Third International Conference on FRP Composites in Civil Engineering (CICE 2006)
December 13-15 2006, Miami, Florida, USA

A Case Study of Life Cycle Cost based on a Real FRP Bridge

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ABSTRACT
In this paper, the authors considered and calculated Life Cycle Cost (LCC) of FRP and Pre-Stressed Concrete (PC) footbridges based on an actual FRP footbridge constructed in Japan. Three types of PC bridges and two types of FRP bridges were set as model cases. The result suggests that FRP bridges have the competitive edge in spite of their initial cost and are more efficient when durability is required in severely corrosive environments.

KEYWORDS
FRP, PC, footbridge, life cycle cost

1. INTRODUCTION

FRP has some excellent properties as a structural material. Its application to bridges offers a possibility to solve problems that bridges made of conventional materials are facing today such as corrosion and damages incurred early in the life-cycle of a structure. Presently, FRP's unit price is usually rather more expensive than that of other conventional materials. This may increase the initial cost of the FRP superstructure and is one of the obstacles deterring widespread use of the material in FRP bridges.
In order to evaluate the benefit of using FRP in bridges, it is important to consider FRP's life cycle cost (LCC) including the cost for maintenance. There has been some research[1)-3)] on the cost benefit of FRP structures; however, because some of those studies begin with the design of the structures and include many suppositions, the LCC estimates of FRP structures are not so reliable.
With this in mind, the authors tried to evaluate the LCC of an actual FRP footbridge, remaining as faithful to actual conditions as possible. The case study is based on an FRP footbridge constructed in Okinawa, Japan, in 2000. It is called "Okinawa Road Park Bridge" and is pictured in Figure 1.

Figure 1: View of the Okinawa Road Park Bridge

2. THE STRUCTURES FOR THE CASE STUDY

A FRP footbridge and PC footbridge crossing a 4-lane road were considered as the case models. The bridges are located close to the seashore and severely affected by sea salt. The main girders of the FRP footbridge are made of hand lay-up FRP; pultruded FRP is used for the stiffeners, decks, and floor systems. Both types of FRP were made of glass fiber and vinylester resin. Parts of the FRP footbridge were made in several factories within the Tokyo area, assembled in a factory in Tokyo Bay, and then shipped to Okinawa. Wall type piers and steel pipe pile foundations were used in the substructure for both bridges.

Table 1: Model cases of FRP and PC bridges

	FRP bridges	PC bridges
Concept	Two span girder bridge with GFRP C-girders	Single span deck girder bridge with hollow post-tension concrete beams
Length	37.8m	36.0m
Span	19.7m+17.2m	35.0m
Width	4.3m	4.3m
Live load	350kgf/m^2 for main girders	
	500kgf/m^2 for decks	

3. CALCULATION METHOD OF LCC

Direct construction costs of the initial cost and the maintenance cost for both FRP and PC bridges were calculated based on the design reports for both bridges. LCC was obtained by the equations:

$$L_{FRP\ bri.} = I_{FRP\ bri.} + M_{FRP\ bri.}$$
$$L_{PC\ bri.} = I_{PC\ bri..} + M_{PC\ bri.}$$

L: Life-cycle cost
I: Initial cost
M: Maintenance cost

We did not calculate the cost for disuse neither did we consider the discount rate to discount future costs to the base year. Initial costs were calculated for both the superstructure and substructure. Maintenance costs were calculated only for the superstructure. The authors tried to set realistic suppositions in situations where no data existed. In this study, the authors made some assumptions for unknown conditions and simplified the calculation. Hence the values of the costs in this study do not indicate the real values of the Okinawa Road Park Bridge itself.

4. RESULTS

4.1 Initial costs

4.1.1 PC footbridges

Five types of superstructure were roughly designed for the PC footbridges. A deck girder footbridge with hollow post-tension concrete beams was selected after considering multiple viewpoints, including economy, workability, structure, view, and maintenance. Table 2 shows the model cases of the PC footbridge. CASE-1 is the base case with two types of corrosive protected cases added. CASE-2 adopts epoxy resin coated reinforcing bar and PC tendon. CASE-3 also adopts coated bar and tendon, with the addition of a paint coating on the concrete surface. The calculated the initial cost of each superstructure is: 48,240,000JPY, 50,620,000JPY and 54,370,000JPY respectively. As regards the substructure, two piers (Pier 1 and Pier 2) were roughly designed for each of three alternatives. The best results are shown in Table 2. The total cost of the substructure was 10,130,000JPY.

4.1.2 FRP footbridges

The initial cost of FRP bridges is roughly divided into three categories: (1) materials, (2) assembly, and (3) mold for hand lay-up. Table 3 shows the initial cost of FRP bridges. The initial cost of the FRP superstructure was 73,600,000JPY. The base model case (CASE-4) of the FRP footbridge has some special points, for example, it is the first real FRP footbridge in Japan and it is located on the seashore, suggesting that it may be possible to reduce its initial cost. The authors considered a modified case (CASE-5) for FRP bridges so as to reduce its initial cost. These modifications were: (1) change of handrail to aluminum, (2) change of design in the joint part of main girders, and (3) sharing of mold by two bridges. The result of the modified initial cost became 62,350,000JPY.

Table 2: Model cases of PC bridges and initial costs

(Unit: 1000JPY)

	CASE-1	CASE-2	CASE-3
Corrosion protection for the superstructure	None	Coated reinforcing bars Coated PC tendon	Coated reinforcing bars Coated PC tendon Surface coating
Initial cost for the superstructure	48,240	50,620	54,370
Substructure system	Pier 1: 6 Steel pipe piles (φ600mm-9mm, L=17.5m) Pier 2: 4 Steel pipe piles (φ600mm-12mm, L=20.0m)		
Initial cost for the substructure	10,130		
Total Initial costs	58,370	60,750	64,500

Table 3: Model cases of FRP bridges and initial costs

(Unit: 1000JPY)

	CASE-4	CASE-5
Modified points for the superstructure	Standard FRP bridge based on the real bridge	(1) Aluminum handrail (2) Change of joint parts of the main girders (3) Sharing the mold by 2 bridges
Initial cost for the superstructure	73,600	62,350
Substructure system	Pier 1: 2 Steel pipe piles (φ500mm-9mm, L=15.0m) Pier 2: 4 Steel pipe piles (φ500mm-9mm, L=18.0m) Pier 3: 2 Steel pipe piles (φ500mm-9mm, L=12.0m)	
Initial cost for the substructure	6,910	
Total Initial costs	80,510	69,260

There are three piers (Pier 1, Pier 2, and Pier 3) for the substructure of the FRP footbridge. When comparing the two pile systems, driven steel pipe piles and PHC (Pretensioned Spun High Strength Concrete) piles with installation by inner excavation, the steel pipe piles substructure showed better results in this case.
Comparing the total costs including both the superstructure and substructure, the difference of the initial cost of the modified FRP footbridge (69,260,000JPY) was only 10% higher than the initial cost of the corrosion protected PC footbridge. This result suggests FRP bridges have significant competitive power even when considering the initial cost.

4.2 Maintenance costs

4.2.1 PC footbridge

Inspection and repair are the main maintenance considerations for bridges. Only the costs for repair were considered in this study. The costs for inspection were omitted because it seems there are not large differences in the inspection of PC and FRP bridges.
For the PC bridges, the authors estimated the penetration of chloride ion into the concrete after the construction, and the repair was set when the concentration of chloride ion at steel reinforcing bars reached 1.2 kg/m^3. Replacement of covering concrete and surface coating was selected as the repair method for the PC bridges. The life of the surface coating which protects against chloride ion penetration was set at 15 years and 30 years, and repair of the surface coating was calculated in these intervals. Table 4 shows the results of the repair costs.

4.2.2 FRP footbridge

Since the Okinawa Road Park Bridge is relatively new, there is not enough information on its repair and maintenance requirements. However, five years after its construction, stainless steel bolts were replaced because of corrosion due to the severely corrosive environment. This amounted to 1,000,000JPY. We therefore considered the same scale of repair may be required at the same interval within a severely corrosive environment and set the repair cost for an FRP footbridge at 1,000,000JPY at 5-year intervals. In the modified case of FRP footbridges, the repair cost was also modified by adopting highly durable bolts. The cost is 3,500,000JPY and the repair interval was set at 40 to 50 years.

Repainting is the major repair concern for FRP footbridges. There will be no corrosion for FRP structures caused by weak points of painting such as edges or bolt parts like a painted steel structure because FRP does not corrode. Hence, we set the repainting interval based on the decrease of thickness caused by the deterioration of the painting material. The repainting interval was set at about 120 years based on the thickness (75 μm) and the material (fluorine resin paint) of the paint. The repainting cost was calculated and the result was 5,600,000JPY including the scaffolding for repainting.

4.3 LCC

Table 4 shows the results of initial cost, maintenance cost and LCC for both PC and FRP footbridges. At 50 years, LCC of the FRP footbridge was 90,510,000JPY; this is lower than the 50-year LCC of the PC footbridge without corrosion protection. The lowest 50-year LCC was that of the PC footbridge with epoxy resin coated reinforcing bar and PC tendon (CASE-2). However, the modified FRP footbridge (CASE-5) showed the lowest 100-year LCC among our five cases. These results suggest that FRP footbridges are more efficient when longer life is required in severely corrosive environments.

Table 4: LCC results of both PC and FRP footbridges

(Unit: 1000JPY)

	CASE-1	CASE-2	CASE-3		CASE-4	CASE-5
			Repair interval: 15 years	Repair interval: 30 years		
Initial cost for superstructures	48,240	50,620	54,370		73,600	62,350
Initial cost for substructures	10,130	10,130	10,130		6,910	6,910
Total the initial costs	58,370	60,750	64,500		80,510	69,260
Maintenance cost for 30 years	24,500	0	18,000	9,000	6,000	3,500
Maintenance cost for 50 years	42,500	0	27,000	9,000	10,000	3,500
Maintenance cost for 100 years	69,500	24,500	54,000	27,000	20,000	7,000
50 years LCC	100,870	60,750	91,500	73,500	90,510	72,760
100 years LCC	127,870	85,250	118,500	91,500	100,510	76,260

5. CONCLUSION

In this paper, the authors considered and calculated the LCC of FRP and PC footbridges, faithfully considering actual conditions based on a real FRP footbridge constructed in Japan. The result suggests that FRP bridges has a competitive edge over other types of construction in spite of its initial cost and that FRP footbridges are more efficient when longer life is required in severely corrosive environments.

6. ACKNOWLEDGEMENTS

This study was carried out as a part of the activity of “The committee for applications of advanced structural materials” of the Japan Society of Civil Engineering (JSCE) from 2004 to 2006. The authors also thank the government of Okinawa prefecture for their cooperation in providing the information on the plans and designs of the FRP and PC footbridges.

7. REFERENCES

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