Repair and Strengthening of Cantilever Continuous Bridges using External Prestressed Cables: The Case Study of the Tan De Bridge in Vietnam

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ABSTRACT

Continuous cantilever bridges utilizing cross-sectional box girders have been widely used worldwide, as well as in Vietnam, with outstanding advantages, such as the ability to cover large spans, good torsional resistance, high stability, and low maintenance costs. The arrangement of the prestressed cables in the span can use all internal cables (cables arranged in a box cross-section) or a combination of internal wires and external cables (cables arranged in a box cavity). The arrangement of the external cables helps reduce the cross-sectional area and self-weight of the span, leading to savings in foundation costs and an increase in the ability to exceed the span. However, the external cables degrade and become damaged. Therefore, repair and strengthening solutions are required to ensure the longevity of the project. This study focused on researching solutions to restore and enhance span structures using external prestressed cables through specific projects implemented in Vietnam.

Keywords-cantilever bridges; box girders; external cables; repair; strengthening

I. INTRODUCTION

Prestressed reinforced concrete structures were fabricated by a French engineer in 1928, Eugene Freyssinet, using high-strength steel fibers to compress concrete. In Vietnam, reinforced concrete bridges were constructed using simple beams or truss bridges during the French colonial period, and redundant girders or truss bridges were constructed utilizing the cast-in-place method. These structures typically have two main beams or trusses: longitudinal and cross beams. The bridge width is approximately 4-5 m, and the single 1000 mm wide railway bridges have a length of less than 20-30 m. There are also several types of continuous beams with span lengths of 30-40 m, and continuous span lengths of 30-40 m. After the resistance war against the French, several bridges were rebuilt with simple-span structures assembled with T-cross sections, horizontally joined by welded joints at the cross beams or reinforced concrete bridge decks poured in place. Reinforced concrete structures are used for small-span bridges, such as slab bridges or beam bridges, with spans of less than 22 m.

Various prestressed reinforced concrete structures have been developed in Vietnam. For instance, the design and construction of the Phu Lo Bridge was applied with a span of 18 m. By the early 70s, prestressed reinforced concrete bridges with 24 m and 33 m spans were designed and built (Thang Long Bridge, Hanoi). In southern Vietnam before 1975, many prestressed reinforced concrete bridges were built using 24.7 m span structures. These span structures were manufactured at the Chau Thoi concrete factory [1]. After the country was unified, many medium- and large-span bridges were built. For example, the Duong Bridge and Rao Bridge are frame structure bridges spanning 63 m (the T wing is 39 m long, constructed by erection segments, and the suspension beam is 24 m long). After the collapse of the Rao Bridge, the Bo Bridge in Thai Binh was constructed using the cantilever method (T-wing 28m long, suspension beam 33 m long). However, this type of structure has been rarely used.

In 1996, the Phu Luong bridge, observed in Figure 1, was constructed on Highway 5 with its main span being 64.75+2×102+64.75, applying balanced cantilever technology. Next, the Song Gianh Bridge was constructed, as shown in Figure 1, along with the Phu Luong Bridge. To date, hundreds of cantilever bridges have been built with increasingly large main spans. Continuous bridges constructed employing medium-span cantilever technology, primarily use internal pre-stressed cables [2]. Utilizing all internal post-tensioned cables for large-span bridges will increase the cross-section and self-weight therefore, internal pre-stressed cables and external cables should be combined to reduce the bridge weight.

External prestressing is widely employed in many countries worldwide, and many prestressed reinforced concrete bridges have been built using external prestressed cables. This technology was used to build European bridges between the 1920s and the 1950s. However, later, external prestressing was almost banned from use because of the lack of anti-corrosion methods for high-strength cables and the high cost of their repair. After the deployment of external prestressing to strengthen prestressed reinforced concrete bridges in the 1970s in France, anti-corrosion systems for cables were significantly developed.

This method was developed rapidly by constructing the Florida Key bridge using external prestressed cables in the US. In designing bridges, only external post-tensioning cables, or in combination with internal pre-tensioning wires, are used, particularly in France. A systematic theory of external prestressing was developed in 1983, and the SETRA released the first draft of its design standards in 1990. In Japan, external prestressing was used more frequently than combined internal and external prestressed cables for the Sassamegawa Bridge on the Tohoku Shinkansen high-speed railway in 1985.

Fig. 1. Phu Luong, Song Giang Bridge.

In Vietnam, external prestressed cables have been utilized to construct several medium-span and large-span reinforced concrete bridges, such as Song Gianh Bridge, Tan De Bridge, Da Bac Bridge, Thi Nai Bridge, and Ham Luong, employing the cantilever technology. In addition, external prestressed cables are widely used to repair and strengthen reinforced-concrete bridges. In particular, the demand for and the ability to apply external prestressed cables combined with the segment assembly technology to build bridges in urban areas is very important. Previous bridges utilized external prestressed cables with the same technical standards as the internal prestressed cables. Thus, many disadvantages arise after a period of use. Although the use of external post-tensioning cables has many advantages, degraded and damaged external post-tensioning cable strands must be evaluated during the management process, and timely repair measures should be proposed.

Numerous investigations have focused on implementing innovative materials to enhance structural integrity and decrease weight, thus improving bridge capacity and longevity. These efforts include exploring the use of composite sheet materials as substitutes for the existing layers [3]. The employment of covering and bridge decks can substantially decrease the weight. Studies have explored the utilization of advanced materials, such as UHPC, for constructing bridge decks as an alternative to coatings, with the aim of diminishing the load capacity and extending coating durability. Furthermore, it is crucial to evaluate the impact of heightened vibrations on structures that have accumulated damage over time [4].

Various approaches have been implemented to sustain and enhance the weight-bearing abilities of bridges. Nonetheless, this research concentrated on addressing the existing damage and substituting damaged external prestressed tendons to preserve the load-carrying capacity of the structure.

II. DAMAGE TO BALANCED CANTILEVER CONTINUOUS BEAM BRIDGES USING EXTERNALLY PRESTRESSED CABLES

External post-tensioning cable systems under repair and new systems under construction can be classified into two main groups. The first group includes old-style prestressed cable systems using non-sheath cables, whereas the second group includes prestressed cable systems with new-generation cables utilizing a protective sheath.

A. Damage to HDPE Pipes

High-Density Polyethylene (HDPE) pipes are susceptible to several types of damage, including:

(1) Punctures along the HDPE pipe owing to mortar pressure.

(2) Cuts or fractions due to impacts during transportation and construction.

(3) Damage to pipe joints due to poor-quality construction.

(4) Damage at flattened diverter positions.

(5) Damage due to HDPE pipe materials not meeting the technical standards. Visual representations of these types of damage are provided in Figure 2.

Fig. 2. Damage to HDPE pipes.

B. Damage to Anchor Head.

Common damage to the anchor head includes loss of the anchor head cap, insufficiently pumped mortar at the anchor head, rusting of the cable strands at the anchor head, hollow mortar at the anchor head, and anchor loss, as displayed in Figure 3.

Fig. 3. Damage to anchor head.

C. Damage to Mortar

1) Damage due to Mortar Voids

Research reports have shown that mortar voids are one of the main causes of cable-strand corrosion in prestressed systems. The typical types of mortar voids that occur in prestressed cable systems are portrayed in Figure 4.

2) Damage due to Mortar Separation

Some studies on prestressed cables have demonstrated that the grout used for pumping in current pipes can exhibit the following damage types:

Type 1: Separation of flexible moist mortar-like clay.

Type 2: Separation of the mortar layer from the black vein layer.

Type 3: Separation of dry mortar with a white powdery texture.

Type 4: Hard, gray, dry mortar.

Of these, Type 4 is usually found along the lower part of the cable bundle, whereas Types 1 and 2 are found at the top. This indicates that gravity plays a role in the layer separation of the mortar, as illustrated in Figure 4.

Fig. 4. Mortar damage on cross-section. Mortar quality is not consistent.

3) Defects in the Chemical Composition of Mortar

Some studies analyzing mortar and residuals with high concentrations of corrosive ions (Cl^- and SO_4^{-2}) in the upper vicinity of the cable bundles showed that the Cl^- concentration exceeded 0.08% of the cement volume limit, as recommended by the American Association of State Highway and Transportation Officials (AASHTO) and the American Concrete Institute (ACI).

4) Some other Types of Damage

Water stagnation inside the box and water intrusion into the tube can also cause damage to cable bundles.

D. Repair and Strenghtening Solutions

1) Restoration of HDPE Pipes with a Cover Layer

A heat-activated shrinkable sheathing material can be installed to wrap and seal the damaged HPDE pipes of the external post-tensioning tendon and repair tears or cracks in the pipe body.

This method is not suitable for HDPE pipes that have been removed from the prestressed cable bundles. However, sheathing can be used when HDPE pipes are left in place, even after a section of the pipe has been lightly stripped to check for corrosion, and the pipes are then returned to their original position.

2) Install a New Half HDPE Pipe

This method is applied to repair tears or cracks by vertically installing a new half HDPE pipe connecting it to the HDPE pipe of the external cable bundle, and then injecting mortar to cover the external cables. This method must be used when the old HDPE pipes of the external cable bundle have been removed owing to damage or when they have peeled off to check the condition of the cable strands or grout.

In addition, this method can be utilized to repair HDPE pipes on installed external cable bundles to enhance the structural repair and restoration in any situation. It can also be deployed to repair HDPE pipes with external cable bundles in prefabricated hollow pillars or in similar applications.

3) Heat Welding Method

This method is applicable for repairing small holes or cuts by heat-welding old HDPE pipes. However, it can only be applied to repair the exterior of the HDPE pipes with small holes or small cuts. This method must be avoided when a pipe experiences water leakage or cracking. This can be caused by other factors, such as inherently defective or substandard materials. Heat welding can be utilized to restore the integrity of the HDPE pipes for the external cables used in external cable systems.

E. Methods for Repairing Mortar Voids in Cable Bundles

1) Methods of Repairing Mortar Voids

Currently, three grouting methods are used to pump mortar for new construction and repair mortar voids in preservative systems. Each method has its advantages and disadvantages. The Pressure Grouting (PG) method is applied with an air outlet in the hollowed pipe. The vacuum pumping method (Vacuum Grouting-VG) uses a vacuum device to pump grout into a void. Pressure Vacuum Grouting (PVG) is a repair method that combines the advantages of the VG and PG methods.

2) Creation of a Grouting Port or Inspection Port at the Anchor Head

Identifying or suspecting a grout void in the anchorage area can be based on previous examinations. Additional investigations may necessitate the use of an endoscope and tube to install a grout pump.

To access the anchor directly, a check port can be drilled into the existing mortar vent or a new one can be created through the current wedges or anchor pads. Alternatively, drilling can be done into the side of the anchor cone or conduit behind the anchor plate, or from the side, beginning, or end of the local anchor block in concrete elements.

The most easily accessible anchors are found in the horizontal bulkheads or blocks at expansion joint ends, where there is sufficient space for equipment or direct personnel access. This approach requires removing, and subsequently replacing, the anchor protection, which can be accessed from behind the anchor. Notably, this method does not involve the removal of the concrete structure.

3) Vacuum Grouting Method at Anchors

This technique can be employed for all types of cable bundles across various bridge designs. It is presumed that a void in the grout has been identified within the anchorage region. Additionally, it has been established that the cable bundles situated in the void behind the anchor meet the criteria for in-situ re-grouting, rather than necessitating complete removal and replacement.

4) Method of Protecting each Anchor Head Cluster

This procedure entails securing each anchor assembly for directly accessible anchors subsequent to the examination of the cable bundle, utilizing endoscopy, and the completion of anchor grouting. Both new construction and renovation projects have been thoroughly cleared of preexisting materials. To facilitate a direct access to the anchor within the enclosure, four levels of protection are requisite: (1) grout, (2) permanent cover, (3) seal layer, and (4) waterproof surface layer. The installation of these protective layers ensures the longevity and stability of the anchor system.

F. Method of Replacing External Prestressed Cables

In instances where a significant reduction in the cross-sectional area and structural integrity of the helmet is observed, potentially resulting in wire entanglement, an alternative approach must be considered. The technical specifications of the existing cables are presented in Table I.

TABLE I. TECHNICAL SPECIFICATIONS OF THE EXISTING CABLES

No	Specifications	Requirement
1	Nominal diameter of bare cable strand before wrapping	15.2 mm
2	Ultimate tensile strength	1860 MPa
3	Cable breaking force	260.7 kN
4	Nominal area of steel cable strands	140 mm^2
5	Maximum low slack after 1000 hours	2.5%

The criteria for determining the appropriate cable type should be established based on empirical test results and the expert judgment of an experienced engineer. The complexity of cable selection is further underscored by the diverse range of bridge designs and configurations encountered in practice. As Table II illustrates, factors, such as the number of cable bundles, bundle types, and connection speeds, can vary significantly across different bridge projects. Additionally, considerations, such as environmental conditions, expected traffic loads, and long-term maintenance requirements, must be taken into account.

TABLE II. TECHNICAL SPECIFICATIONS OF THE REPLACING CABLES

No	Specifications	Unit	Requirement
1	Nominal diameter of bare cable strand before wrapping	mm	15.2
2	Ultimate tensile strength	MPa	1860 MPa
3	Cable breaking force, min	kN	260 kN
4	Nominal area of steel cable strands	mm2	140 mm^2
5	Maximum low slack after 1000 hours	%	≤2.5%
6	Yield limiting force	kN	230
7	Elastic modulus	kN/mm2	195±5
8	Zinc coverage	g/mm2	190÷350
9	The bend (flexibility) of the cable strand	mm	15

However, some of the following principles should be considered:

(1) The tension of a bundle is reduced by 30% compared to the original limit (level AA when evaluating cables according to tension criteria).

(2) Identified loss of detail due to corrosion of approximately 5% of the entire cable-box cross-section.

(3) Two cable bundles on the same side of the block box with the same fat loss rate were not allowed (depending on the analysis configuration).

Research on inspecting the damage to external prestressed cable systems needs to be conducted systematically in many parts using different methods to assess the damage. It is important to note that no single tool or evaluation method can comprehensively assess all types of damage in these systems. Therefore, it is crucial to carefully select appropriate equipment and testing procedures for each specific component and damage type.

Given the numerous inspection methods available, it is essential to select an appropriate technique based on a specific type of damage. After evaluating the characteristics of various methods, the following approach is recommended for assessing the external cable system:

(1) Utilize visual inspection to assess the current state of the HDPE pipes.

(2) Evaluate the cable in the anchorage zone using endoscopy, radiography, and thermal imaging techniques.

(3) Examine cables within diverter points or cross beams employing endoscopic and X-ray methodologies.

(4) Assess the present condition of cross-section corrosion and cable breakage at free cable bundle sites using magnetic detection.

(5) Evaluate the mortar void status in the external cable bundle through sound recognition analysis.

(6) Verify the tension in the cable bundle using fluctuation methods or magnetic sensors, which are appropriate for providing solutions to repair an externally prestressed cable system.

Based on the assessment of the damage and the operating conditions of the project, appropriate solutions are proposed for repair or strengthening.

III. CASE STUDY OF TAN DE BRIDGE

A. The Problems of the Bridge

The primary bridge consists of a continuous prestressed concrete structure featuring a span configuration of 70.0 m+3x120 m+77.8 m, with a box-girder cross-section and varying box-girder height from 3.0 to 6.5 m. This design incorporates both internal prestressed beams and external prestressing. The structure employs 30 external prestressed cable bundles, which are distributed as follows: four bundles in each of the two side spans (N6 and N10), eight bundles in each of the two adjacent spans (N7 and N9), and six bundles in the main span (N8). The number of strands per bundle differs across spans, with N7 and N9 containing 18 strands each, whereas the remaining spans have 19 strands per bundle. The cables utilize Type 7 strands with a 15.2 mm diameter, conforming to the ASTM A416 standard [5], and feature a low slack level of 270. These cable strands lack individual protective layers and are shielded solely by the cement mortar injected into the HDPE pipe.

The bridge, which has been in service for over two decades, has begun to show signs of deterioration owing to increased traffic and vehicle weight. Structural damage has emerged in various parts of the bridge, including the main box-girder's interior, the web's sides, and cracks extending from the bottom to the top of the web. The deck also exhibits numerous cracks along its length. In April 2016, an external prestressed cable bundle (No. 156S) on the downstream side of span No. 8 failed and was promptly replaced. Subsequently, in January 2017, another external prestressed steel cable bundle (No. 157N) in the same span broke. This was urgently replaced following the design and construction principles used for the previous cable bundle replacement. In July 2020, an upstream external prestressed steel cable bundle (No. 156N) in span No. 8 also failed and was replaced using the same methodology as in the previous replacements [6]. In addition, the cable anchor protection box exhibited signs of corrosion. Figure 5 depicts these typical forms of damage.

Fig. 5. Some typical damages.

B. Damage Assessment

The fractured components of the bundles within a 5 m proximity to the cable anchor bed indicate a lack of solid mortar within the 3 m – 4 m interior range of the cable, containing only mortar foam. This absence of solid mortar allows for water accumulation, leading to rapid corrosion. Given the small diameter of the wires (5 mm), they corrode, lose their cross-sectional area, and fail first within the cable strands. The tension in the remaining strands increases due to variations in the wire quality and area; some wires break from fatigue, while others fail due to limited strength. Thus, the primary cause of cable deterioration is attributed to flawed grouting techniques, resulting in mortar foam within the inner pipe of the cable bundle near the anchor head. Water retention on the cable surface occurs due to this foam, causing rust.

Other areas of the cable bundle also contained air bubbles in the mortar. Even if mortar inspections show no voids in the sleeve, these air pockets can lead to condensation, creating surface water and an uncontrollable rust formation. The protective mortar layer surrounding the outer cable bundle is not highly reliable. Air bubbles persist even in densely pumped mortar areas, leading to moisture and a subsequent corrosion of the prestressed steel. Consequently, reinforcement creep may occur, potentially resulting in an unpredictable cable failure.

C. Repairs and Strengthening

Based on the current state of the bridge, the damage to the external post-tensioning cable system is evident, affecting its ability to withstand a design load of 1.25*HS20-44. Out of 30 external prestressed cable bundles, 27 were aged and susceptible to corrosion and degradation, with only three of them having been previously replaced. The installation of new cable bundles to replace the existing ones must adhere to specific technical standards, as outlined in [5-8]:

To maintain the unaltered resistance of the bridge, the new cable bundle area, incorporating its physical and mechanical properties, must be at least equal to or larger than that of the existing cable bundles.

The bridge's structural deformation, including the span deflection and rotation angle, remained constant, with no changes affecting the bridge bearing. The design of new external prestressed cable bundles comprises several key components.

- The cable strands were 07-wises with a nominal diameter of 15.2 mm and galvanized for each single strand.
- HDPE sheath for each cable strand.
- A protective grease layer between each cable strand and its HDPE sheath.
- High-strength adhesive tape wrapped around the cable bundle.
- The HDPE sheath covers the entire cable bundle.

Prior to replacing the main cable bundle, a trial replacement of one bundle is necessary to refine the sequential replacement technique. The process involves:

- Implementing safety measures to protect workers inside the box girder from sudden cable bundle breakage.
- Removing the HDPE pipe at the cable bundle cutting area and remove the cable mortar layers at the cable bundle.
- Cutting each cable strand using air or a saw, with the cutter secured in a protective device at the navigation anchor.
- Cleaning the steel pipes at the anchor after cutting and removing the cable bundles and anchor heads using old anchors.
- Installing HDPE pipes into redirected steel pipes and inserting new cable bundles according to the installation and tensioning procedures.

The replacement of the cable bundle follows the following principles:

- Symmetrical replacement of bundles in cross-sections (upstream and downstream).
- Replacing cables starting from the center span (span No.8, No.9, No.7, No.6, and No.10).
- Continuous monitoring of deflection at specified points during replacement.
- Grouting of the anchorage area after completing cable bundle tensioning in each span.

Figures 6 and 7, and Tables III and IV show the analysis results under the effect of the design load 1.25*HS20-44.

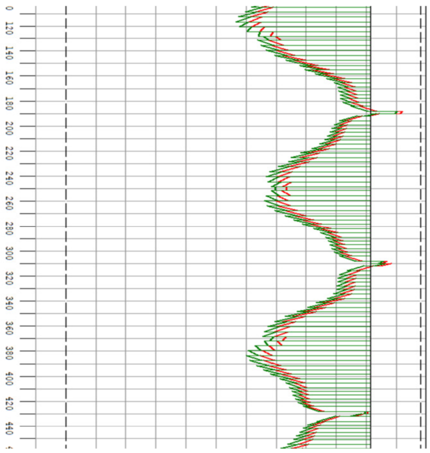

Fig. 6. The diagram of the stress on the top flange span under a live load 1.25HS20-44.

TABLE III. SUMMARY OF THE RESULTS OF CALCULATING STRESS ON TOP FLANGER

Stress on the top flange of box-girder (Mpa)									
Location	0.4L span 6	Pier P7	0.5L span 7	Pier P8	0.5L span 8	Pier P9	0.5L span 9	Pier P10	0.4L span 10
1,25HS20-44	6.5	0.3	8.5	-2.2	6.5	-1.5	8.3	0	8

$\sigma_{compression} \leq \sigma_{permissible\ stress} = 27$ MPa, $\sigma_{tensile\ stress} \geq \sigma_{permissible\ stress} = -3.35$ MPa

TABLE IV. SUMMARY OF THE RESULTS OF CALCULATING STRESS ON THE BOTTOM FLANGER

Stress on the bottom flange of box-girder (Mpa)									
Location	0.4L span 6	Pier P7	0.5L span 7	Pier P8	0.5L span 8	Pier P9	0.5L span 9	Pier P10	0,4L span 10
1,25HS20-44	-0.8	8	-0.3	12	-0.3	12	2	8.3	-1.7

$\sigma_{compression} \leq \sigma_{permissible\ stress} = 20.25$ MPa, $\sigma_{tensile\ stress} \geq \sigma_{permissible\ stress} = -3.35$ MPa

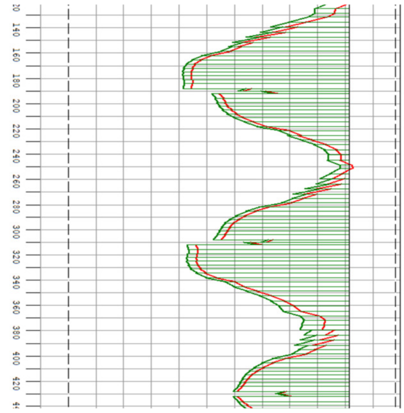

Fig. 7. The stress diagram of the bottom flanger under the box on the live load span 1.25HS20-44.

Thus, the effect of the design load of 1.25*HS20-44 on the stresses on the top and bottom flanges of the box girder was within the allowable stress range [9].

Fig. 8. Tensioning the external cable bundle Tan De Bridge.

The construction process must strictly control the tension of the cable bundle and consider the stress loss due to concrete shrinkage and creep. Figure 8 illustrates the tension of the cable bundle.

D. Cable Bundle Replacement Procedure

Removing the existing cable bundle requires the following steps:

- Protective systems should be installed to prevent cable bundles from breaking suddenly, which could endanger workers and cause structural impact.

- Remove the HDPE and mortar layers from the cable bundle cutting area.
- Utilize air or stone tools to cut individual cable strands.
- Clean the anchor head and steel pipes at the cable anchor and navigation site.
- Install new HDPE pipes in redirected steel pipes and insert new cable bundles according to the installation sequence design.

For replacing the new cable bundle, each bundle must be removed in a symmetrical manner across the cross-section (both downstream and upstream sides).

IV. CONCLUSIONS

Following an assessment of the HDPE pipe using X-rays to evaluate the cable anchor condition, sound recognition techniques to identify mortar voids, and magnetic sensors to gauge wire tension, it was determined that 27 of the 30 external prestressed cable bundles required replacement.

Rigorous construction and quality control measures ensured that the cable bundles meet the process quality and efficiency standards.

The bridge remained open to vehicular traffic during the repair work, thereby demonstrating the effectiveness of the proposed design solution.

Post-repair and strengthening evaluations conducted by independent parties confirm that the bridge operates safely under a design load of 1.25HS20-44, fulfilling the area's transportation and circulation needs.

REFERENCES

[1] D. N. Dac, N. L. Ngoc, and N. T. Duc, "Simulation the effect of torsion on the shear key in segmental box-girder bridges," *Transport and Communications Science Journal,* vol. 70, no. 5, pp. 386–396, 2019, https://doi.org/10.25073/tcsj.70.5.3.

[2] N. D. Duc and H. N. Minh, "Investigation on the effect of cross beams in single span bridges under dynamic aspect by using finite element method," *Journal of Materials and Engineering Structures*, vol. 9, no. 4, pp. 435–445, Dec. 2022.

[3] D. N. Tien, N. X. Tung, and N. N. Lam, "Analytical Solution for Bending Steel Concrete Composite Plates considering the Shear Deformation Effect," *Engineering, Technology & Applied Science Research*, vol. 14, no. 5, pp. 16090–16094, Oct. 2024, https://doi.org/10.48084/etasr.7801.

[4] T. B. D. Nguyen, V. H. Mac, T. N. Vu, and V. T. Nguyen, "An Effective Method for the Determination of the Natural Frequency of piled Pier Segments through Impact Vibration Testing," *Engineering, Technology & Applied Science Research*, vol. 14, no. 5, pp. 16326–16333, Oct. 2024, https://doi.org/10.48084/etasr.8143.

[5] *ASTM A416/A416M, Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*. ASTM International, 2016.

[6] *ASTM A475, Standard Specification for Zinc-Coated Steel Wire Strand*. West Conshohocken, PA, USA: ASTM International, 2003.

[7] *LRFD Bridge Design Specifications*. Washington, DC, USA: AASHTO, 2020.

[8] *TCVN 11823-2-2017. Highway bridge design specification - Part 2: General design and location features*. 2017.

[9] *Guide Specifications for the Design and Construction of Segmental Concrete Bridges*, 2nd ed. Washington, DC, USA: AASHTO, 1999.