

Environmental Sustainability Approaches Adopted for Anhsin Bridge Construction of Ankeng Metro System in New Taipei City in Taiwan

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Abstract. The Ankeng Light Rail Metro System (ALRMS) is a Design-Build (DB) construction project located in New Taipei City. The Anhsin Bridge (AB) is one of the major parts of ALRMS. The original concept from the client, the Department of Rapid Transit Systems (DRTS), New Taipei City Government, was to design Anhsin Bridge as a steel arch bridge, which inevitably would require construction of some piers in the river reservation zone. Also, a temporary access bridge would be necessary during the erection of the steel frame. All these would pose a harmful situation for the river flow. Considering environmental sustainability, the contractor proposed a sustainable construction method, the unbalanced cable-stayed design with truss frames (UBCSTF), to build the Anhsin Bridge. Without constructing piers in the river reservation zone, the pylon of the Anhsin Bridge was laid on a 5.5m thickness foundation supported by 42 2m-diameter bored piles. A friendly environmental achievement was made by adopting UBCSTF. In this paper, the authors will share the rare construction experiences with the Anhsin Bridge construction, and present the detailed design concept, construction, and environmental sustainability achievements in this project.

1 Introduction

1.1 Foreword

Sustainability indicators for infrastructure were proposed in the past decades [1][2], with the Key Assessment Indicators proposed for evaluating sustainability issues in engineering fields [3]. In recent years, sustainability issues have been widely studied and discussed in all engineering fields as well as construction. The main purpose of conducting sustainability research is to prevent construction projects from depleting resources and/or causing harmful effect and impact on the environment and ecology during their lifecycles [3][4]. In this project, engineers have been focusing on environmental sustainability to minimize potential impact on the environment during the lifecycle of the Ankeng Light Rail Metro System (ALRMS). Fig. 1 shows the research framework in this paper.



Fig. 1. Research framework

1.2 Project description

The Ankeng Light Rail Metro System (ALRMS) is an important public transportation system under construction and is expected to complete in 2021, including the

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completion of the depot zone. Fig. 2 shows the route layout of the whole project.

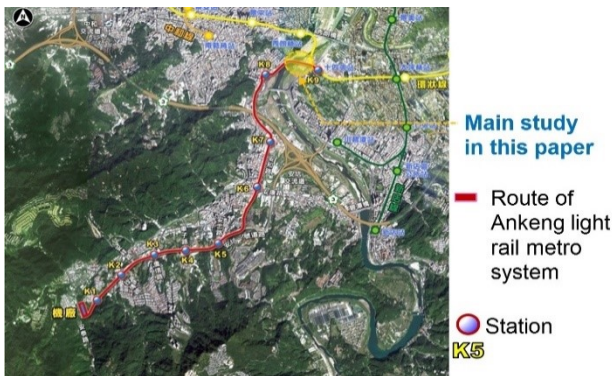


Fig. 2. The route layout of the Ankeng project. (Source: Tai-Yi Liu)

ALRMS has a total length of 7.5 kilometers and nine stations, including five elevated stations and four at-grade stations. The three bridges crossing the No. 3 Freeway, Hsinpei Highway and Hsindian River were designed differently in accordance with the design codes.

In addition to design codes, environmental and ecological sustainability was considered in conceptual design. In this paper, the environmental sustainability approaches adopted for Anhsin Bridge (AB) construction will be presented.

2 Challenges and Solutions

2.1 Environmental sustainability

The route between K8 and K9 stations passes the Hsindian River and building a bridge is easier than building an underground tunnel. The original design proposed by the client DRTS was a steel arch bridge, as shown in Fig. 3.



Fig. 3. The original design concept of Anhsin Bridge.

As shown in Fig. 3, it was unlikely to avoid construction of piers and setup of temporary access bridges, scaffoldings, and other temporary supporting structures in the river reservation zone. With this design, the influence on the river flow would not only occur in the construction stage, but also in the operation stage. Considering environmental sustainability, other bridge designs that are more environmentally friendly should be proposed for this project.

The Ankeng Light Rail Metro System (ALRMS) project is a Design-Build (DB) project, and the contractor, New Asia Construction and Development Corporation, is one of the largest construction companies in Taiwan. With the responsibility for environmental protection in mind, the contractor decided to build the Anhsin Bridge (AB) using the unbalanced cable-stayed design with truss frames (UBCSTF) method, even if it might be more costly

than the original steel arch bridge design. Fig. 4 shows the draft sketch and simulation image of the new AB. The UBCSTF design greatly reduced the impact on the environmental and exemplified how engineers could help achieve a sustainable environment.



Fig. 4. The draft sketch and simulation image of new Anhsin Bridge. (Source: Tai-Yi Liu)

2.2 Huge load on pier foundation

The total length of AB is 502m. A total of four piers, P9-15, P9-16, P9-17, and P9-18 are designed as the substructure of the bridge. AB includes three major parts, including a 130m height pylon, a 502m truss frame, and 24 (12 pairs) steel cables. 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. Thus, most of the bridge loads are taken by the P9-16 pier, and a huge load capacity is required for the P9-16 pier.

A total of 42 2m-diameter, 35m-deep bored piles were designed to bear the huge load transferred from the 5.5m thickness pile cap. Fig. 5 shows the construction of the piles and Fig. 6 shows the inspection of foundation.



Fig. 5. The construction of the 2m-diameter piles supervised by the first author.



Fig. 6. The inspection of foundation by the authors.

To verify the actual performance of the piles, a pile static loading test was conducted in the field, and a well-planned test procedure [5] was carried out. Table 1 shows the basic data for the pile test.

Table 1. Basic data for the pile test.

items	Values
Design vertical load-normal condition (t)	974
Design vertical load-earthquake condition (t)	2,287
Design pile length (m)	35.0
Diameter of test pile (cm)	200
Extended portion length (m)	12.5
Friction of extended portion (t)	593.96
Maximum test load	2,881t
Total pile length (m, includes extended portion)	35.0+12.5=47.5
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

The maximum test load is calculated using Eq. (1).

$$Max.\{(2 * Normal\ vertical\ load),\ Earthquake\ vertical\ load\} + Friction\ of\ extended\ portion \quad (1)$$

where the maximum test load was $(2,287+593.96) = 2,880.96$, namely 2,881 tons.

The bearing capacity of the test pile and the friction of anchor pile were calculated using Eqs. (2) and (3), respectively.

$$Q_u = q_b A_b + \sum f_s A_s \quad (2)$$

$$Q_s = (N_s/3) * 2 \pi * A_s \quad (3)$$

The testing was carried out with some major components, including hydraulic jacks, anchor beams, reference beams and monitoring instruments. Fig. 7 shows the testing scene.



Fig. 7. The testing scene.

According to the test procedure [5], vertical loads should be gradually applied using the hydraulic jacks. Table 2 shows the pile test steps and the load applied in each step.

Table 2. The pile test steps and the load applied in each step.

Loading Steps	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	0	358	716	1074	1433	1791	2149	2507	2881
1 st hour		○							
2 nd hour			○						
3 rd hour				○					
4 th hour					○				
5 th hour						○			
6 th hour							○		
7 th hour								○	
8 th hour									○
20 th hour							●		
21 st hour					●				
22 nd hour			●						
34 th hour	▲								
Release steps	12		11		10		9		8

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. The net settlement was 3.52mm, measured after full release of loads. The maximum settlement and net settlement verified that the actual pile capacity met the design requirement with a safe factor of 3. Fig. 8 shows the load-settlement diagram of the pile static loading test.

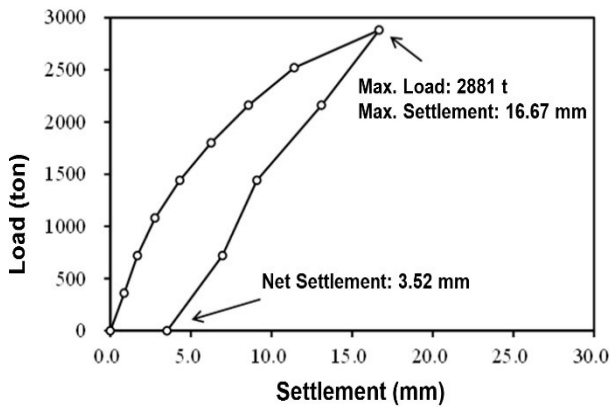


Fig. 8. The load-settlement diagram of the pile static loading test.

2.3 Steel truss frame erection

To avoid the river flow from being affected by the temporary shoring system during the erection of the steel truss frame, the contractor proposed to use the erection system for truss frame (ESTF) for the erection work. The ESTF included three major pieces of heavy-duty equipment, a lifting crane, a mobile trolley and an erection crane. They were specially designed for the construction of steel truss frame of AB.

With ESTF, no temporary equipment or structure was needed in the river reservation zone during the construction of the steel truss frame. Figs. 9 and 10 show the design drawing and site photo of ESTF, respectively. Fig. 11 shows the bolt tightening of steel truss frame under the first author’s supervision.

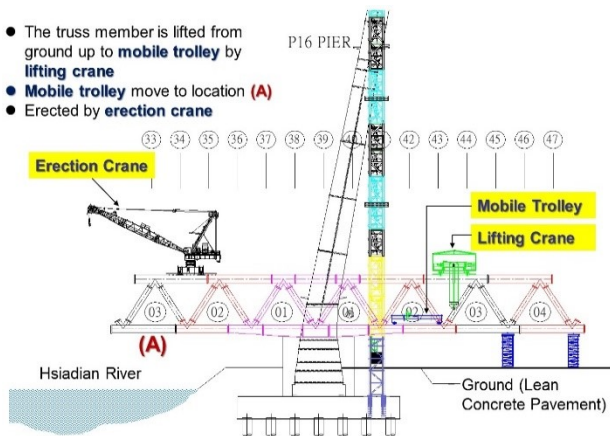


Fig. 9. The design drawing of the erection system for truss frame (ESTF).



Fig. 10. The site photo of the erection system for truss frame (ESTF).



Fig. 11. The bolt tightening of steel truss frame under the first author’s supervision.

2.4 Wind force

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 steel truss frame. For realization of the lateral displacement of steel truss frame under cantilever condition, wind tunnel tests [6] were conducted.

The bridge members were produced by 3-D printing in a 1/100 scale. A series of tests in different wind directions, inclusive of 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 wind speed of 74m/second. The maximum wind force was calculated using Eq. (4).

$$P = 0.124 * V^2 \quad (4)$$

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. Fig. 12 shows the wind tunnel test in the laboratory.

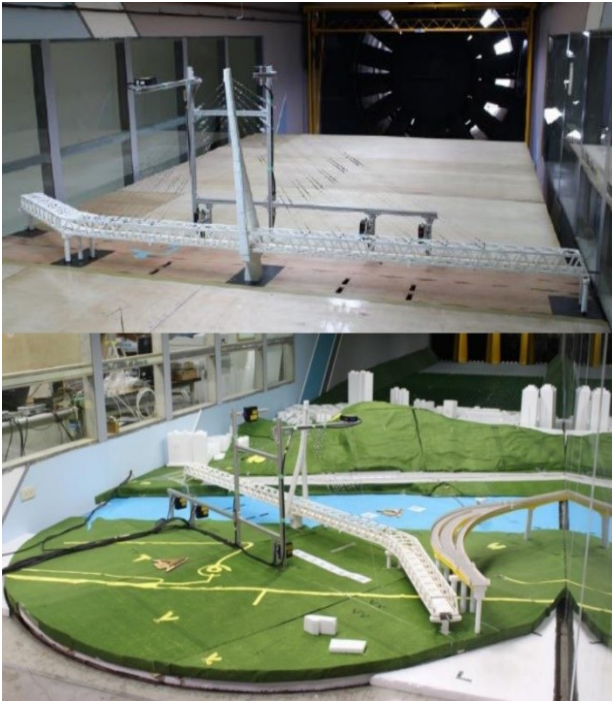


Fig. 12. The wind tunnel test in the laboratory.

2.5 Management of massive member sizes

There were more than fifty thousand steel members of various shapes and sizes 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. Fig. 13 shows the traceability of material management.

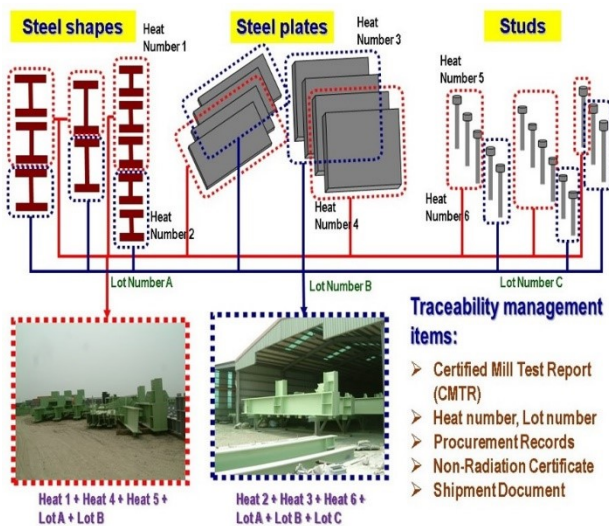


Fig. 13. The traceability of material management.

Adopting building information modeling (BIM) [7] helped engineers with excellent management for Anhsin Bridge (AB) construction. Each 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 in an efficient and effective way, but also detected potential clashes between different members and resolved them prior to installation and/or erection. Fig. 14 shows BIM output for the AB steel truss frame.

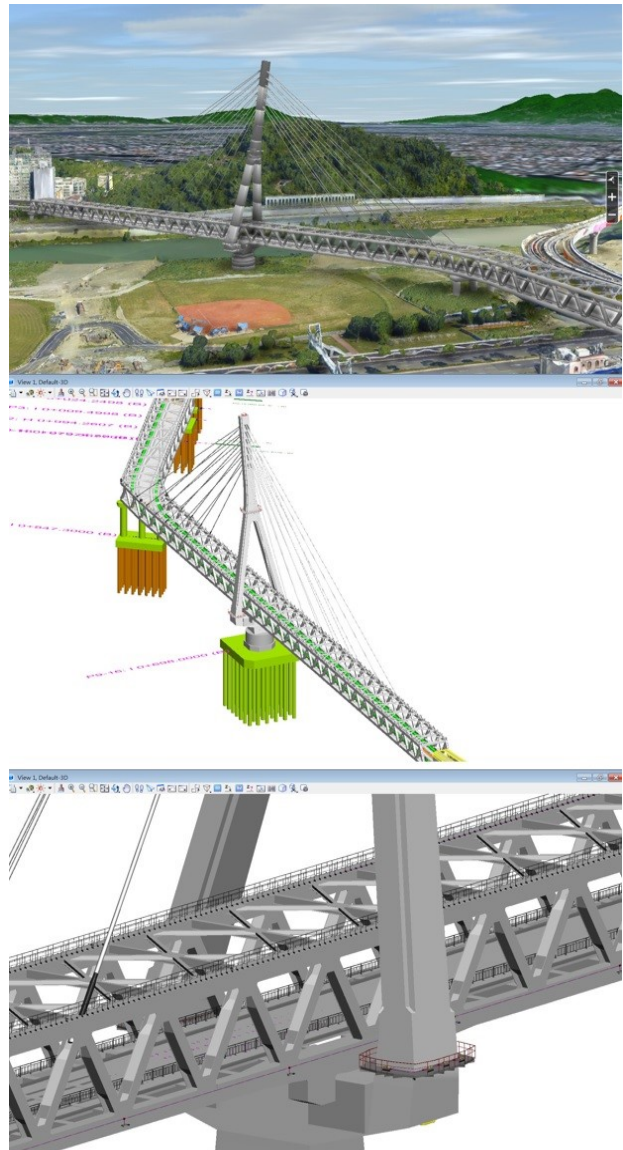


Fig. 14. BIM output for the steel truss frame of the Anhsin Bridge.

3 Environmental Sustainability Achievement

3.1 Key sustainability indicators for green civil infrastructure

The authors established a set of key sustainability indicators for green civil infrastructure, including safety,

ecology, environmental protection and carbon emissions reduction, energy saving, waste reduction, durability, benefit, landscape, humanities and culture reservation, and creativity [3]. Three evaluation levels with weights are contained in this system. Table 3 shows the major evaluation items (Level 2) contained in each indicator (Level 1) that are discussed in this project. The evaluation items that are well-considered and discussed in this project are marked in yellow. Fig. 15 shows the three levels of the green civil infrastructure assessment system [3].

Table 3. The major evaluation items contained in each indicator those are discussed in this project [3].

Indicator	Evaluation items
Ecology	Ecological environment investigation, data collection and impact assessment
	Original spot's preservation and indicative trees protection
	Ecological environment monitoring
	Selection of low impact construction methods and preservation of biodiversity and animal habitat integrity
Environmental protection and carbon emissions reduction	Establishment of safety facilities for animals
	Environmental impact assessment
	Monitoring of carbon emission in the lifecycle
	Selection of low carbon emission materials
	Establishment of carbon emission reduction mechanism and selection of the construction methods with low-carbon emissions
	Construction methods and procedures with low pollution (airborne particles, waste water, wastes, etc.)
	Lifecycle soil and water conservation plan
	Planting of trees with high carbon-absorption abilities
Durability	Underground reservoir design with long-term maintenance for the facility
	Durable structure design
	Use of durable materials
	Adaptive/upgradable design
	Adoption of long earthquake and flood regression periods for design
	Establishment of excellent operation/maintenance mechanism
Landscape, humanities and culture reservation	Cost down in the lifecycle
	Take local culture into consideration in structure design
	Design of structure for landscape fusion
	Beautification of design of structure and landscaping
	Provision of participation and communication to the public
	Care for minorities
Creativity	Protection of historical sites and cultural relics
	Creation of public art
	Introduction of new materials, new construction methods, new technologies, etc.
	Innovation in engineering project design
	Combination of project with scenery and culture

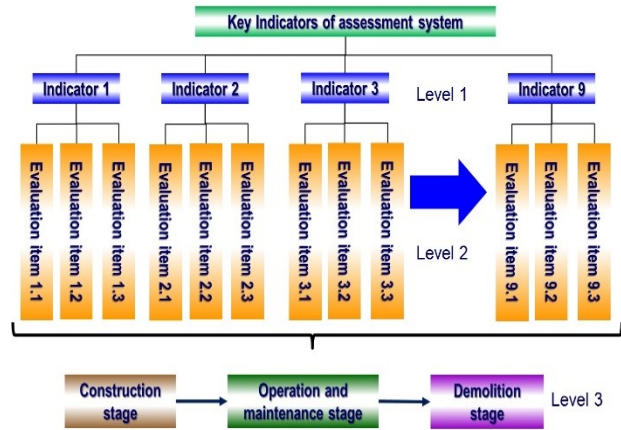


Fig. 15. Three levels of the green civil infrastructure assessment system [3].

3.2 Environmental sustainability achievement by Anhsin Bridge

In this paper, the authors highlighted some major sustainability practices of the Anhsin Bridge (AB) as follows:

- Environmental sustainability: Through adopting UBCSTF and cancelling of piers and other construction facilities that might be located and constructed in the river reservation zone, potential impacts on Hsindian River were avoided. Also, impact on river flow and species in the river was minimized in the construction and operation stages.
- Efficiency of equipment and machines for carbon reduction [8]: Carbon emission was reduced through optimizing equipment and machine management. This achievement was realized especially due to good planning of BSTF.
- Research on specified species [9]: 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. Fig. 16 shows some species that were monitored, observed and analyzed.

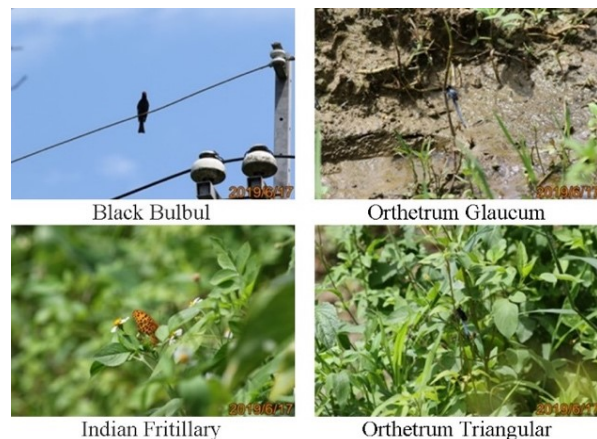


Fig. 16. Some species that were monitored, observed and analyzed.

4 Conclusion

The contractor proposed the unbalanced cable-stayed design with truss frame (UBCSTF) method for the Anhsin Bridge construction to meet the goal of environmental sustainability, ecology protection, landscape, and carbon emission reduction. Moreover, the efficiency of materials management was optimized through the use of building information modeling (BIM). The presented successful practices adopted in this project for environmental sustainability during construction could serve as a good reference for similar bridge projects in the future.

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References

1. World Bank. World development rep. 1994: *Infrastructure for development*, Oxford University Press, Oxford, UK, 1–12. (1994).
2. World Bank. “Infrastructure at the crossroads: Lessons from 20 years of World Bank experience.” Washington, DC, 1–9, 65–80. (2006).
3. T.Y. Liu, P.H. Chen, Nelson N.S. Chou “Comparison of Assessment Systems for Green Building and Green Civil Infrastructure.” *Sustainability 2019*, **11**, 2117. (2019).
4. Shen, Liyin, M.ASCE, Wu, Yuzhe, and Zhang, Xiaoling, (2011). “Key Assessment Indicators for the Sustainability of Infrastructure Projects.” *J. Constr. Eng. Manage.*, ASCE **137**(6): 441-451.
5. New Asia Construction and Development Corp., “Piles static loading test for the Ankeng Light Rail Metro System construction project.”, Taiwan, R.O.C., (2017, in Chinese)
6. New Asia Construction and Development Corp., “Wind tunnel test plan for the Ankeng Light Rail Metro System construction project.”, Taiwan, R.O.C., (2017, in Chinese)
7. New Asia Construction and Development Corp., “Establishment of BIM model for the Ankeng Light Rail Metro System construction project.”, Taiwan, R.O.C., (2016, in Chinese)
8. New Asia Construction and Development Corp., “Equipment management plan for the Ankeng Light Rail Metro System construction project.”, Taiwan, R.O.C., (2016, in Chinese)
9. New Asia Construction and Development Corp., “Ecology research annual report for the Ankeng Light Rail Metro System construction project.”, Taiwan, R.O.C., (2016-2019, in Chinese)