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REPORT ON JSCE COMMITTEE ACTIVITIES ON LCA AND LCC OF FRP INFRASTRUCTURE

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ABSTRACT

The paper introduces a case study on life cycle cost (LCC) and life cycle assessment (LCA) of environmental aspect of a real FRP bridge. The work was done by a working group in the JSCE Committee during 2004-2005. A FRP footbridge under severe environment with wind-blown chlorides was assessed. Its LCC and LCA were calculated based on the actual data and compared with conventional concrete structure. The results show that FRP structure has an enough competitive LCC because of its high durability. In addition, FRP structure decreases total amount of carbon dioxide emission than conventional concrete structure due to its light weight.

Keywords: LCC, LCA, environmental aspect, CO_2 emission, FRP footbridge

1 INTRODUCTION

A technical committee on application of innovative structural material in the field of civil engineering was organized in Japan Society of Civil Engineers (JSCE) from July 2004 until March 2005. The mission of the committee was to survey the possibilities of effective use of FRP as structural material for civil structures from various viewpoints. One of the working groups in the committee focused on life cycle cost (LCC) and life cycle assessment (LCA) of environmental aspect of FRP. Since high durability is one of the advantages of FRP when compared with conventional structural materials such as steel, FRP structure may be competitive in LCC including maintenance cost. On the other hands, environmental issue has become of great importance in construction industry. Environmental aspect of FRP structure is also a matter of public interests.

The working group carried out a case study of assessment of LCC and LCA of environmental aspect of a real FRP structure based on data of an actual structure. A FRP footbridge under severe environment with wind-blown chlorides was assessed. Its LCC and total emission of carbon dioxide during the life cycle were calculated and compared with those of conventional concrete structure [1][2].

2 EVALUATED STRUCTURES

A FRP footbridge and a PC footbridge crossing a 4-lane road were chosen as the case models (Table 1). Input data for FRP footbridge were adopted from those of actual FRP footbridge which was constructed in Okinawa, Japan in 2000: the first FRP bridge in Japan, Okinawa Road Park Bridge shown in Figure 1. The bridge is locating close to seashore and, therefore, severely affected by sea salt, which causes steel corrosion. The superstructure type of the FRP bridge is two span continuous girder bridge, while the superstructure type of PC footbridge is one span post-tension hollow slab girder bridge. Wall type piers and steel pipe pile foundation were used in the substructures of both bridges.

The main girders of the FRP bridge are made of hand-lay up FRP and pultruded FRP is used for the stiffeners, decks and floor systems. Both FRPs were made of glass fiber and vinylester resin. All members of the FRP bridge were made in factories in Tokyo area, assembled in a factory in Tokyo bay and then transported to Okinawa by ship.

(a) Overview **(b)** Deck

Figure1: FRP footbridge (Okinawa Road Park Bridge)

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 METHOD OF ASSESSMENT

3.1 LCC

Direct construction costs of the initial costs and the maintenance costs of both FRP and PC bridges were evaluated based on their design documents. Their LCC was calculated by following equations.

$$L_{FRP\ bri.} = I_{FRP\ bri.} + M_{FRP\ bri.} \quad (1)$$

$$L_{PC\ bri.} = I_{PC\ bri..} + M_{PC\ bri.} \quad (2)$$

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

Cost for demolition of the structures was not taken into account here. Neither was considered the discount rate to discount future costs to the base year. Initial costs of both superstructures and substructures were accounted. Maintenance costs were calculated only for superstructures. LCC of FRP bridge was according to actual data of Okinawa Road Park Bridge as much as possible. However, some unknown items were evaluated based on assumption. Therefore, the obtained LCC is not exactly actual LCC of this bridge. Input data for PC bridge were determined based on experiences of similar structures.

3.2 LCA of environmental impact

The evaluation scheme of an environmental impact of FRP footbridge and PC footbridge is shown in Figure 2. Carbon dioxide emission at the material stage and the construction stage of structures were evaluated here. Carbon dioxide emission at the service stage and the demolition stage of structures were not evaluated.

The unit of carbon dioxide emissions used in this paper is shown in Table 2. The unit of carbon dioxide emissions of FRP was referred to the reference [3]. The unit of carbon dioxide emissions of concrete, prestressing steel wire, steel pipe pile, and construction of concrete was referred to the committee report [4]. The unit of carbon dioxide emissions of transportation was referred to the values [5] showed on the website of Ministry of Land Infrastructure and Transport in Japan.

4 RESULTS AND DISCUSSION

4.1 Initial costs

In the case study of LCC, five types of superstructures were assessed. Table 3 shows the model cases of PC bridges. CASE-1 is a standard case. In CASE-2 and 3, corrosion protection for reinforcing steel and PC tendon was adopted.

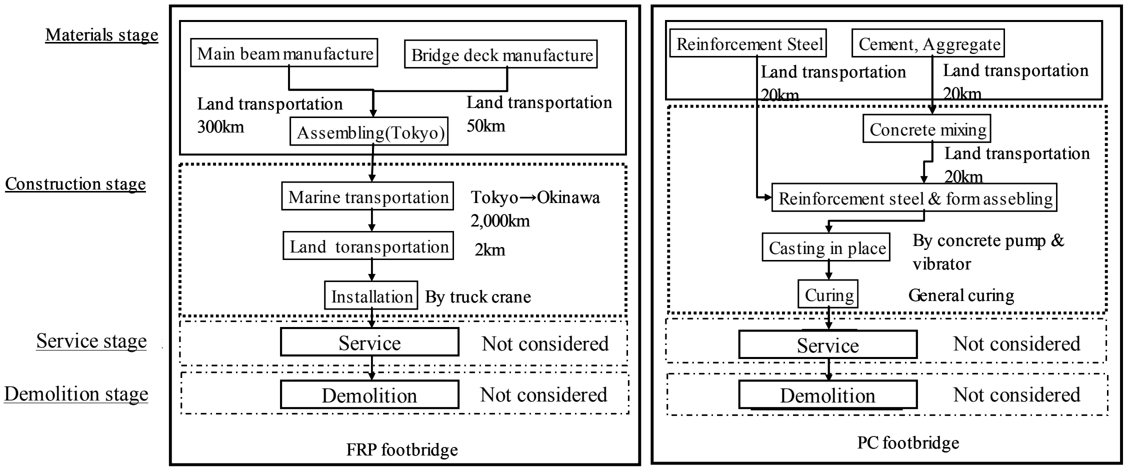

Figure 2: Evaluation scheme of life cycle CO_2 emission of bridges

Table 2: Unit of CO_2 emissions

Heading		Unit	Unit of carbon dioxide emissions
Materials	FRP(Hand-lay up)	kg	4.97 $kgCO_2/kg$
	FRP(Pultruded)	kg	3.09 $kgCO_2/kg$
	Concrete(Fc27N/mm^2)	kg	0.0918 $kgCO_2/kg$
		m^3	211.1 $kgCO_2/m^3$
	Reinfoecement steel	kg	0.755 $kgCO_2/kg$
	Prestressing steel wire	kg	1.31 $kgCO_2/kg$
	Steel pipe pile	kg	1.25 $kgCO_2/kg$
Transportation	Marine transportation	t*km	0.039 $kgCO_2/t*km$
	Land transportation	t*km	0.154 $kgCO_2/t*km$
Construction	Concrete	m^3	39.0$kgCO_2/m^3$

In CASE-2, epoxy resin coated reinforcing bar and PC tendon were used. In CASE-3, coating paint on concrete surface was applied in addition to epoxy coated reinforcement and PC tendon.The calculated initial costs of these superstructures are 48,240,000 JPY, 50,620,000 JPY and 54,370,000 JPY respectively. As for substructure for PC bridge, two abutments (A1 and A2) were designed. The total cost of the substructure was 10,130,000 JPY.

The initial costs of FRP bridge are roughly divided into three items; (1) materials, (2) assembly and (3) mold for hand-lay up. Table 4 shows the initial cost of FRP bridges. The calculated initial cost of FRP superstructure was 73,600,000 JPY. CASE-4 is a standard case of FRP footbridge, in which all structural members are made of FRP. In another FRP footbridge case (CASE-5), some modifications to reduce initial cost were made in following points: (1) change of handrail to Aluminum, (2) change of design in joint part of main girders and (3) sharing of mold by two bridges. As results, the calculated initial cost became 62,350,000 JPY.

The substructure of the FRP bridge consists of two abutments (A1 and A2) and one pier (P1). After comparing two pile systems, steel pipe piles substructure was employed.

Comparing the total initial costs of superstructures and substructures, the initial cost of the modified FRP bridge (CASE-5) is only 10% higher than that of corrosion protected PC bridge (CASE-3). This result suggests that FRP bridge is enough competitive even in its initial costs.

4.2 Maintenance costs

Inspection and repair are the main maintenance items 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, penetration process of chloride ion into the concrete during service was calculated by a diffusion model. It was assumed that repair is set when the concentration of chloride ion at steel reinforcing bars reaches 1.2 kg/m^3. Replacement of covering concrete and surface coating was selected as the repairing method for the PC bridges. Effective life of the surface coating materials to prevent chloride ion penetration was assumed as 15 years and 30 years, and repair of the surface coating was calculated in these intervals. Table 4 shows the results of the repairing costs.

Table 3: Model cases of PC bridges and the 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	A1: 6 Steel pipe piles (φ600mm-9mm, L=17.5m) A2: 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 4: Model cases of FRP bridges and the 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	A1: 2 Steel pipe piles (φ500mm-9mm, L=15.0m) P1: 4 Steel pipe piles (φ500mm-9mm, L=18.0m) A2: 2 Steel pipe piles (φ500mm-9mm, L=12.0m)	
Initial cost for the substructure	6,910	
Total Initial costs	80,510	69,260

Table 5: Total LCC of 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

For FRP bridges, there is no enough information about the intervals in repair. In case of Okinawa Road Park Bridge, stainless bolts were replaced five years after the construction because of the severe corrosive environment. It costs 1,000,000 JPY. Same repair is assumed here at the same interval; repairing cost for FRP footbridge was set 1,000,000 JPY every 5 years. In the modified case of FRP footbridge, repairing cost can be also modified by adopting highly durable bolts. It is assumed that the repairing cost is 3,500,000 JPY and repairing interval is 40 to 50 years.

Repainting is the more major repairing method for the FRP footbridge. Different from steel structures, there will be no fear of corrosion in FRP structures because FRP itself will not corrode. Hence, the repainting interval of FRP bridge is determined based on the decrease of thickness of the painting material caused by the environmental attack. The repainting interval was set 120 years considering the thickness (75μm) and the kind of material of the paint (fluorine resin paint). The calculated repainting cost was 5,600,000 JPY including the scaffolding for repainting.

4.3 Total LCC

Table 5 shows the calculation results of initial cost, maintenance cost and total LCC of five model cases of PC and FRP footbridges. 50 years LCC of FRP footbridge was 90,510,000 JPY, and this is lower than the 50 years LCC of PC footbridge without corrosion protection. The lowest 50 years LCC was that of PC footbridge with epoxy resin coated reinforcing bar and PC tendon (CASE-2). However, modified FRP footbridge (CASE-5) showed the lowest 100 years LCC in the all cases. These results suggest that FRP footbridge become more effective when longer life is required under severe corrosive environment.

4.4 CO_2 emission at material and construction stage

The amount of carbon dioxide emissions at the materials stage and at the construction stage is shown in Figure 3 and 4 respectively.

At the materials stage, for superstructure, the amount of carbon dioxide emissions of FRP footbridge is about 8 percent greater than that of PC footbridge. This is because the unit of carbon dioxide emissions of FRP is much larger than that of concrete, though the weight of superstructure of FRP footbridge is lighter than that of PC footbridge. For substructure, the amount of carbon dioxide emissions of FRP footbridge is about 50 percent smaller than that of PC footbridge. This is because the substructure of FRP footbridge, particularly its steel pipe pile, could be reduced. At the materials stage, the amount of carbon dioxide emissions of FRP footbridge can be about 18 percent reduced than that of PC footbridge.

At the construction stage, for superstructure, the amount of carbon dioxide emissions of FRP footbridge is about 80 percent reduced than that of PC footbridge. This is because the necessary work in construction of FRP bridge was almost its transportation by ship from Tokyo to Okinawa and the amount of carbon dioxide emissions of the transportation was very small. For substructure, the amount of carbon dioxide emissions of FRP footbridge is about 45 percent reduced than that of PC footbridge. This is because the amount of concrete of the substructure of FRP footbridge was much smaller than that of PC footbridge due to the light weight of FRP footbridge. At the construction stage, the amount of carbon dioxide emissions of FRP footbridge can be about 70 percent reduced than that of PC footbridge.

4.5 Total LC CO_2 emission

The total amount of carbon dioxide emissions on the materials stage and the construction stage is shown in Figure 5. The amount of carbon dioxide emissions of FRP footbridge can be about 26 percent reduced than that of PC footbridge. Though the unit of carbon dioxide emissions of FRP are much larger than that of concrete, the total amount of carbon dioxide emissions at the materials stage and the construction stage of FRP footbridge was smaller than that of PC bridge. This is because the substructure of FRP footbridge can be reduced due to the light weight of FRP footbridge.

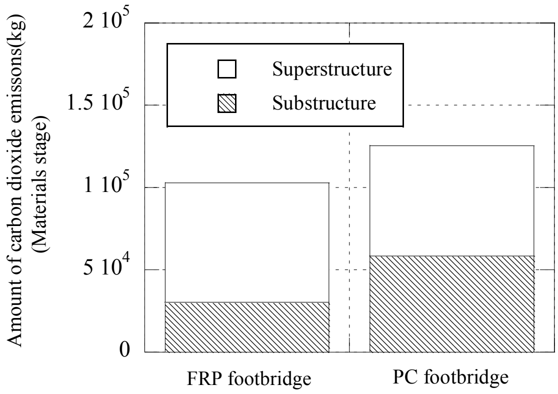

Figure 3: Carbon dioxide emissions at the materials stage of FRP and PC footbridges

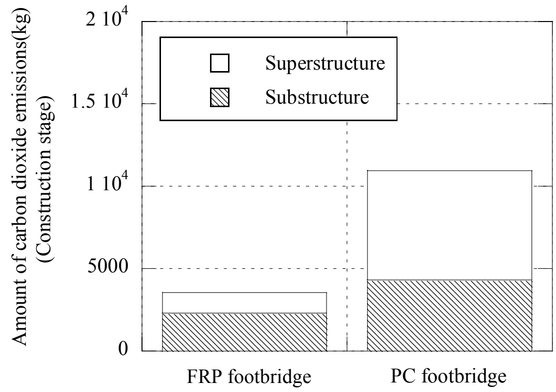

Figure 4: Carbon dioxide emissions at the construction stage of FRP and PC footbridges

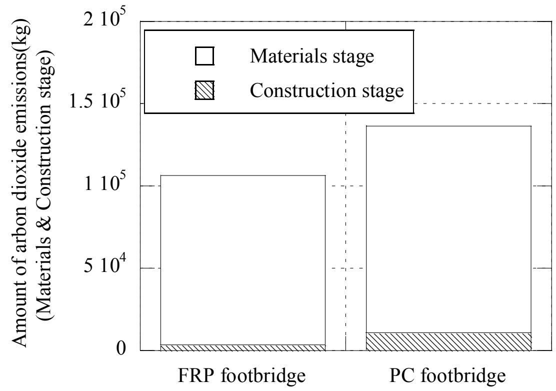

Figure 5: Total carbon dioxide emissions at the materials and construction stage of FRP and PC footbridges

5 CONCLUSIONS

Case study of LCC and LCA of CO_2 emission of FRP footbridge which was done by the technical committee in JSCE was introduced. Calculation was based on the data of an actual FRP bridge in Japan as much as possible. Calculated LCC and LC CO_2 emission of FRP bridge was compared with those of conventional PC bridge.

1) The result of LCC suggests that FRP bridge can be enough competitive with conventional PC bridge even in its initial costs and that FPR footbridge become more effective when longer life is required under severe corrosive environment.
2) The amount of carbon dioxide emissions of FRP footbridge at the materials stage is slightly reduced than that of PC footbridge, while, at the construction stage, the amount of carbon dioxide emissions of FRP footbridge is greatly reduced than that of PC footbridge.
3) The total amount of carbon dioxide emissions of FRP footbridge at the material and construction stage can be reduced than that of PC footbridge. This is because the substructure of FRP footbridge can be reduced since the weight of superstructure of FRP footbridge is much lighter than that of PC footbridge.

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