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FULL REPLACEMENT OF STAY CABLE SYSTEM: STATE OF THE ART PRACTICES, DEDICATED METHODS, MODERN SYSTEM INTEGRATION, AND RISK MITIGATION

Summary: As many cable stayed bridges built in the 1960s reach the end of their original service life, replacing aging stay cable systems has become a major challenge for infrastructure owners. Corrosion, obsolete protection systems, and modern durability requirements drive the need to upgrade these structures with high performance cables. Freyssinet has developed strong expertise in this field, combining advanced engineering, dedicated equipment, and rigorous risk management. This paper presents Freyssinet's approach through recent projects such as the Hooghly River Bridge, the Galecopper Bridge, and the Marqués de Zafra footbridge. These cases highlight two main challenges: integrating modern cable systems into structures designed for older technologies, and safely managing detensioning operations despite uncertainties about existing cable conditions. Freyssinet addressed these issues by engineering tailored solutions, including redundancy systems, controlled detensioning methods, and the installation of durable, replaceable parallel strand systems. This methodology ensures safe cable replacement while preserving structural integrity and minimizing user impact.

Keywords: stay cable, replacement, clamp, detensioning

POTPUNA ZAMENA SISTEMA KOSIH ZATEGA: SAVREMENA PRAKSA, SPECIJALIZOVANE METODE, INTEGRACIJA MODERNIH SISTEMA I UPRAVLJANJE RIZICIMA

Rezime: Kako se brojni mostovi sa kosim zategama izgrađeni tokom 1960-ih približavaju kraju projektovanog radnog veka, zamena postojećih sistema zatega postaje značajan inženjerski izazov. Glavni razlozi za intervencije su korozija, zastareli sistemi zaštite i savremeni zahtevi u pogledu trajnosti. U radu je prikazan Freyssinetov pristup potpunoj zameni zatega na mostovima Hooghly River i Galecopper i pešačkom mostu Marqués de Zafra, sa posebnim osvrtom na integraciju savremenih sistema u postojeće konstrukcije i bezbedno kontrolisano rasterećenje zatega uprkos neizvesnostima u pogledu njihovog postojećeg stanja. Primenjena rešenja obuhvataju pomoćne sisteme, kontrolisane postupke rasterećenja i ugradnju trajnih i zamenljivih sistema sa paralelnim užadima, uz očuvanje konstrukcijske sigurnosti i minimalno ometanje saobraćaja.

Ključne reči: kose zatege, zamena, stega, smanjenje sile prednaprezanja

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1. INTRODUCTION

1.1. AGEING INFRASTRUCTURES FROM THE EARLY DAYS

Cable-stayed bridges and pedestrian footbridges constructed during the 1960s and 1970s are now entering an advanced stage of their service life, where durability-related issues are increasingly observed. Developed during the early phase of stay cable technology, these structures often incorporated design approaches and protective systems that, by today's standards, present limitations in terms of long-term performance. Consequently, a growing body of evidence highlights the occurrence of ageing mechanisms such as steel corrosion, water ingress within cable encapsulation systems, and fretting fatigue between individual wires, occasionally leading to wire failures and a progressive loss of structural capacity. In this context, ensuring the structural integrity and serviceability of such infrastructure has become a critical concern for asset owners and operators.

Regular and comprehensive inspection programmes therefore play a pivotal role in the management of cable-supported structures. These programmes must aim not only to detect visible defects but also to assess hidden degradation mechanisms and predict their evolution. The implementation of appropriate inspection strategies requires a detailed understanding of both the structural system and the specific stay cable technology involved.

1.2. CHALLENGES FOR INSPECTION AND REPLACEMENT

Before the industry evolved by taking into account the first feedbacks on the durability achieved, the installation method improvements and optimal structural solutions & constructive details, many different designs were implemented. This leaves our generation of engineers with a very diverse patrimony of infrastructures:

- Wide diversity of structural configurations & materials (steel or concrete decks and pylons)
- Variability of anchorage layouts (embedded, accessible, saddle-based or discrete anchorages)
- Multiplicity of stay cable technologies (parallel strand systems with or without grout, parallel wire systems, locked coil cables etc.)
- Limited redundancy of certain early designs affecting replacement feasibility
- Operational constraints related to traffic management (partial or full closure)

As a result, both inspection methodologies and cable replacement strategies must be specifically tailored to each individual structure. The feasibility of cable replacement depends strongly on the initial design assumptions, including structural redundancy and the capacity to accommodate load redistribution and acceptable deck deformations during intervention. Furthermore, operational constraints—ranging from partial lane closures to full traffic interruption—significantly influence the construction approach.

This paper presents three representative case studies that illustrate a range of engineering solutions, construction methods, and risk mitigation measures implemented to ensure safe stay cable replacement. Particular emphasis is placed on the integration of modern stay cable technologies into existing structures, thereby enhancing durability, robustness, and long-term performance.

2. HOOGHLY RIVER BRIDGE IN INDIA

2.1. EXISTING CABLE SYSTEM AND MATERIALS

The Vidyasagar Setu (Second Hooghly River Bridge), commissioned in 1992 in Kolkata, is a major cable-stayed bridge with a main span of 457 m and a total length exceeding 800 m. The structure carries very high traffic volumes and is a critical component of the regional transport network. The original stay cable system was based on Parallel Wire System (PWS) technology, consisting of bundles of 7 mm diameter high-strength wires assembled into large cable units. This solution was selected at the time for its high axial stiffness and ease of local manufacturing, contributing to controlled deck deformations and efficient erection procedures.

The cables are arranged in vertical planes outside the main longitudinal girders and are directly anchored into the steel deck structure, without intermediate deviation devices. While structurally efficient, this configuration results in limited redundancy and a high dependency on the integrity of each individual cable. After more than three decades of service in a demanding environment, inspections revealed widespread corrosion phenomena, internal deterioration, and visible wire damage affecting a significant proportion of the stay system. These findings, combined with the strategic importance of the bridge, led to the need for a comprehensive inspection campaign of all 152 cables, and the replacement of a given first batch of cables.

2.2. DETENSIONING SCHEME

The replacement of the PWS cables was governed by exceptionally stringent constraints: the structure offers virtually no redundancy, full traffic closure is not acceptable, and no modification of the existing deck or pylons was permitted. In addition, operations had to be performed primarily under live traffic conditions. These constraints required the development of a highly robust and fully reversible load transfer methodology.

A key innovation lies in the implementation of a modular detensioning system installed directly within the pylon head. This system, referred to as a detensioning chair, enables load transfer at the top anchorage using a hollow jack and threaded mechanical connection. The approach eliminates the need for cutting cables under tension and avoids the use of resins or grouted clamping devices, thereby significantly enhancing safety and controllability. The original anchorage socket remains in place during operations, acting as an inherent fail-safe mechanism in the event of unexpected slippage.

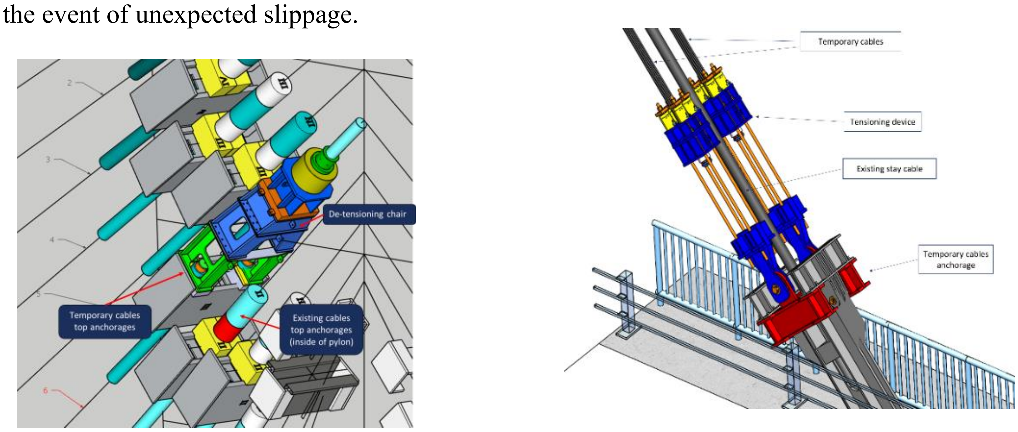


Figure 1: Detension set up at pylon side and innovative tempoary cable anchorage on the existing steelworks

Load transfer is ensured through a temporary stay cable system composed of multiple parallel strands. These temporary stays are anchored to existing structural elements both at the pylon and at deck level, without any intervention below the deck. The system is adjustable via strand jacks, allowing precise control of force redistribution. Progressive detensioning is performed through controlled release of elastic elongation, with continuous monitoring of forces and structural response.

Once fully detensioned, the existing cable is removed using an innovative lowering system based on rollers running directly on the temporary stay. This eliminates the need for additional highline systems and simplifies operations significantly. The cable is then lowered using a deck-mounted winch, enabling full removal in less than one day, even for long and heavy stays. The entire methodology is designed for repetition and reuse, allowing efficient execution across all 152 cables, if deemed necessary after the initial inspection campaign.

Figure 2: Detensioned cable being lowered on the temporary cables with roller assemblies

The technological approach delivers several major advantages. From a safety perspective, the elimination of cutting under tension and the avoidance of works below the deck significantly reduce operational risks. In terms of productivity, the use of rapid lowering systems and modular equipment enables short intervention cycles compatible with limited traffic closures. Environmental performance is also improved through the high rate of reuse of temporary equipment and the reduction of heavy temporary structures.

Beyond the specific case of the Vidyasagar Setu, the developed methodology establishes a benchmark for the replacement of ageing PWS cable systems worldwide. Many cable-stayed bridges constructed in the late 20th century are now facing similar durability issues, and the approach developed for this project offers a scalable and transferable solution applicable to a wide range of structures.

2.3. IMPLEMENTATION OF A MODERN STAY CABLE SYSTEM

The replacement strategy is built on the implementation of a modern stay cable system compatible with the existing structure while significantly enhancing durability, maintainability, and overall robustness. Although the detailed configuration of the final system is project-specific, the design philosophy focuses on modularity, inspectability, and ease of future replacement.

The modern stay cable system was designed to feature every refinement one would expect from a high durability stay cable system:

- High fatigue resistance anchorage with reversible watertightness design,
- High performance viscous dampers,
- Fire protection for a 1100°C load case and a 60 minute rating up to a heigh of 10m above deck level and including a full encapsulation of the anchorage area above the deck.

Figure 3: Cable fire encapsulation at deck anchorage

3. MARQUES DE ZAFRA FOOTBRIDGE IN SPAIN

3.1. EXISTING CABLE SYSTEM AND MATERIALS

The Marqués de Zafra footbridge, constructed in 1976 in Madrid, is one of the earliest cable-stayed pedestrian bridges in Spain. The structural system consists of a prestressed concrete deck supported by reinforced concrete pylons and a network of inclined, vertical, and backstay cables. The original stay cables were composed of ungalvanized 7 mm diameter prestressing wires with a tensile strength of approximately 1770 MPa, enclosed within polyethylene sheaths and injected with cementitious grout.

The cable system included inclined stays supporting the main span, vertical stays aligned with the pylons, and backstays connected to the side spans and anchored to abutments through tiedown cables. While this configuration ensured global equilibrium, it relied on a relatively low level of redundancy and on protective systems typical of the 1970s. Inspections performed in 2020 highlighted significant durability issues, including water ingress, lack of watertightness at the upper anchorages, internal voids in grout, and active corrosion of steel wires. In extreme cases, cross-sectional losses approaching 30% were observed in critical cables, raising concerns regarding structural safety and long-term performance. These findings led to the decision to replace the entire stay cable system.

Figure 4: PWS cable recorded during inspection stage

3.2. DETENSIONING SCHEME

Given the uncertainty regarding the residual capacity of the existing cables and the need to maintain structural stability, the replacement strategy was based on a staged approach ensuring continuous load transfer. New stay cables were first installed with a low initial tension prior to any intervention on the existing system. This approach allowed the creation of a redundant load path before unloading the original cables.

The detensioning of the existing stays was performed using a bypass system, enabling a controlled transfer of forces from the old cables to the newly installed parallel strand cables. Particular attention was given to the synchronization of operations: new stays were stressed simultaneously and progressively to maintain the global equilibrium of the structure and avoid excessive deformation of the deck and pylons.

In the main span, temporary stays were introduced prior to the replacement of the original cables to further enhance redundancy during critical phases. Replacement operations were generally carried out in pairs of cables to maintain symmetry. Continuous monitoring of structural behaviour—including deck geometry, stay forces, and pylon displacements—was implemented throughout the process, ensuring that the structure remained within acceptable limits at all times. This methodology enabled safe detensioning and removal of the original cables while minimizing risks associated with unknown internal conditions.

3.3. IMPLEMENTATION OF A MODERN STAY CABLE SYSTEM

The rehabilitation project included the installation of a modern parallel strand stay cable system designed to improve durability, robustness, and maintainability. The new system consists of galvanized seven-wire strands (15.7 mm diameter) complying with modern standards, each strand incorporating a triple-layer protection system combining galvanization, wax filling, and individual polyethylene sheathing.

The stay cables are arranged in bundles enclosed within external high-density polyethylene (HDPE) ducts with UV protection. Anchorage systems are based on clevis-type connections, with fixed anchorages at the pylon and adjustable anchorages at the deck, allowing for precise tensioning and future adjustments. The anchorage zones are protected by metallization and paint systems, ensuring long-term corrosion resistance.

Significant design improvements were introduced at the interface between the cables and the structure. At the pylons, a lug-based connection system using prestressing bars enables force transfer while providing accessibility and allowing individual component replacement. At deck level, innovative connection details were developed to minimize intervention on the existing structure while ensuring direct load transfer and redundancy during the replacement process. For backstays, a new independent prestressed concrete anchoring beam was constructed to improve force distribution and durability.

Figure 5: Modern cable layout and connection to the existing structure

The overall system was conceived to facilitate inspection and maintenance, with accessible components and reversible design solutions. In addition, a comprehensive structural health monitoring system was installed to track cable forces, structural displacements, and dynamic behaviour over time. The integration of these modern stay cable technologies significantly enhances the durability and resilience of the structure, while preserving its original architectural concept and heritage value.

Figure 6: Works being delivered about the main ring road in Madrid

4. GALECOPPER BRIDGE IN THE NETHERLANDS

4.1. EXISTING CABLE SYSTEM AND MATERIALS

The Galecopper Bridge, constructed in the early 1970s, is a major cable-supported steel bridge located on the A12 highway in the Netherlands. The original stay cable system consisted of locked-coil cables arranged in a central fan configuration with very limited structural redundancy. Each stay cable was composed of six locked-coil strands of approximately 76 mm in diameter, passing over steel saddles at the pylon tops and anchored into the steel deck structure at both ends.

Figure 7:Corroded lock coil strand used to make up a complete stay cable

After more than 50 years of service, significant durability issues were identified, primarily concentrated at the anchorage zones. These included corrosion phenomena linked to water ingress within the cable system and multiple wire breaks affecting individual strands. The degradation mechanisms were attributed to insufficient sealing and protection in early cable designs, allowing water to penetrate and accumulate at critical points. Given the limited redundancy of the structural system and the strategic importance of the bridge, these pathologies led to the conclusion that a full cable replacement was required.

4.2. DETENSIONING SCHEME

The detensioning and dismantling of the existing locked-coil cables represented a critical phase of the project due to uncertainties regarding their residual capacity and condition, particularly at the lower anchorage zones. The initial concept considered during the tender phase involved the use of double friction clamps and temporary towers positioned at mid-span to cut the cables in elevated locations. However, this approach raised significant safety and constructability concerns, notably related to working at height and the complexity of temporary works.

An alternative detensioning scheme was therefore developed, based on the implementation of a bypass system installed at deck level. This system relied on a single friction clamp connected to a strand jack and anchored to a dedicated detensioning frame fixed to the bridge deck. The bypass arrangement enabled the transfer of cable forces away from the most deteriorated zones, thereby enhancing operational safety and reducing dependency on the original cable integrity.

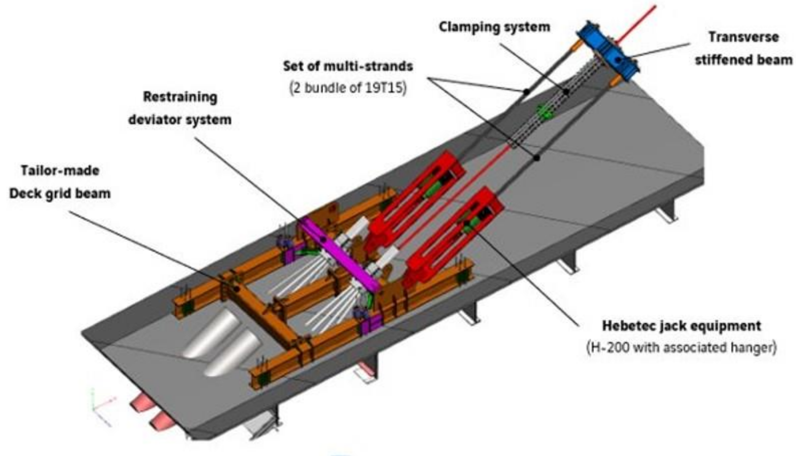


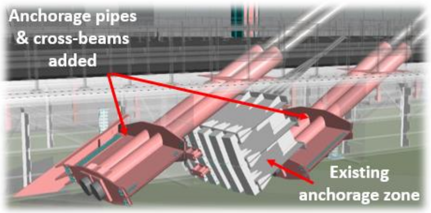
Figure 8: Bespoke detensioning layout allowing to bypasse the most damaged cable section at deck level

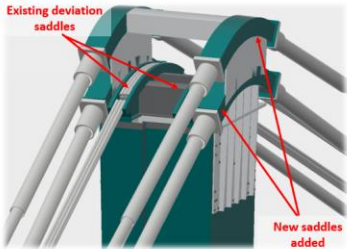
The detensioning process was carried out through a carefully controlled sequence involving progressive load transfer from the existing locked-coil strands to newly installed parallel strands. The operation was performed in multiple cycles, ensuring structural stability and maintaining traffic conditions. Continuous monitoring of deck geometry, cable forces, and clamp performance was implemented, with hold points introduced prior to cutting operations. The final cable cutting was carried out remotely using diamond wire sawing techniques, further improving safety conditions. This methodology significantly reduced construction risks while maintaining structural integrity throughout the operation.

4.3. IMPLEMENTATION OF A MODERN STAY CABLE SYSTEM

The replacement strategy was based on the installation of a modern parallel strand system (PSS), selected for its modularity, enhanced durability, and ease of maintenance. This technology allows for staged installation and individual strand replacement, which is particularly advantageous for bridges with limited redundancy such as the Galecopper Bridge.

At deck level, new anchorage systems were designed to improve durability by preventing water ingress. The anchorage pipes were extended above deck level and connected to sealed ducts, ensuring effective protection against environmental exposure. At pylon level, a new saddle system incorporating Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) was installed. This multi-hole saddle concept allows individually sheathed strands to pass through concrete recesses, providing high friction capacity and continuous corrosion protection without the need for additional grouting.





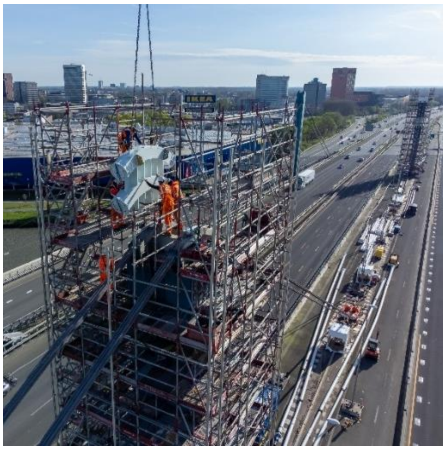


Figure 9: Integration of a modern PSS system into the existing steel structures

In addition to corrosion protection, the new cable system was designed to enhance robustness against accidental actions. A fire protection system was implemented over the lower part of the cables, designed to withstand hydrocarbon fire scenarios with temperatures up to 1100°C for a duration of 60 minutes. The protective system was made accessible and replaceable, contributing to long-term maintainability.

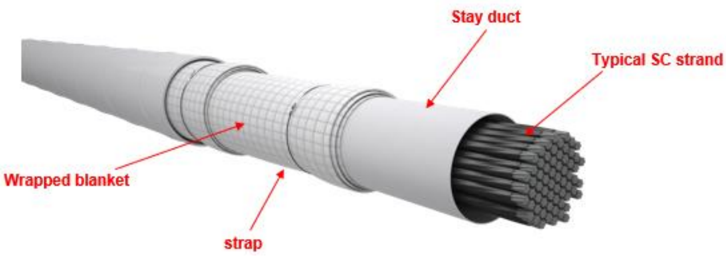


Figure 10: Modern fire protection layout on PSS stay cables

Overall, the integration of the modern stay cable system provided a significant improvement in terms of durability, inspectability, and replaceability. The combination of enhanced protection measures, modular design, and innovative saddle technology ensures that the upgraded bridge meets current standards for performance and resilience while facilitating future maintenance interventions.

5. CONCLUSION

The three case studies presented illustrate the wide spectrum of challenges associated with the inspection and replacement of stay cable systems, ranging from early lock-coil technologies to grouted strand systems and parallel wire systems. Despite their differences in scale, materials, and structural configurations, a number of common engineering principles emerge. Firstly, all projects highlight the critical importance of comprehensive inspection and diagnostic capabilities, enabling the identification of underlying degradation mechanisms—often hidden—and the quantification of residual structural capacity. Secondly, they demonstrate that a deep understanding of stay cable technologies and their historical evolution is essential to define suitable replacement strategies, particularly when dealing with non-redundant systems or obsolete protection concepts.

Furthermore, these case studies underline the necessity of developing project-specific construction methodologies, tailored to the constraints of each structure in terms of redundancy, accessibility, and traffic management. Whether through the implementation of bypass systems, staged redundancy, or fully reversible detensioning methods, the success of each intervention relies on the ability to control load transfer with a high degree of precision and safety. Finally, all three projects confirm the central role of advanced structural modelling, used not only for design verification but also as a real-time decision-support tool to predict structural behaviour throughout the replacement process and to ensure serviceability criteria are met at all stages.

Taken together, these experiences demonstrate that successful stay cable replacement projects require an integrated expertise combining inspection, diagnosis, material and system knowledge, construction engineering, and structural analysis, forming the foundation for a rigorous and reliable approach to the rehabilitation of ageing cable-supported structures.

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