Urban Rail Transit

Sustainability Practices for Anhsin Bridge Construction of Ankeng MRT System in New Taipei City

--Manuscript Draft--

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Additional Information:	
Question	**Response**

Sustainability Practices for Anhsin Bridge Construction of Ankeng MRT System in New Taipei City

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Dear Editor:

Enclosed please find the manuscript entitled “Sustainability Practices for Anhsin Bridge Construction of Ankeng MRT System in New Taipei City” by Cheng-An Lee, Hong-Kee Tzou, Tai-Sheng Chu, Mao-Yi Chou, Jui-Jiun Lin, and Tai-Yi Liu. I would like to have this manuscript reviewed by Urban Rail Transit for potential publication. This manuscript has never been published by any other Journal for publication.

If you have any questions, please feel free to contact me at tylaytpe@ms9.hinet.net. Thank you very much.

Best regards,

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Sustainability Practices for Anhsin Bridge Construction of Ankeng MRT System in New Taipei City

ABSTRACT

The Ankeng Light Rail Metro System (ALRMS) is a Design-Build (DB) based contract project, which is located in New Taipei City, Taiwan. The Anhsin Bridge (AB) is one of the major parts of ALRMS and serves as the most critical transportation route to connect two banks of the Hsindian River, Ankeng and Hsindian districts. For the sustainability consideration, the Contractor, New Asia Construction and Development Corporation (NA), of the ALRMS made some efforts by adopting the sustainable practices starting from the design stage of this project. These sustainable practices, including **Risk mitigation and reliability**, **Ecology**, **Environmental protection and carbon emissions reduction**, **Energy saving**, **Waste reduction**, **Durability**, **Benefit and Function**, **Landscape**, and **Creativity,** are being considered and discussed as key indicators of sustainability issues. In this paper, the authors would like to share the experiences on the significant achievement of sustainable practices. Furthermore, the development of the sustainability indicators and concept is introduced in this paper.

Keywords: Sustainability practices, Ankeng Light Rail Metro System, Anhsin bridge

1. Introduction

Sustainability indicators for the development of infrastructure projects were proposed in the past decades [1-3], with the key assessment indicators proposed for evaluating sustainability issues in engineering fields [4]. The corresponding author, Tai-Yi Liu, of this paper, proposed a reliable and practical sustainability assessment system for green civil infrastructure (SASGCI) in his doctoral dissertation in January 2020 [3]. It provided a new consideration for sustainability practices when developing a new infrastructure project. In recent years, sustainability issues have been widely studied and discussed in all engineering fields as well as construction. It is also aware of taking sustainability considerations from the beginning, such as the plan and design stages of a new project. The primary purpose of conducting sustainability research is to prevent construction projects from depleting resources and causing harmful effects and impact on the environment and ecology during their lifecycles [4-5]. In this project, engineers discussed all sustainability practices for the AB construction to minimize the possible impact on the environment and human life during the lifecycle of the ALRMS [6]. The authors all involve this project and would like to share the references on developing sustainability research during this project. Fig. 1 shows the research framework in this paper.

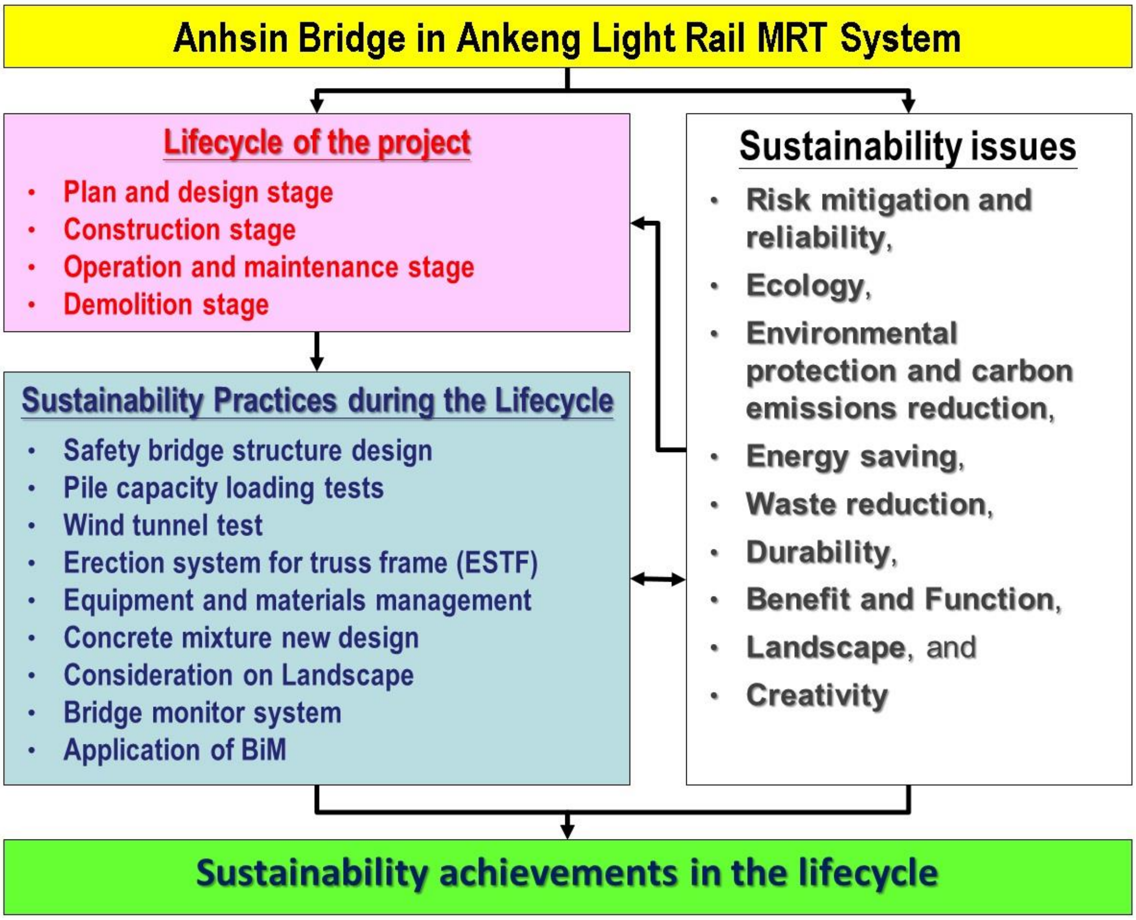

Figure 1: The research framework.

2. The concept for the sustainability indicators

Efforts in sustainability draw attention and public support for infrastructures such as residential houses, roads, highways, bridges, tunnels, water supply, sewers, electrical grids, and telecommunications, just to name a few. Specifically, sustainable and green infrastructures are being emphasized through designs and constructions that support long-term sustainability [7]. Sustainable and green civil infrastructure, including bridge, may contain the following criteria [8-11]:

- Maintain safety management, risk mitigation, and reliability during the lifecycle.
- Minimize the CO_2 emission during the lifecycle, and harmful impacts on the environment and ecology.
- Optimize the landscape for the project developed zone.
- Maximize the benefit/function of project development.
- Reduce the waste-producing and try possible recycle for the wastes during the lifecycle.
- Save the energy during the lifecycle.
- Extend the durability of the project.
- Preserve the local culture, and maintain the social conscience.
- Encourage creativity.
- Keep a reasonable cost during the lifecycle.

Liu performed the research for the evaluation of the civil infrastructures [3]. Some important issues are taken into consideration as the "Key Indicators" of the **Sustainability Assessment System for Green Civil Infrastructure** (SASGCI). It is the first level of the assessment system. Each indicator should contain some related evaluation items as the second level of the assessment system. For consideration of the entire lifecycle of a project, it is necessary to cover four stages, which include design, construction, operation, and demolition, to be level three of the system [3].

Ten sustainability indicators for the bridge were proposed in Liu's research, which are listed as follows [3]:

- **Risk mitigation and reliability**
- **Ecology**
- **Environmental protection and carbon emissions reduction**
- **Energy saving**
- **Waste reduction**
- **Durability**
- **Benefit and function**
- **Landscape**
- **Humanities and culture preservation)**
- **Creativity**

Table 1 illustrates the evaluation items for each key indicator.

Table 1: The evaluation items for ten key indicators [3].

Key indicators	Evaluation items
Risk Mitigation and Reliability	• **Providing large enough safety factor in the design** • **Design and construction documents approved by certified professional engineers** • **Establishment of risk mitigation mechanism** • **Minimization of the interference to the flooding and disaster protection**
Ecology	• **Ecological environment investigation, data collection, and impact assessment** • **Site preservation and indicative trees protection** • **Selection of low impact construction methods and preservation of biodiversity and animal habitat integrity**. Establishment of safety facilities for animals
Environmental	• Monitoring of carbon emission in the lifecycle

Protection and Carbon Emissions Reduction (ER and CER)	• **Reduction of the carbon emission in the lifecycle** • **Adoption of the construction methods and materials with low-carbon emission** • **Construction methods and procedures with low air pollution.**
Energy Saving	• Adoption of green energy (e.g., solar energy, wind energy, etc.) • **Selection of energy-saving materials and construction methods** • **Use of local materials to save energy and to reduce carbon emission** • **Use of energy-saving machinery to reduce energy consumption**
Waste Reduction	• **Use of recyclable and environmentally friendly materials** • **Adoption of waste reduction construction methods (e.g., precast, modularization, etc.)** • Use of industrial or construction by-product (e.g., fly ash, ground-granulated blast-furnace slag, reservoir silt, etc.) • Balance of cut and fill at the same site
Durability	• **Durable structure design** • **Use of durable materials** • **Establishment of quality assurance measures to increase the life expectancy of the structures** • **Adoption of design that facilitates easy maintenance**
Benefit and function	• **Boost of the local economy and increase of the job market** • **Enhancement of the design/construction/operation quality and ability** • **Shortening of construction duration to maximize the benefit** • **Cost down in the lifecycle**
Landscape	• **Consideration of local culture in the structure design** • **Beautification of structure and landscape. Design of structure for landscape fusion**
Humanities and Culture Preservation (H and C)	• Provision of participation and communication to the public • Safeguarding of social justice and care for minorities • Protection of historical sites and cultural relics
Creativity	• **Introduction of new materials, new construction methods, new technologies, etc.** • **Innovation in engineering project design**

	• **<u>Establishment of incentives mechanism to encourage innovation</u>** • Application of value engineering

In table 1, the underlined, with the bold font items, which are well performed in the ALRMS project.

3. Project description

The Ankeng Light Rail Metro System (ALRMS) is a Design-Build (DB) based contract project, which is located in Hsindian District, New Taipei City, Taiwan. The ALRMS project was started in 2016, and estimated to serve for transportation service in 2022. The client of the ALRMS is the Department of Rapid Transit Systems (DRTS), New Taipei City Government. The main Contractor of ALRMS is New Asia Construction and Development Corporation (NA), which includes the detailed design and construction stages. The ALRMS has a total length of 7.5 kilometers, and it contains nine stations, K1 to K9, including five elevated stations (K2, K6 to K9) and four at-grade stations (K1, K3 to K5). The route of the ALRMS started with a depot yard near to the Antai Road and ended in the Shisizhang station to connect to the MRT Cycle Line. Figure 2 shows the route layout of the ALRMS project.

There are three prime bridges, which crossing the Hsiapei Highway, No.3 Free Way, and the Hsindian River, respectively. The Anhsin Bridge (AB) is the one to cross the Hsindian River and it is one of the major parts of ALRMS, and serves as the most critical transportation route to connect two banks of the Hsindian River, Ankeng and Hsindian districts.

In the design stage, all of the sustainability issues mentioned above were taken into consideration to determine the bridge structure type. The engineers evaluated all key indicators with the evaluation items to select the most sustainable option for detailed design and site construction.

Figure 2: The route layout of the Ankeng Light Rail Metro System (ALRMS).

In figure 2, the marked pink area is the location of AB in the ALRMS route. It connects the two banks of the Hsindian River, between the K8 and K9 stations.

The engineers focus on the sustainability achievements that might be reached for selecting the options of the structure type for the AB. The AB structure frame's final determination is designed to be an asymmetry cable-stayed design with truss frames (ABCSTF). A total of 12 pairs of steel cables are installed between the steel pier column and the top steel box beam of the truss frame. Four different numbers of tendons, 55, 61, 66, and 73, are contained in different pairs of cables depending on the analyzed necessary prestressing-force.

In this paper, the authors would like to share their experiences on the option decision and the followed sustainability practices of the AB in the ALRMS project.

4. The evaluation and determination for the Bridge structure type

When developing the Anhsin Bridge (AB) construction for the ALRMS project, the original concept from the client, DRTS, was to design AB as a “steel arch” bridge (SAB). Figure 3 shows the original idea of the design and construction for the Abhsin Bridge [6].

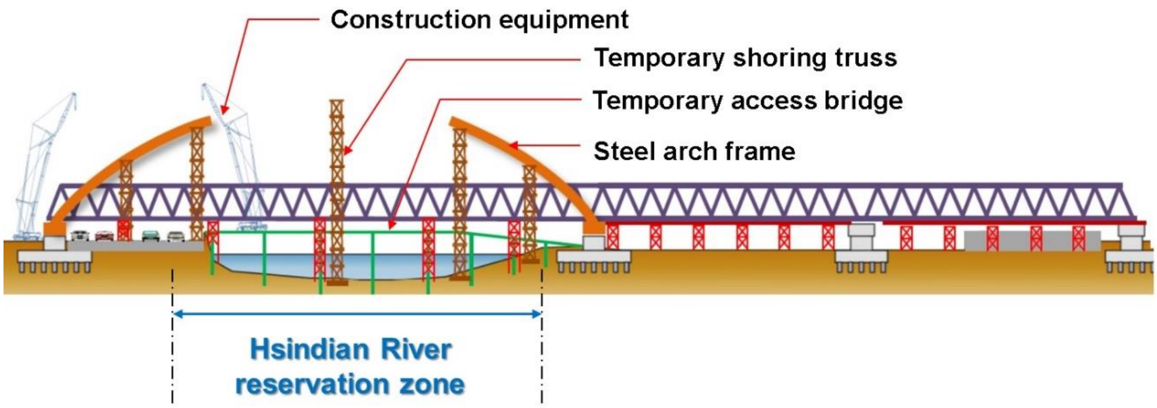

Figure 3: The original idea of the design and construction for the Abhsin Bridge [6]

This option is indicated in the basic design concept of the Contract documents provided by the client, DRTS. The construction of the steel arch bridge would inevitably require the setting of some piers to be located in the Hsindian River reservation zone. As shown in Figure 3, the temporary shoring truss needed to be installed in the reservation zone to support the members of the steel arch frame. Also, the temporary access steel bridge is necessary to use the construction equipment. Under this condition, the steel materials would be used in a massive quantity, and the total duration will be significantly enlarged. In addition, the risk of construction work might be substantially increased during the erection of steel columns. To minimize the possibility of danger, engineers made their efforts to prevent the pier from being located in the flow area. All these construction method s would pose a harmful situation for the river flow. It might also impact the environment and ecological condition of the Hsiindian River.

Furthermore, Taiwan is a high typhoon-frequent area during the summer season; all the construction machines and equipment will be hazardous whenever the typhoon attack the construction site. The equipment would be faced a high-risk condition to stay in the access steel bridge during the frequent typhoon season. Thus, the Contractor NA proposed an alternative method with new, safer structure type, the ABCSTF, which instead of the original steel arch frame for this prime bridge of the ALRMS. Figure 4 shows the draft sketch and simulation image of the new AB.

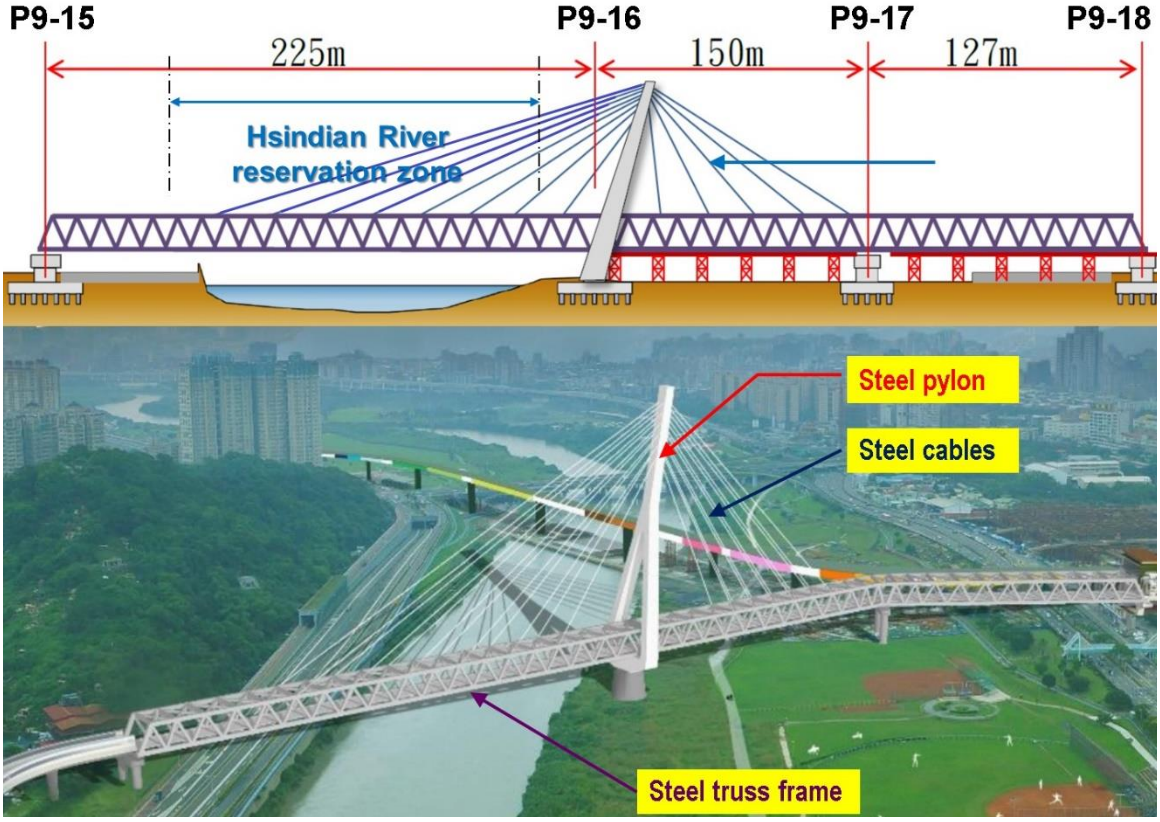

Figure 4: The draft sketch and simulation image of the new AB [6]

When selecting the structure type of the AB, based on the sustainability key indicators listed in Table 1, the engineers compare the performances between the SAB and the ABCSTF to provide sufficient information for the decision-maker's final determination. Table 2 lists the evaluated performances for SAB and ABCSTF. The operation/maintenance stage, as well as the construction stage, are covered in the evaluation of these two options. From the lifecycle of the bridge, to reduce the harmful impact to the environment protection and ecological conservation in the construction stage represent the equivalent importance with the operation/maintenance stage.

Table 2: The evaluated performances for SAB and ABCSTF, based on sustainability key indicators.

Key indicators	**Original planning:** The steel arch bridge (SAB)	**Alternative option:** The asymmetry cable-stayed design with truss frames (ABCSTF)
Safety and risk mitigation		●
Reliability	●	●
Environment protection		●
Ecological conservation		●
Durability	●	●
Landscape		●
Construction Duration		●
Creativity		●
Final determination		●

Table 2 shows that the Contractor (NA) obtained the comparison results based on the sustainability key indicators, and made the final determination to select the ABCSTF as the structure type of the Anhsin Bridge (AB).

5. Sustainability Practices in Anhsin Bridge (AB)

Most of the sustainability issues are well-discussed and performed in the ALRMS project. Since the AB is a part of the entire project, it focuses on some critical items of the sustainability ke indicators, including Risk Mitigation and Reliability, Environmental Protection, Ecology, Durability, Landscape, and Creativity.

5.1 Risk Mitigation and Reliability

The safety of infrastructure is always the top priority of consideration. Verification and enhancement of safety management during the lifecycle are essential to the engineers. The alternated structure type of AB includes three major parts, which are the 130m height steel pylon, the 502m steel truss frame, and the 1,250 tons of steel cables, respectively. Even though the engineers determine to use the ABCSTF structure type for the AB, however, every parts' construction might lead to the happiness of danger. Therefore, the risk mitigation work is the essential responsibility of the engineers to prevent such a risk possibility. To resolve and decrease the risk possibility, some unique-designed reliable construction facilities and equipment were proposed in the construction of AB, including the heave duty tower crane, and the erection system for truss frame (ESTF).

5.1.1 Erection for steel pylon and truss frame

A heavy-duty tower crane, ST3330, was installed for the erection of 17 segments of the steel pylon. The tower crane was established near the steel pylon and fixed by four tie-in frame layers. Figure 5 shows the tie-in members connecting to the mast tower members.

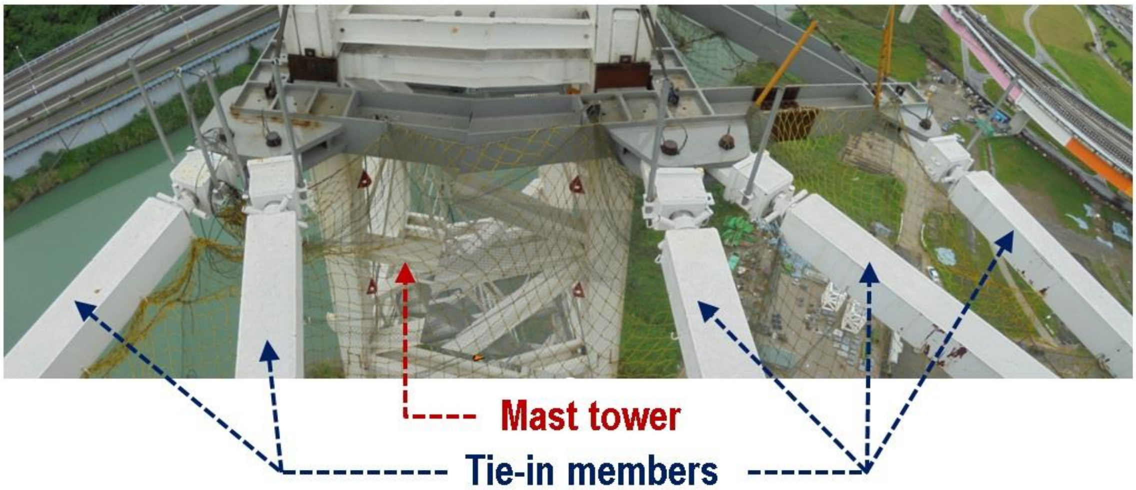

Figure 5: The photo of ST3330 tower crane

The assembly of tower crane and AB steel pylon, which are connected by the tie-in sets, can reduce the influences of river flow during the typhoon season. The temporary working platform was pre-installed to each pylon segment and lifted along with the segment erection. Figures 6 and 7 show the ST3330 tower crane photos and the inspection of the temporary working platform by the corresponding author, respectively.

Figure 6: The photo of ST3330 tower crane

Figure 7: The inspection of the temporary working platform by the corresponding author

To avoid the river flow from being affected by the temporary shoring system during the erection of the steel truss frame, the engineers proposed to use the erection system for the truss frame (ESTF) for the erection work. Since the tower crane and other mobile cranes are not feasible for the erection of all steel members, the ESTF shall provide the lifting, transporting, and erection function for the construction of the steel truss frame. Thus, the ESTF is newly designed to serve as the construction facility that contains some devices for the erection of the prominent horizontal steel truss members. It included three major devices of heavy-duty equipment:

1. a **Lifting Crane** with a capacity of 48 tons
2. a **Mobile Trolley** that can handle the steel members up to 35 tons
3. an **Erection Crane** with a lifting ability of 50 tons

The ESTS is a specially designed equipment set to fit the site necessity of the steel truss frame construction of AB [6]. Figure 8 shows the prime devices of the ESTF.

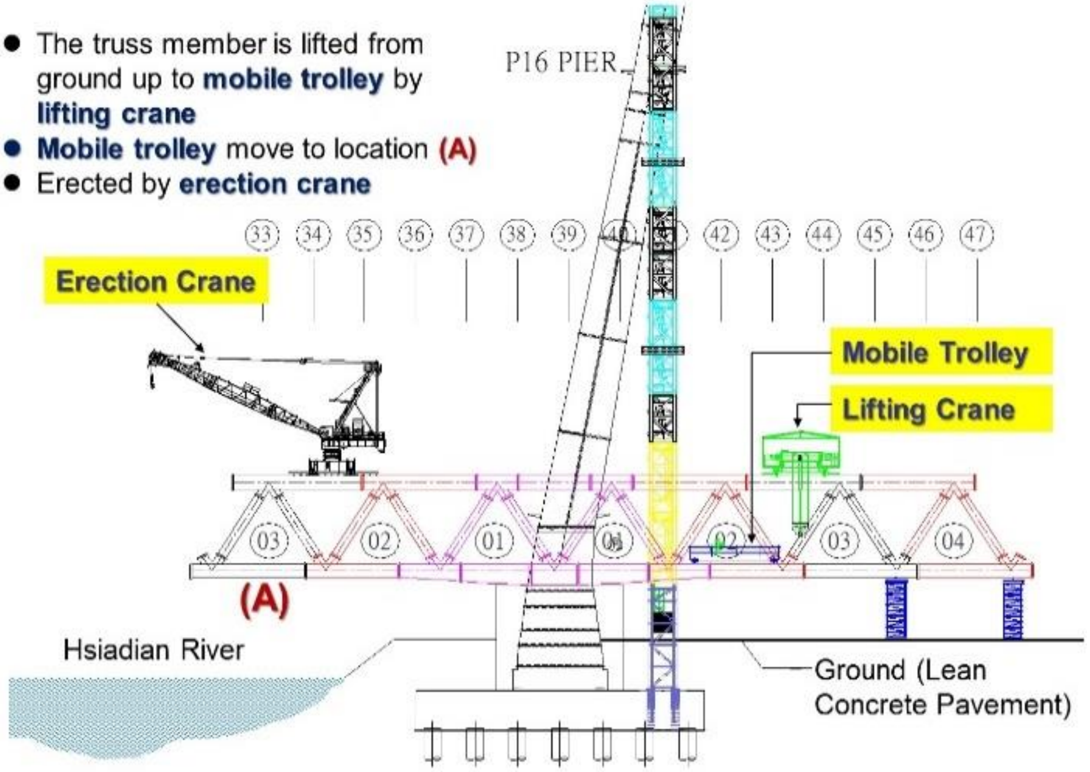

Figure 8: The design drawing of the erection system for the truss frame (ESTF) [6].

The lifting crane lifted the truss frame member onto the mobile trolley platform. The mobile trolley then delivered the member, moved at a speed of six meters per minute, toward the erection zone, refer to the location (A) of Figure 8. After the steel members arrived at the erection zone, the ereetion crane took over all installation work. Figure 9 shows the installation steps of the steel truss frame.

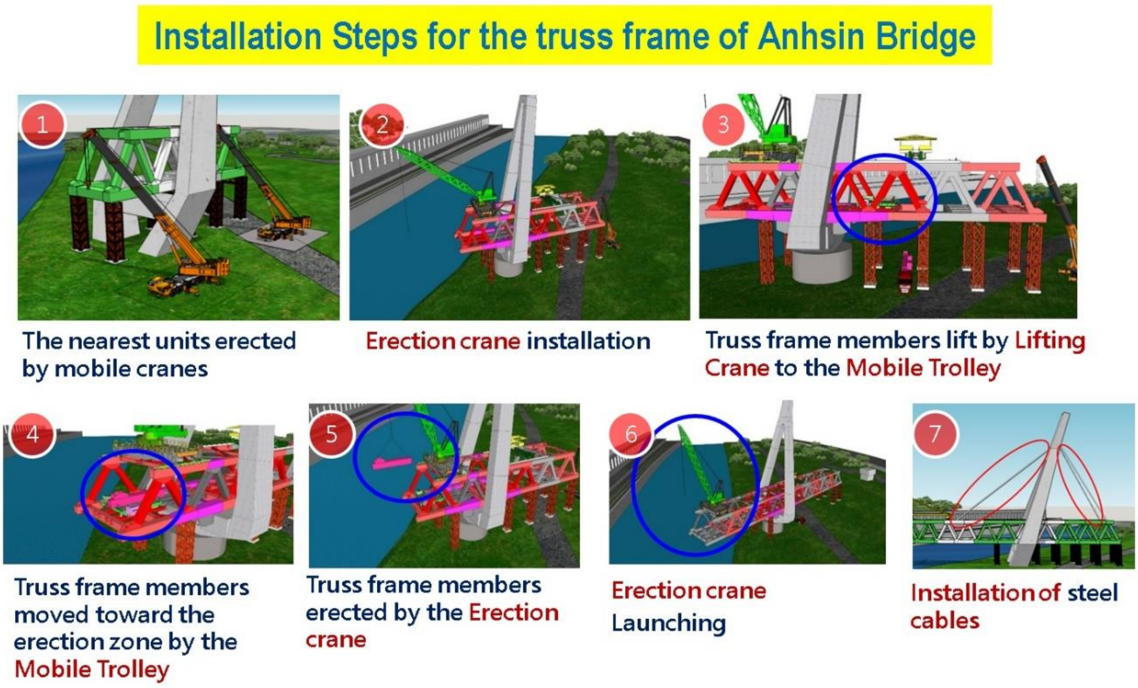

Figure 9: The installation steps of the steel truss frame

By adopting ESTF, no temporary equipment or structure was needed in the river reservation zone during the construction of the steel truss frame. It had significantly reduced the possibility of the risk. Moreover, the overall construction duration is shortened due to the absence of the temporary shoring system and the access steel bridge in the river reservation zone. Figures 10 and 11 show the site photos of the ESTF and the bolt tightening of the steel truss frame under the corresponding author's supervision, respectively [6].

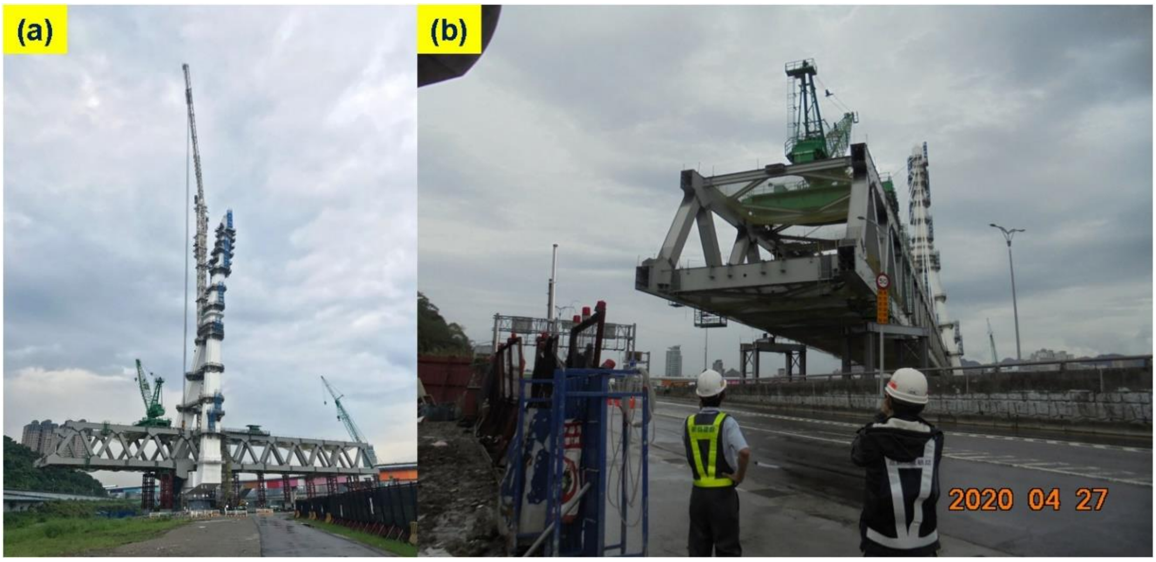

Figure 10: The site photos of the ESTF: (a) near to the steel pylon, (b) near to P9-18 pier.

Figure 11: The bolt tightening of the steel truss frame under the corresponding author's supervision [6]

We know that performing the proper safety management during the installation of steel cable could guarantee excellent quality for the bridge. The arrangement of cat way with safety guard and temperory stairs/ladders, which provided the safe environment for the installers when performing the steel cable installation work. Figure 12 shows the safety facilities for the installation work. Figure 13 shows the site photos of the safety facilities.

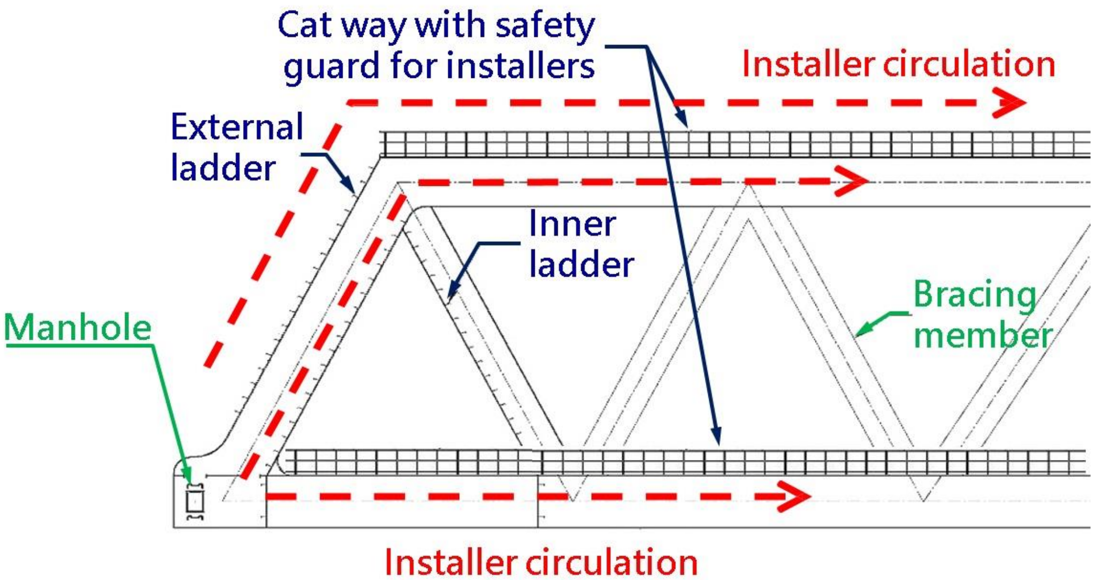

Figure 12: The safety facilities for the installation work.

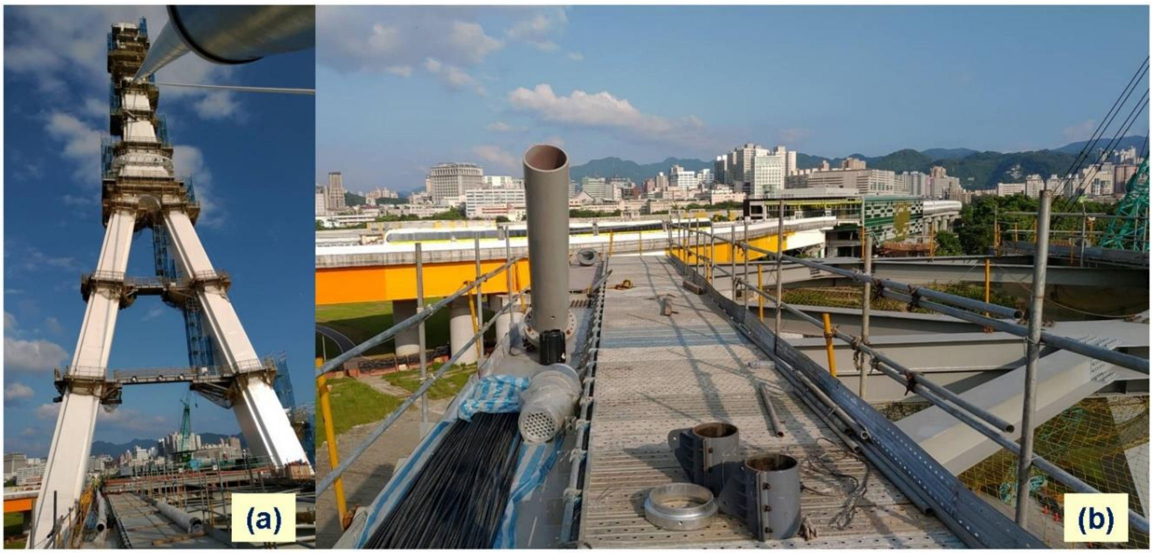

Figure 13: The site photos of the safety facilities: (a) External stairs and temporary platform, (b) cat way with the safety guard.

5.2 Environmental Protection and Ecology

Considering environmental sustainability, with the statements in the above sections, the Contractor (NA) proposed the newly designed ABCSTF to be the structure frame type of the Anhsin Bridge (AB). This well-designed structure frame, combined with the 12 pairs of steel cable, achieves the most extended bridge span length of 225 m for the rail system in Taiwan. A friendly environmental achievement was made by adopting ABCSTF. Besides, the impact on river flow and species in the river was minimized in the construction and operation stages [12]. Also, carbon emission was reduced through optimizing equipment and machine management [13]. This achievement was realized especially due to the good planning of BSTF [6]. In addition, since construction could severely impact the habitats of local species, biologists were engaged in the AB project, and they implemented a research program for Hsindian River and its tributaries to monitor any changes in species' population and health during construction [6]. Figure 14 shows some species that were monitored, observed, and analyzed [12]. Besides, the cleanup work for the Hsindian River's siltation was periodically performed for the smooth river flow. Monitoring for the quality of river quality was also executed regularly to verify the influence of the water caused by the AB construction work.

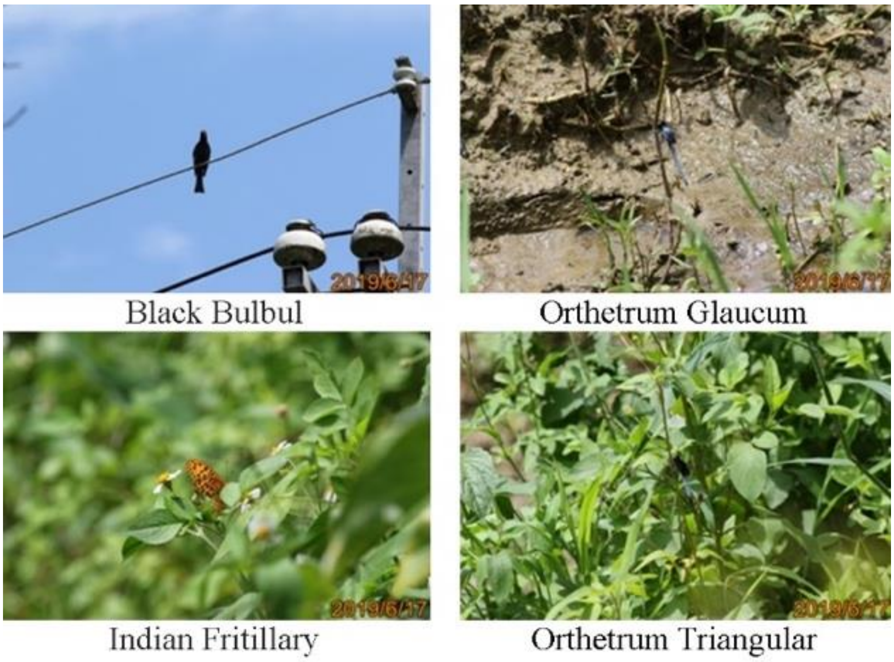

Figure 14: Some species that were monitored, observed, and analyzed [12].

5.3 Durability

5.3.1 Huge load on pier foundation: design, construction, and inspection

The total length of AB is 502m, and it includes four piers, P9-15, P9-16, P9-17, and P9-18, are designed as the substructure of the bridge. There are three spans on these four piers with a span length of 225m, 150m, and 127m, respectively, as shown in Figure 4. Due to the long span length (225m) of the Anhsin Bridge by adopting ABCSTF, no pier is necessary to be built in the Hsindian River flow zone. Therefore, most of the Anhsin Bridge's load, including the pylon, steel truss frame, and the life load by the trains, will apply to pier No. P9-16. Thus, the loading capacity of the P9-16 should be sufficient to bear the extremely huge loads. The live and dead loads of the 375m truss frame are transferred to the pylon of the P9-16 pier by the 24 steel cables. Undoubtedly, most of the bridge loads should be taken by the P9-16 pier, and a large load capacity is required for the P9-16 pier and the piles. [6].

The foundation of P9-16 is designed to be laid on a 5.5m thickness foundation, which is supported by 42 pieces of 2m-diameter, 35m-depth borehole piles. For the success of the P9-16 and other piers' construction, a well-prepared construction working plan [14], as well as the strict on-site quality control (QC) procedures for the piles and pile-cap [15], would be the best guarantee for the durability of the bridge [6]. According to the working and QC procedures, a qualified QC team was established to conduct the strict inspection and test. All tests and inspection results represented a high quality of the constructed piles and the pile-cap. Figure 15 shows the construction of the piles supervised by the corresponding author, and Figure 16 shows the inspection of the foundation by the QC engineers..

Figure 15: The construction of the 2m-diameter piles supervised by the corresponding author.

Figure 16: The inspection of the foundation by the QC engineers.

5.3.2 Pile static loading test

Since the extremely massive loads will be applied to the P9-16 pier, the verification of the pile capacity is essentially necessary before the construction of P9-16 foundation. The bearing capacity of the test pile and the friction of the anchor pile were calculated using Eqs. (1) as follows:

$$Qu = q_b Ab + \Sigma f_s A_s \quad (1)$$

Where:

Qu: The total bearing capacity of the pile.

qb: The bearing stress of the soil in the pile tip zone.

Ab: The section area of the pile tip.

fs: The friction stress between the pile's side surface and the soil.

As: The area of the pile's side surface.

Figure 17 shows the principle of Eq.(1).

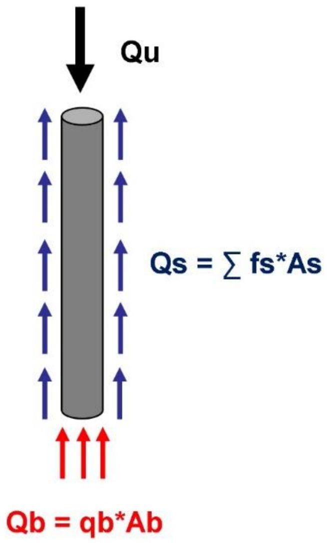

Figure 17: The principle of Eq.(1): $Qu = q_b Ab + \Sigma f_s A_s$

Besides, the total bearing capacity of the piles can also be calculated from the Eq.(2) as follows:

$$Qs = (Ns/3)*2\pi*As \quad (2)$$

Where:

Ns: N-value of soil obtained from the standard penetration test (SPT).

As: The area of the pile's side surface.

In this case, the total bearing capacity of the test and anchor piles are specified by the larger value of the Qu and Qs. It also defined the detailed design for the pile diameter and the length of the piles for the P9-16 foundation/pile cap. The followed processes are to verify the capacity of the pile could meet the designed requirement. The engineers established a detailed test procedure to verify the actual performance of the piles [16]. Table 3 shows the specified data for the pile test [6].

Table 3: Basic data for the pile test [6, 14].

items	Unit	**Values**
Design pile length	m	35.0
Diameter of the test pile	cm	200
Extended portion length	m	12.5
Total pile length (includeing extended portion)	m	35.0+12.5=47.5 m
Design vertical load (under normal condition)	Tons	974
Design vertical load (under earth quake condition)	**Tons**	**2,287**
Friction of extended portion	**Tons**	**593.96**
Maximum test load	**Tons**	**2,881 t**
Anchor force type		Anchor piles
Anchor force supply		4 anchor piles, Diameter =2.0m，L＝47.2m
Connection rebars		SD420W#11-24×2=48 Pics.
Rebar welding		Fillet weld, L=16cm

Based on the Table 3, the maximum test load is calculated using Eq. (3) as follows:

Max.{(2* Normal vertical load), Earthquake vertical load}+ Friction of extended portion (3)

According to Eq.(3), the maximum test load was calculated as:

Maximum test load = (2,287+593.96) = **2,880.96**, namely **2,881** tons.

There are two options for applying the test load: the concrete mass blocks and the hydraulic jack sets. In this case, the engineer selected the hydraulic jack sets due to the extremely massive load needed to be provided for the test. Eight pieces of 500 tons hydraulic jacks were assembled to provide sufficient forces for the static loading test. Figure 18 shows the assembly of the pile static loading test.

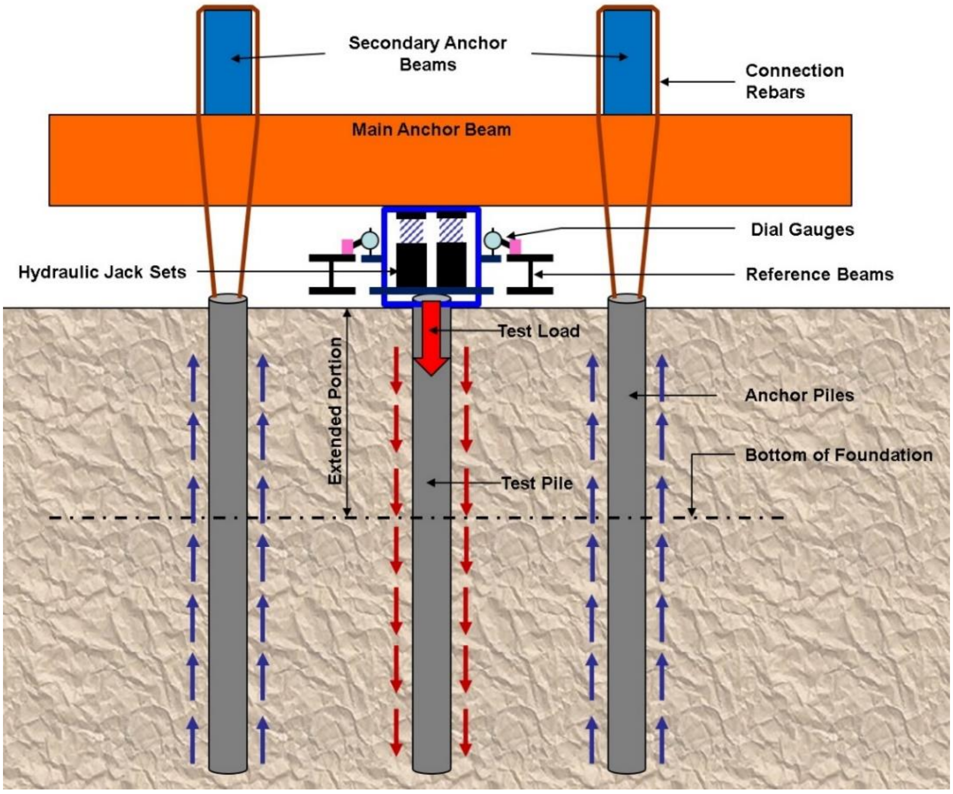

Figure 18: The assembly of the pile static loading test.

The testing equipment was set by the major components, including hydraulic jack sets, main and secondary anchor beams, reference beams, dial gauges, and monitoring instruments, as shown in Figure 18. Figure 19 shows the site photos of the test equipment.

Figure 19: The testing equipment: (a) the site test assembly, and (b) monitor instruments checked by the corresponding author.

According to the test procedure [16], the test pile was selected from the 42 permanent piles, and the neighboring four piles served to provide the anchor force during the conducting of the static loading test. The main anchor beam and two secondary beams were the reflection members for the vertical load transferring, as shown in Figure 18. The vertical loads of 2,881 tons should be gradually applied using the hydraulic jack sets. Table 4 shows the pile test steps and the load applied in each stage [6, 16].

Table 4: The pile test steps and the load applied in each stage [6, 16].

Loading Stages	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Load percentage(%)	0	12.5	25.0	37.5	50.0	62.5	75.0	87.5	100
Load (t)	**0**	**358**	**716**	**1074**	**1433**	**1791**	**2149**	**2507**	**2881**
1st hour		□							
2nd hour			□						
3rd hour				□					
4th hour					□				
5th hour						□			
6th hour							□		
7th hour								□	
8th hour									□
20th hour							■		
21st hour					■				
22nd hour			■						
34th hour	▲								
Release steps	**12**		**11**		**10**		**9**		**8**
Note	□ : Load increasing			■ : Load decreasing			▲ : Load release		

After eight hours of static loading test, the maximum load and the corresponding pile top settlement were 2,881 tons and 16.67mm, respectively. The load was gradually released down to zero after keeping of maximum load for 12 hours. During the load releasing stage, the pile top settlement was gradually re-expanded. The net settlement, 3.52mm, was measured immediately while the vertical load was released down to zero. Figure 20 shows the load-settlement diagram of the pile static loading test.

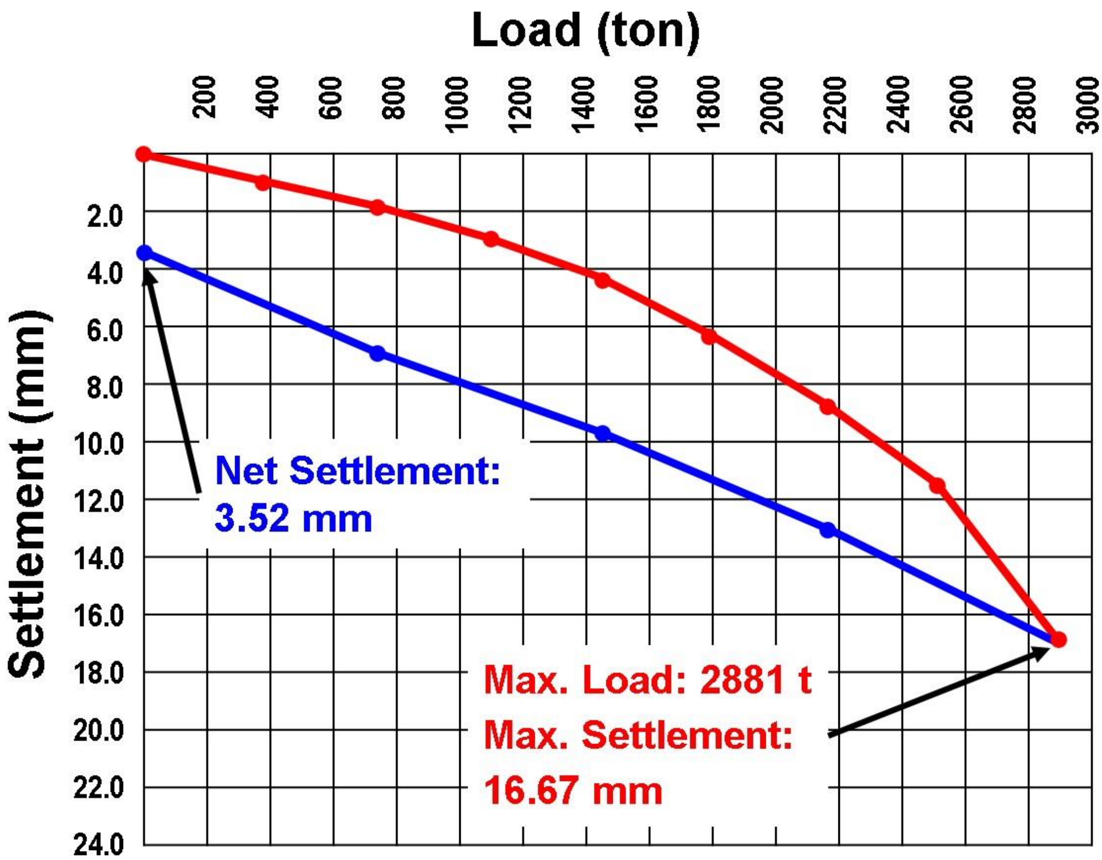

Figure 20: The load-settlement diagram of the pile static loading test [6].

The maximum settlement and net settlement verified that the actual pile capacity met the design requirement with a safety factor of 3. The test results indicated excellent and reliable durability for the lifecycle of the AB.

5.3.2 Wind force: wind tunnel test

We are aware that the wind force might cause incredibly harmful damages to the bridge's structure. It had some bridge's collapse experiences, which were not sufficiently designed to bear the horizontal wind force, especially from the Tacoma Narrows Bridge collapse accident. In the Anhsin Bridge of ALRMS project, the wind force had been considered during the design stage. Furthermore, prior to the connection of the steel truss frame and Pier P9-15, the bridge body was not stable due to the cantilever condition. The horizontal force caused by wind, such as that from typhoons, might seriously damage the structure of the steel truss frame. For the realization of the lateral displacement of the steel truss frame under cantilever condition, wind tunnel tests [17] were conducted.

The bridge members were produced by 3-D printing on a 1/100 scale. A series of tests in different wind directions, including 30°, 45°, 60°, 90°, 120°, 135°, and 150°, were conducted. The maximum lateral displacement under the most critical condition was measured as 830mm with a 74m/second wind speed. The maximum wind force was calculated using Eq. (4).

$$\boldsymbol{P = 0.124*V^2} \qquad (4)$$

Through careful analysis of the steel truss frame with a lateral displacement of 830mm, the bridge structure was confirmed to be safe with a reliable safety factor. Figure 21 shows the wind tunnel test in the laboratory [6, 17].

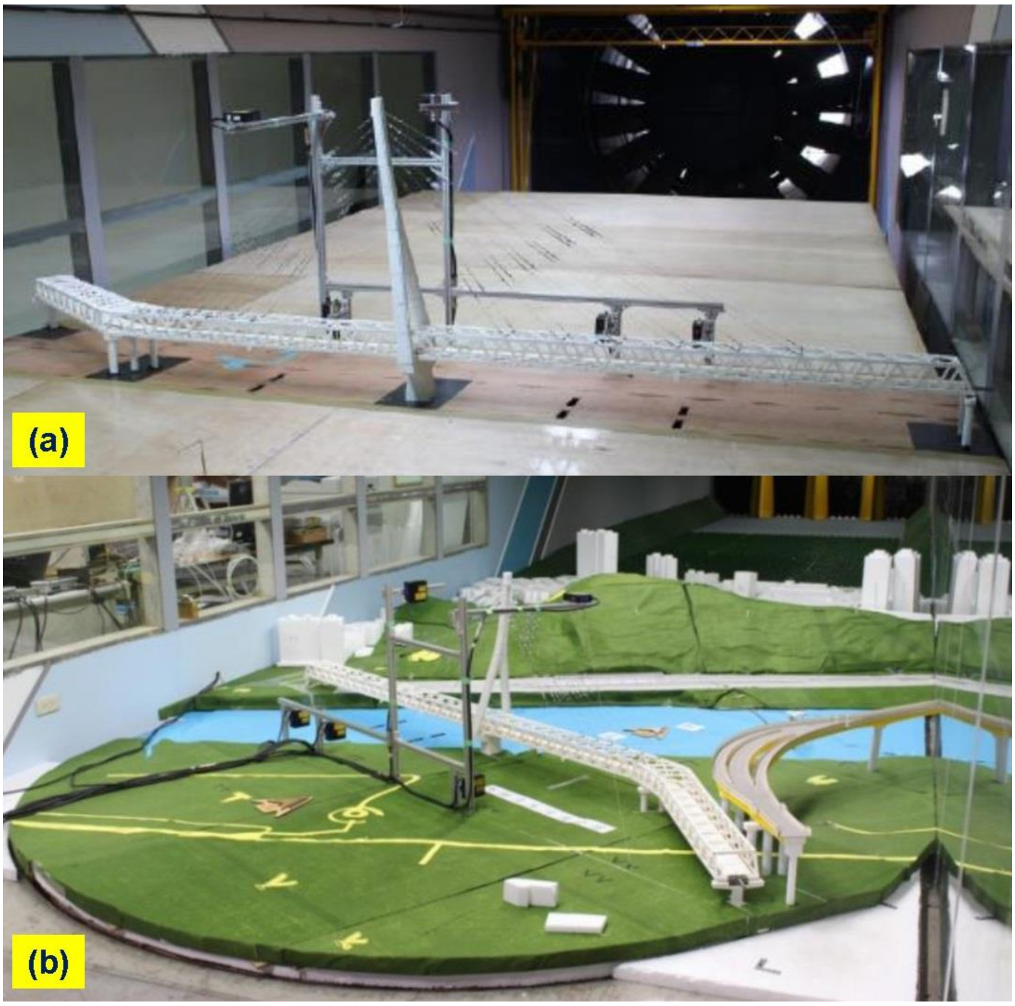

Figure 21: The wind tunnel test in the laboratory [6, 17].

5.3.3 Management of massive member sizes

More than fifty thousand steel members of various shapes and sizes were specified in the drawing. A reliable management system for raw materials and their manufacturing, assembly, transportation, and erection should be established in order to carry out construction work without any mistakes [6]. Figure 22 shows the traceability of material management.

Engineers establish the traceability of material and steel members management system for numbering, batching, identification, and verification of the manufacture, transportation, and site installation of the AB [18]. The functional management system's operation leads the construction of AB to a successful performance.

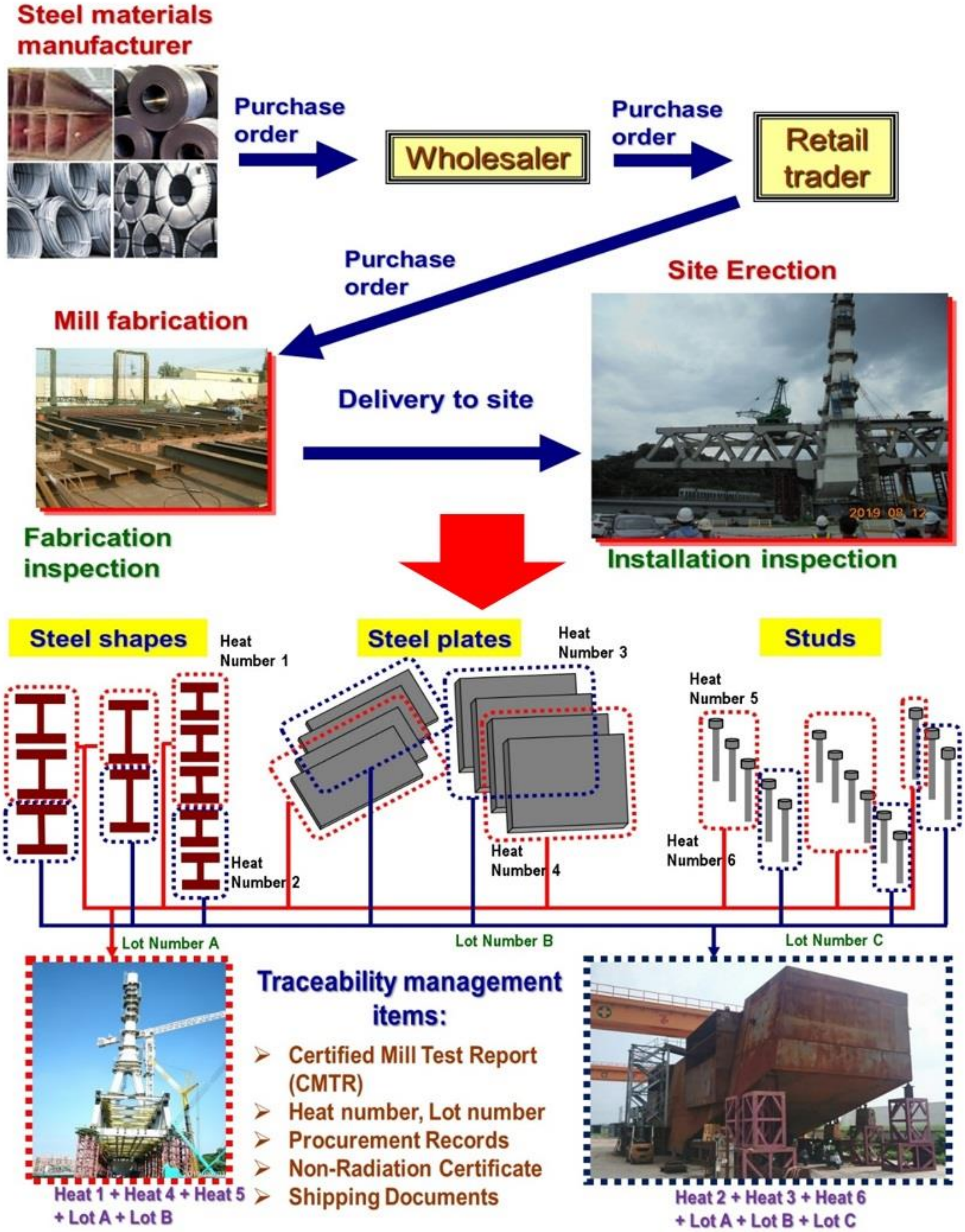

Figure 22: The traceability of material management.

5.3.4 Steel Cable system

The quality of steel cables represents the durability of the AB. Corrosion protection for the cables is the most critical issue of the quality assurance processes. Figure 23 illustrates the detailed assembly and corrosion protection system for the steel cables. Figure 24 shows the tendon and HDPE pipe inspected by the corresponding author.

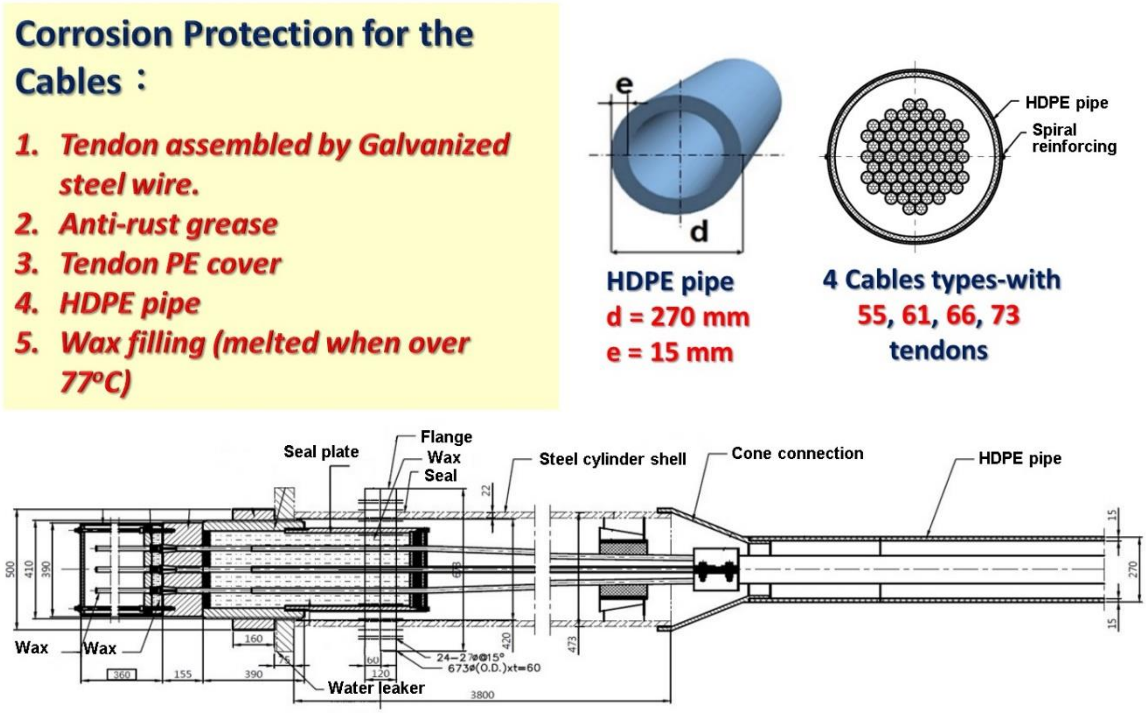

Figure 23: detailed assembly and corrosion protection system for the stell cables.

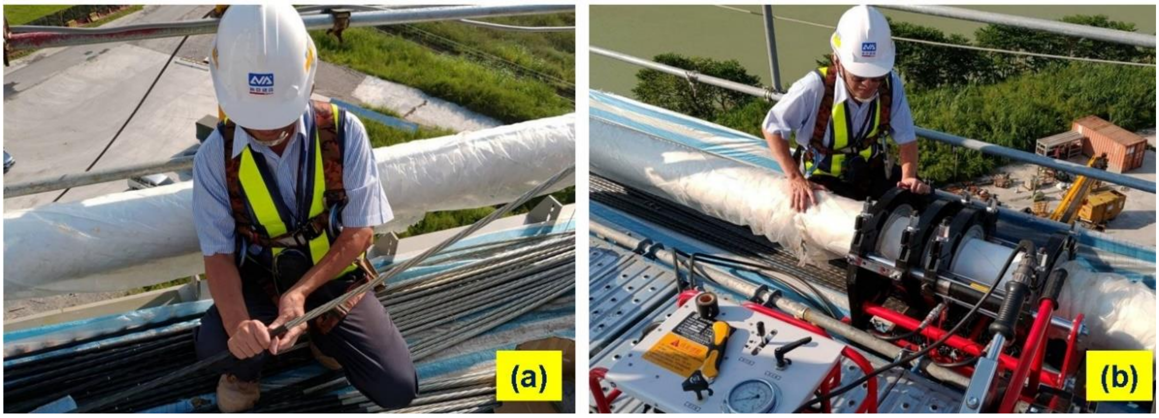

Figure 24: The (a) tendon, and (b) HDPE pipe inspected by the corresponding author.

5.4 Landscape and Creativity

When people watch the shape of the AB, combine the pylon with the cable-stayed system, it could be imagined to be a high flying eagle. The outstanding landscape design represents the widely, freely, and broadly minds of humans. Figure 25 shows the imagination of the landscape design.

Figure25: The imagination of the landscape design.

Adopting building information modeling (BIM) [19] helped engineers with excellent management for Anhsin Bridge (AB) construction. Every single piece could be modeled in 3-D using BIM with traceable ID number, shape, size, installation location, etc. BIM not only enabled engineers to manage construction work efficiently and effectively, but also detected potential clashes between different members and resolved them prior to installation and/or erection [6]. Figure 26 shows the BIM output for the AB steel truss frame.

Figure26: The BIM output for the steel truss frame of the Anhsin Bridge (AB).

Conclusion

The contractor proposed the asymmetry cable-stayed design with truss frame (ABCSTF) method for the Anhsin Bridge construction to meet the goal of sustainability achievements, including Risk Mitigation and Reliability, Environmental Protection, Ecology, Durability, Landscape, and Creativity. Besides, the application of BIM technique helped engineers to play their talents and creativities for the bridge design. Moreover, the outstanding landscape design had accomplished the accomplishments of humanity. The presented successful practices adopted in this project for sustainability issues during the design, construction, and operation stages, could serve as a useful reference for similar bridge projects in the future.

Availability of data and materials

All data, materials, models, and code generated or used during the study appear in the submitted article

Competing interests

On behalf of all authors, the corresponding author states that there is no competing interest.

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