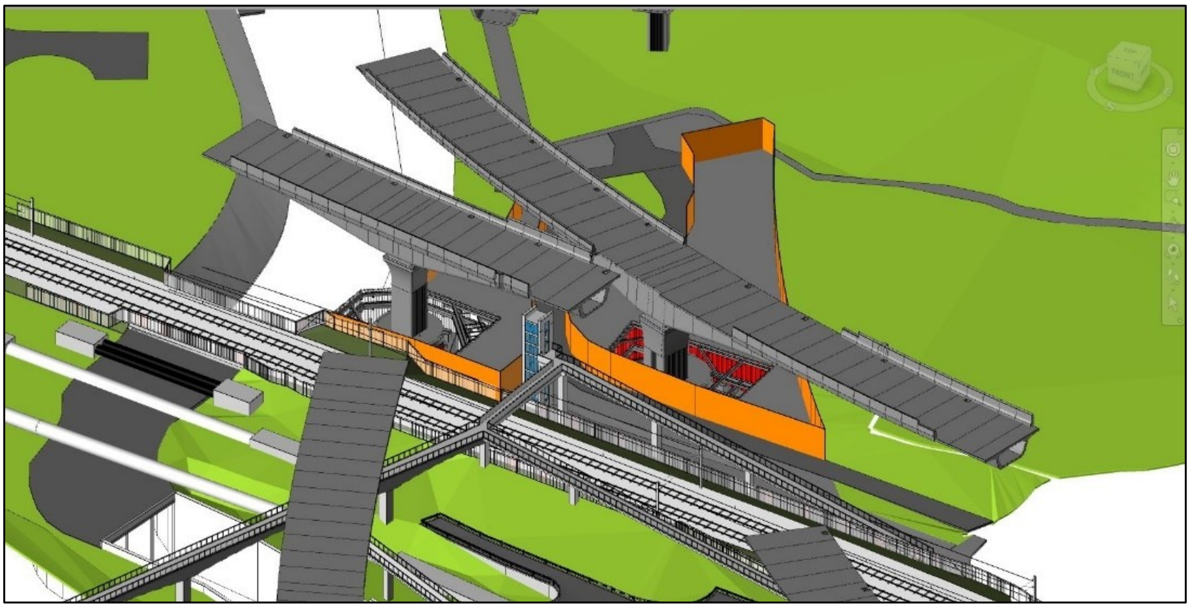


Figure 6.10 - 3D Coordination

Figure 6.11 - Existing Conditions Modeling by Photogrammetry

Figure 6.12 - Phase Planning (4D Modelling)

Figure 6.13 - Site Utilisation Planning

Augmented Reality (AR) Modelling was also employed to enhance stakeholder understanding by showcasing the future bridge deck alignment (**Figure 6.14**) and the components of the bridge rotation system to be installed (**Figure 6.15**). This integration of BIM and AR significantly improved planning, communication, and decision-making during the project.

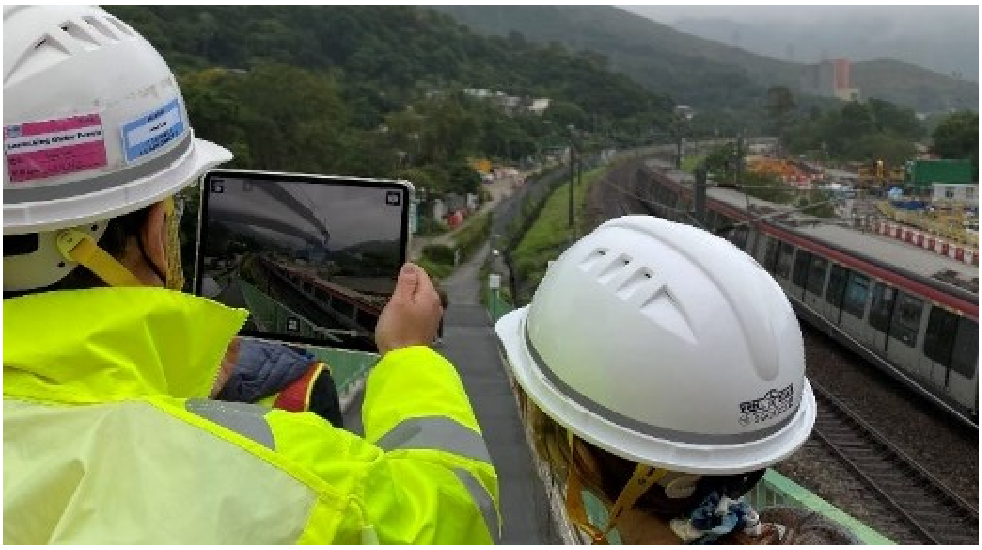


Figure 6.14 - AR BIM visualization during site visit

Figure 6.15 - Capture of Bridge Rotation Elements in the AR BIM Visualization

7. Conclusion

The success of the FLBP bridge rotation project can be attributed to several critical factors, foremost among them being the comprehensive adoption of the NEC3 Target Cost contract framework (Option C) under Contract ND/2019/05. This contract model fostered a collaborative environment deeply aligned with the NEC spirit, emphasizing early engagement, proactive risk management, and transparent communication among all stakeholders. By encouraging genuine partnership between the project team, contractor, and client, the NEC framework created a foundation of shared responsibility and innovation that was pivotal in overcoming the project's complex challenges.

A cornerstone of this success was the exemplary collaboration with the MTR, a critical stakeholder due to the proximity of construction to one of Hong Kong's busiest railway lines. Sustained early engagement with MTR, from project inception through construction and commissioning, ensured comprehensive understanding and alignment on safety protocols, operational constraints, and risk mitigation measures. Numerous meetings at multiple organisational levels, joint site visits, and two technical tours in Mainland China to observe comparable bridge rotation projects reinforced mutual trust and knowledge sharing. This enabled the railway protection team and the project stakeholders to collaboratively endorse construction methods and operational plans with confidence, safeguarding uninterrupted railway services during the bridge rotation. Such collaboration also contributed to significant cost savings and time efficiencies.

The project leveraged valuable insights from prior bridge rotation endeavors in Mainland China while tailoring innovations specifically to Hong Kong's unique urban environment. Under the NEC framework's flexibility, the project adopted design innovations like the reverse rotation system as an emergency fallback and installed robust steel shear supports to counteract stability challenges arising from the viaduct's curved alignment and eccentric loading. NEC's clear mechanisms for programme revisions and management of compensation events facilitated adaptive responses to these technical complexities.

Complementing these measures was the deployment of smart monitoring systems integral to the risk mitigation strategy. These technological systems effectively managed challenging constraints—including congested utility corridors, heavy railway traffic, typhoon exposure, and severely limited access within MTR's stringent railway protection windows. NEC contract provisions supported the dynamic revision of schedules and ensured equitable risk-sharing, enhancing overall safety and operational efficiency.

The project also demonstrated exemplary cooperation across a multidisciplinary and multinational team—local Hong Kong engineers, specialist subcontractors from Mainland China, and a contractor's design team from Singapore. The NEC Option C contract incentivised this integrated teamwork through transparent cost control and target cost sharing, catalysing innovation and smooth coordination throughout the project lifecycle.

Ultimately, the integration of NEC3 Option C contract principles with advanced engineering, innovative construction methodology, and international collaboration delivered a groundbreaking outcome for bridge construction over active railway lines. The FLBP project not only minimized risks to railway operations and neighboring communities but also set a new benchmark for future infrastructure development in densely populated urban contexts. It exemplifies how NEC's collaborative contract framework, combined with cutting-edge technology and cross-border expertise, can drive safer, faster, and more sustainable infrastructure solutions.

The lessons learned and best practices established through this project offer valuable guidance for upcoming infrastructure initiatives in Hong Kong and beyond, promising continued advancement in construction innovation and management excellence.

Reference

1. 刘明辉 (2016) *跨越既有铁路线桥梁平转体施工技术及应用*. 北京：科学出版社

2. 中国铁建股份有限公司 (2024) Q / CRCC 23202—2023 *Technical Specification for Bridge Swivel Construction 中国铁建股份有限公司企业标准*. 北京：人民交通出版社