Optimizing LCC for Pier Bridges using FRP Members

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ABSTRACT

This paper deals with the feasibility of FRP pier footbridges. Steel pier bridges have generally used in Japan, but have some problems for corrosion; the total cost including maintenance is much expensive in the long term. This study verifies that the LCC for FRP pier bridges is expected to be smaller than that for conventional steel pier bridges. The present adopted FRP pier bridges are of the girder or truss type due to referring the existing FRP footbridges in Japan. Construction cost and maintenance cost have been estimated through the investigation of the Japanese domestic achievements and guidelines. It has also been shown that FRP pier bridges have large merit considering LCC and are recommended to be constructed in the future.
Keywords: FRP, Pier Bridge, Cost, LCC

1 INTRODUCTION

Conventional reinforced concrete or steel has been used as the structural material of pier bridges in Japan, however, it now has serious problems on durability.

Fiber reinforced polymer (FRP) is anticipated for the use as innovative structural members that replace these conventional materials, and in the last decade in USA, many interesting applications to the structural, girder, slab and truss members have been presented. Also in Japan, a several FRP foot bridges [1], [2] have already constructed based upon various energetic research developments including those by the authors.

To infiltrate FRP footbridges into Japan, *the Task Committee on FRP Hybrid Bridges* in Japan Society of Civil Engineers has engaged to make and almost completed a FRP foot bridge design guideline. Meanwhile, it would be also important to find the new places to apply FRP structural member for spread of it, and from the viewpoint, the task committee has also targeted the investigation of this application development problem.

It would be well known that a pier bridge is usually located on hard salt environment and connects between wharf and pontoon. The pier bridge varies from the large pier bridge which is able to pass a car as shown in Fig.1, to small pier bridge which passes people mainly as shown in Fig.2. This study focuses the grade of footbridge considering the possibility of the data for recently constructed FRP footbridges in Japan and evaluates the initial construction cost and life cycle cost (LCC) through the analyses of maintenances and repaints.

Figure 1: A pier bridge

Figure 2: A pier footbridge

2 SITUATION OF STEEL PIER BRIDGES

Now almost pier bridges are of steel, however, a lot of administrators of pier bridges are ordinary concerned about durability and maintenance for steel members due to the use under the hard environment.

Main deterioration factors are corrosion due to splash salt as shown in Fig.3, and fatigue due to waves in the storm and enforcement deflection by landing ship as shown in Fig.4. Actually, it has been confirmed that some pier bridges are damaged by compound corrosion of salt and fatigue.

It is much difficult for an administrator to inspect and sustain his pier bridges as offshore structures. He tends to overlook and leave progress of corrosion because the speed of corrosion under the deck is quicker than one over the deck. Also, the maintenance requires hard working because as shown in Fig.5 the workers need a boat for the inspection and painting.

The other point of view is its ability of rehabilitation after damage due to a heavy storm; pier bridges drop from pontoon and sink into the sea, so they would be required to be taken to salvage and to be recovered after storming as soon as possible.

In order to solve these problems, the FRP pier bridges having various advantages (hard corrosion, hard fatigue, light weight and short construction period) are now anticipated strongly by many administrators.

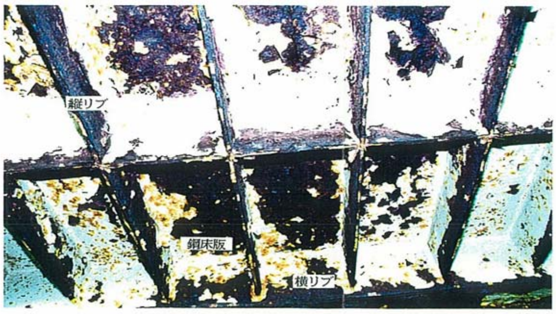

Figure 3: Corrosion under the pier bridge by salt

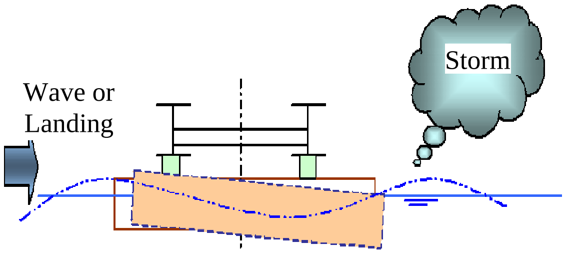

Figure 4: Image of fatigue by wave

Figure 5: Inspection of a pier bridge

3 COST ANALYSES FOR PIER BRIDGES

3.1 Initial Construction Cost

After preliminary roughly evaluating the cost performances for a few typical types of FRP bridges, the cost of the FRP girder and truss types for pier bridges were concentrated to be analyzed using the actual construction data of recently constructed FRP footbridges in Japan; we have four FRP footbridges whose detailed data were already presented in Japan. All are of girder or truss types, so these two types are adopted in this study. According to domestic achievement, it seems that length of span about girder and truss limited 20 meters due to serious specification of deflection in Japanese conventional design guidelines for steel bridges.

The obtained analytical results are represented in Appendix 1 in which each completion time, weight, structure cost, maintenance cost are listed, consequently they can be easy compared together.

Next, through the preliminary design for steel as well as FRP pier bridges of above bridge types, these initial construction costs are estimated. In this study, the effective width of pier bridges is fixed to be of 2m, and the length of span varies to be 5m, 10m, 15m and 20m. The design load is 3.5 kN/m^2, and the limit of deflection for main girders are adopted as L/600 (L = length of span) and L/400, for steel pier bridges and for FRP pier bridges, respectively. The allowable deflection limitation L/400 for FRP pier bridges is adopted in this paper on the basis of that in *Japanese Standard for Vertical Cross Footbridges* 1979.

For the estimation of the construction costs of a steel pier bridge, its weight in ton unit was computed as referring the design data of selected existing steel pier bridges in Japanese *Design Data Book*, then its computed weight was multiplied with the constant, 1 million JPY/ton or 1.2 million JPY/ton, for the girder type or for the truss type, respectively.

On the other hand, for the estimation of the construction costs of a FRP pier bridge, its floor space in square meter was computed and was multiplied with the constant, 450 - 470 thousand JPY/m^2 or 320 - 350 thousand JPY/m^2, for the girder type or for the truss type, respectively.

Examples of the present results for the estimation of initial construction costs for 2m width bridges are shown in Fig.6 and the cost performances varied with the length of span are represented. It is made clear that the FRP girder pier bridge is the most expensive, but the cost of FRP truss pier bridges is suggested to be not very high rather than those of steel pier bridges.

3.2 Comparison of Costs Considering LCC

Generally, steel pier bridges require the periodic repaint due to preventing from corrosion. Thus, the interval of repaint for steel pier bridges is 10 years from actual achievement. The unit cost of paint for steel pier bridge is 9,000 JPY/m^2 as polyurethane paint with epoxy on sand blasted base. The interval of repaint for FRP pier bridges is assumed to be 15 years because FRP did not corrode but needs to keep surface for preserving aesthetic view against ultraviolet ray degradation. The unit cost of paint for FRP pier bridge with effective width 2m was estimated to be 0.6 million JPY/m from the domestic achievement, e.g. acrylic urethane paint or fluorine paint.

The result of comparison of LCC is shown in Figs.7, 8, 9 and 10. According to those figures, it appears that the FRP truss pier bridges are superior to the steel pier bridges at 20 years after completion, and the cost of FRP girder pier bridges is also shown to be smaller at 30 years or 40 years than that of the steel truss pier bridges.

4 CONCLUSIONS

Studying on the feasibility of FRP pier footbridges, it has been interpreted that the LCC for FRP pier bridges is expected to be smaller than that for conventional steel pier bridges. It would be surmised that optimizing span length of the FRP pier footbridges is approximately from 10m to 20m under the cost data of recently constructed four FRP footbridges in Japan and the truss type is the better choice rather than the girder type for FRP pier footbridges.

ACKNOWLEDGMENTS

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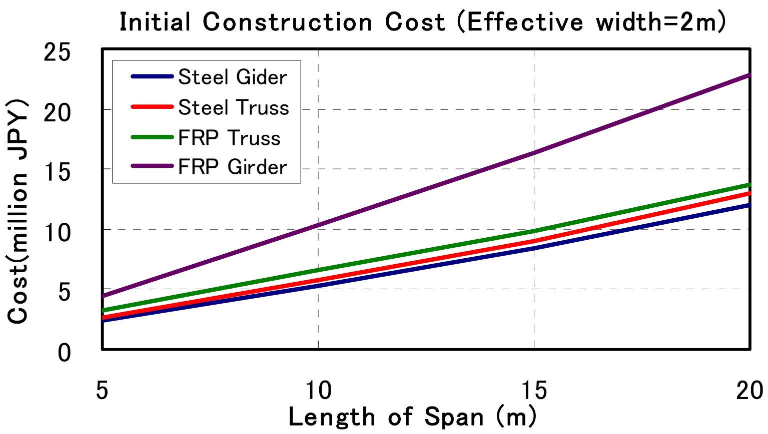


Figure 6: Initial Construction Cost (Effective width=2m)

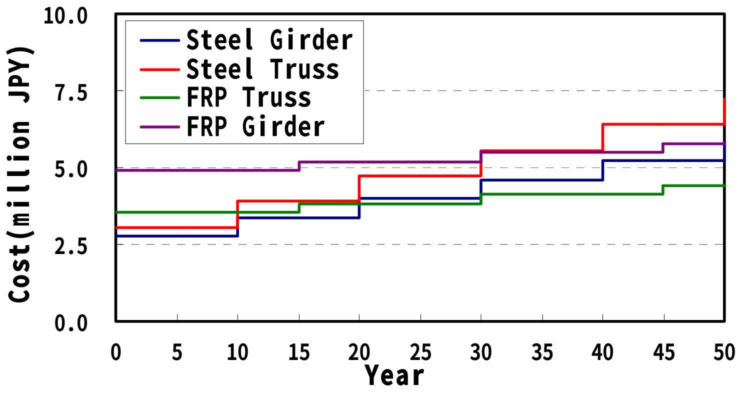


Figure 7: Life Cycle Cost (Length of Span=5m)

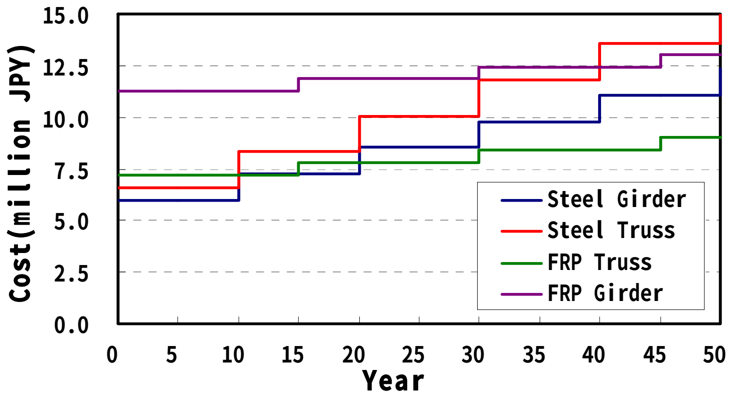


Figure 8: Life Cycle Cost (Length of Span=10m)

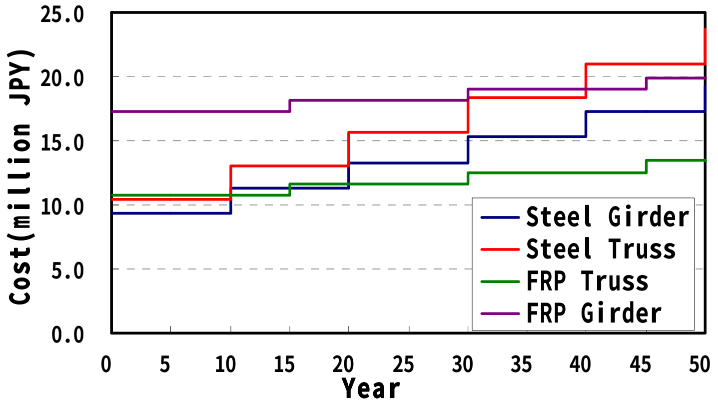


Figure 9: Life Cycle Cost (Length of Span=15m)

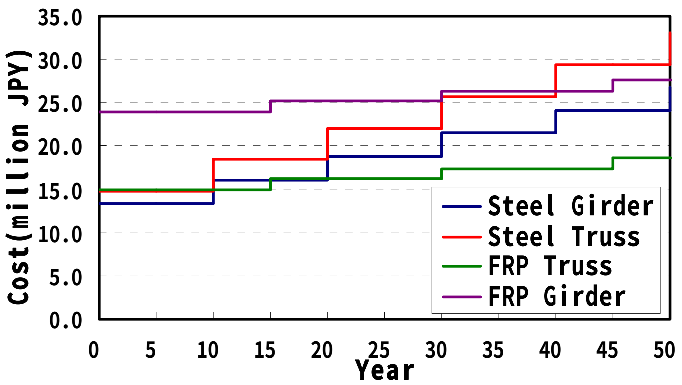
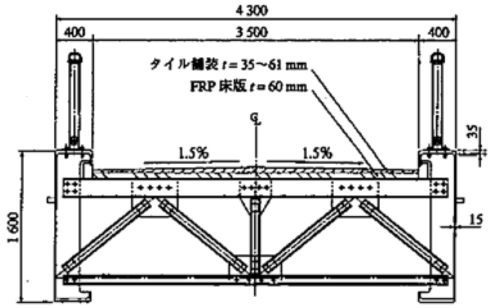
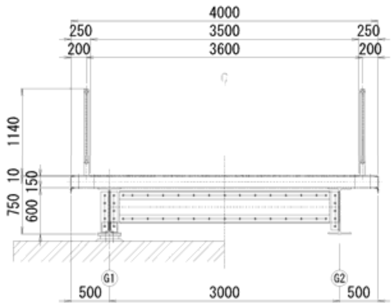
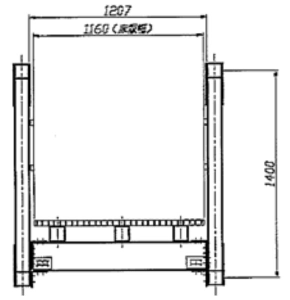
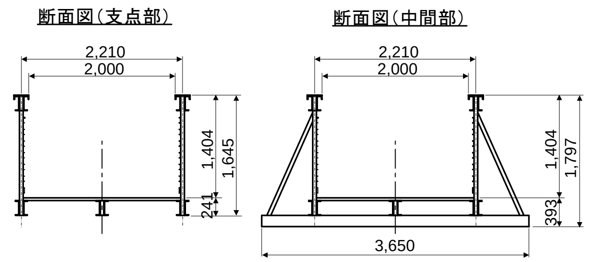


Figure 10: Life Cycle Cost (Length of Span=20m)

Appendix 1 : FRP Footbridge in Japan

		FRP Footbridge			
		Half through Girder FRP Footbridge (Okinawa) (Span: 19.68m+17.22m, Effective width: 3.50m)	**Girder FRP Cycle Bridge (Hakui, Ishikawa) (Span: 10.6m, Effective width: 3.5m)**	**Domestic Truss FRP Footbridge (Hida-Takayama, Gifu) (Span:7.50m, Effective width: 1.16m)**	**Imported Truss FRP Footbridge (Maizuru, Kyoto) (Span:17.76 m, Effective width: 2.0 m)**
Draw-ing	**Side View**				
	Cross Section				
Completion Time		March.2000	March.2008	April.2009	January.2009
Weight		W= 31 tf (w= 0.191 tf/m^2)	W= 3.7 tf (w= 0.100 tf/m^2)	W=1.2 tf (w=0.138 tf/m^2)	W=3.06 tf (w= 84 kgf/m^2)
Construction Term		1 day（erection work）	2 day	―	3 day（ground work）、1 day（erection work）
Struct-ure	**Members**	Main Girder : GFRP（[-1600*390*15*35] Cross frame : GFRP（[-200*70*7*10） Deck slab : GFRP（□-500*60*4） Handrail : GFRP, Shoe : Rubber shoe	Main Girder : GFRP (H-600*300*12*18) Cross beam : GFRP (H-406*211*5*6.3) Deck slab : GFRP (Box500*500*125*4) Handrail : GFRP, Shoe : Rubber shoe, Steel roller	Top chord, Down chord, cable stay : GFRP (Box103*103*9.3) Cross beam : GFRP (H200*100*14*10) Deck slab : GFRP grating (40*40 t)	Top chord, down chord, cable stay : GFRP (C8”*2-3/16”*3/8”) Cross beam : GFRP (C6”*1-11/16”*3/8”) Cable stay : GFRP Bar (2”*2”), Box(2”*2”*1/4”) Handrail : GFRP, Shoe : Rubber shoe
	Structural Character	Main girder made by Hand ray up method because the size of girder can not make by pultrusion method.	Main girder made by pultrusion method	Using GFRP grating considering mounting of snow	- 3 main GFRP members made by pultrusion method. - Joints are of a bearing joint using bolts - Designing the direction of cable stay and combination of chord to satisfy the limit of deflection
Maintenance		Exchange the stainless bolts and nuts	Exchange the stainless bolts and nuts	- Fluorine paint considering weather proofing - Rivets and gusset plate use stainless	- Suggesting a repaint against deterioration of ultraviolet - Bolt is covered by top coating
Cost	**Initial Construction Cost**	62,350,000 JPY (483,000 JPY/m^2) *Including carriage cost	14,500,000 JPY (391,000 JPY/m^2)	7,500,000 JPY (862,000 JPY/m^2)	12,400,000 JPY (344,000 JPY/m^2) *Not including foundation, shoe, temporary stage
	Life Cycle Cost	3,500,000 JPY/50years as repaint and exchange of bolts LCC = 62.35+3.5=67.850million JPY	No plan for repaint etc	Total maintenance cost considering of repaint among 30 years - unit cost of repaint : 300,000 JPY - number of repaint : 1（1 time/15years） LCC ＝7.5＋0.3＝7.8million JPY	Service life assumed 100 years in design. It is considering that 9 times as periodic inspection and 1 time as exchange joint filler. LCC ＝ 12.4 + 0.57 = 12.97 million JPY