Lifecycle Analysis of Bridges Considering Longevity of Bridge and Severe Earthquakes

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KEYWORDS: *lifecycle analysis, lifecycle cost (LCC), lifecycle* CO_2 *(*$LCCO_2$*) emission, earthquake*

INTRIODUCTION

Newly developed bridges, which are less costly than conventional bridges, come into wide use recently. in the Japanese bridge industry. The bridges named rationalized bridges are made to reduce the total construction costs of about 15%. The reduction of the environmental impact in the bridge lifecycles is also expected. Itoh (2001) presented that the LCC and $LCCO_2$ of the minimized girder bridge$^{1)-3)}$, one of the rationalized bridges, was less than those of the conventional plate girder bridge. However, the other types of the rationalized bridges ware not known. The effect of environmental condition of the bridge site on the LCC and LCCO2 is not clear.

It is also necessary to consider the effect in LCA when natural events such as earthquake causes damages for transportation infrastructures during their lifecycles. In this research, focusing on earthquakes that cause serious damages, lifecycle evaluations were performed considering probabilities of losses caused by earthquakes.

BASIC ASSUMPTION FOR THELIFECYCLEASSESSMENTOFBRIDGES

Longevity of Bridge

Since service life of bridges had been set about 60 years in Japan, design, construction, and maintenance of the bridges had been perfomed based on 60 years. In 2002, the Specifications for Japan Highway Bridge (2002) recommended that the service life of constructions is 100 years. For this reason, the service of bridge is set 100 years in this study.

Bridge Data for the Lifecycle Assessment (LCA)

In LCA, three types of the bridges, I-girder bridge, box-girder bridge and truss bridge constructed in the mountain areas, are considered. It is also assumed that the bridges have the same width of 10.5m and the same span allotment (Steel 3-span continuous non-composite truss bridge). Each structural drawing is shown in Figure 1. It shows that new types of bridges are simpler than conventional types by performing omission of the lateral or reduction of the girder.

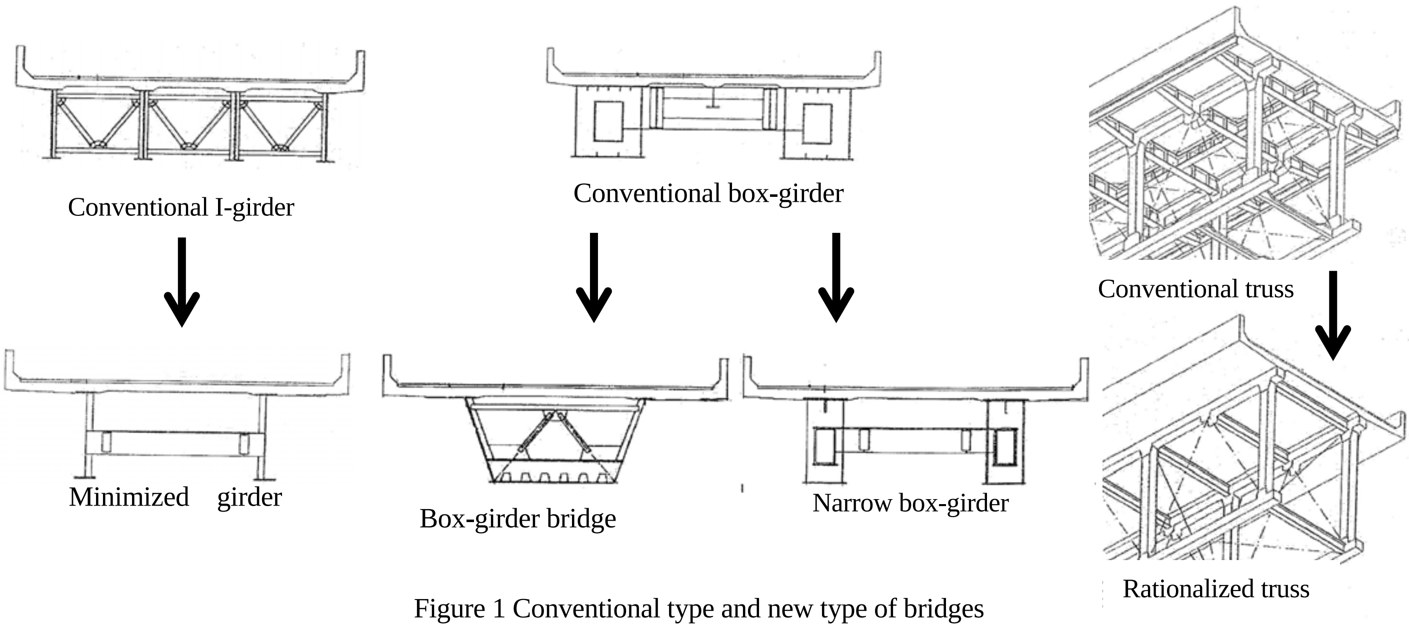
Basic assumptions for maintenance stage

Table 1 shows the maintenance cycles of each component of the bridge. In the maintenance stage, five components of the bridge; the deck, painting, bearing, expansion joint and pavement, are considered for the lifecycle evaluation of the bridge. The service life of these components are defined as that, each component are replaced as soon as facing their service lives and it is assumed that exchange of them is continued with a fixed life period until the end of the service life of the bridge.

Estimations of costs and environmental impacts from maintenance activities of those bridge components are difficult for the time being and the values used in this study are abstracted from the Ref. 5) and 6) and interview with the practical bridge engineers.

Table 1 Maintenance cycles of each components of the bridge

Components	Conventional bridge		New type of bridge	
	Sub-components	Life	Sub-components	Life
Deck replacement		50		100
Deck rehabilitation		25		50
Painting	A painting systems	15	I painting systems	40
Bearing	Steel bearing	30	Rubber bearing	100
Expansion joint	Finger joint	30	Finger joint	30
Pavement	Highly efficient pavement	20	Highly efficient pavement	20


Conventional I-girder

Conventional box-girder

Conventional truss

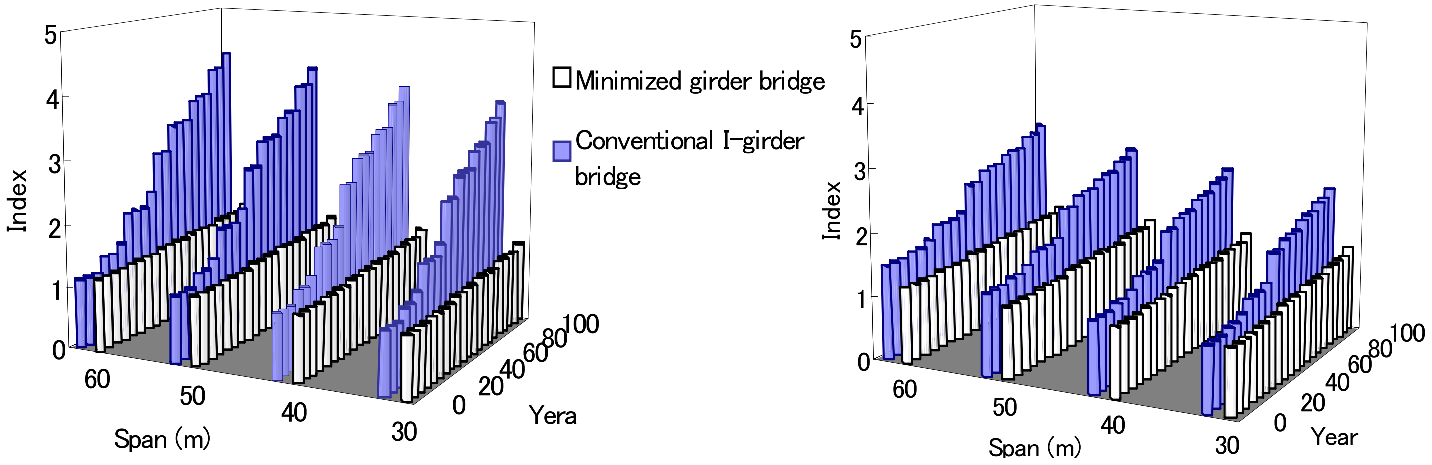
Minimized girder

Box-girder bridge

Narrow box-girder

Rationalized truss

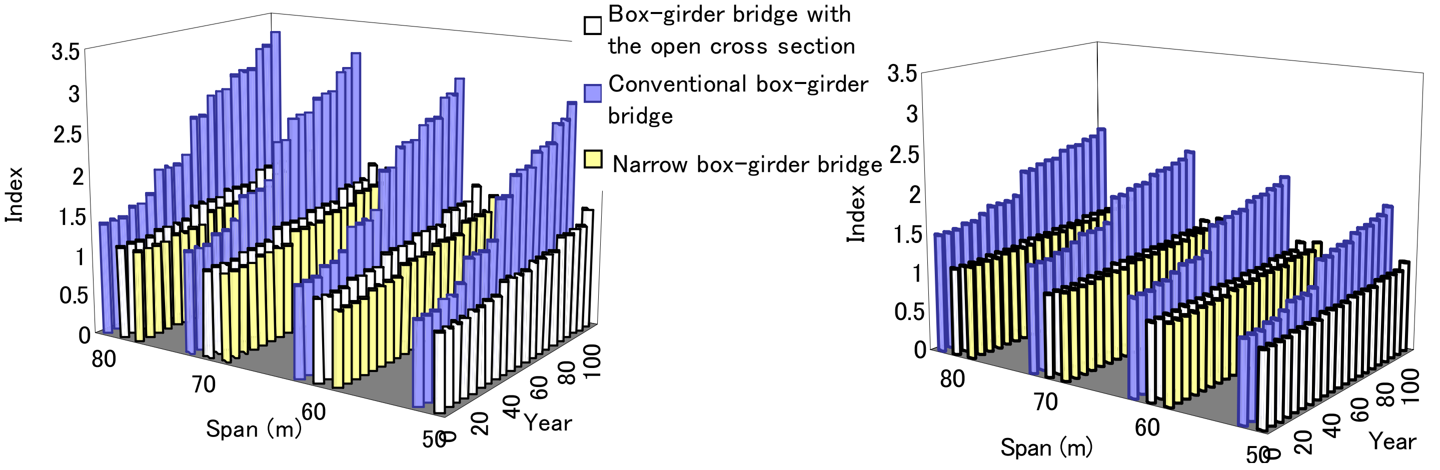
Figure 1 Conventional type and new type of bridges



a) LCC

b) $LCCO_2$

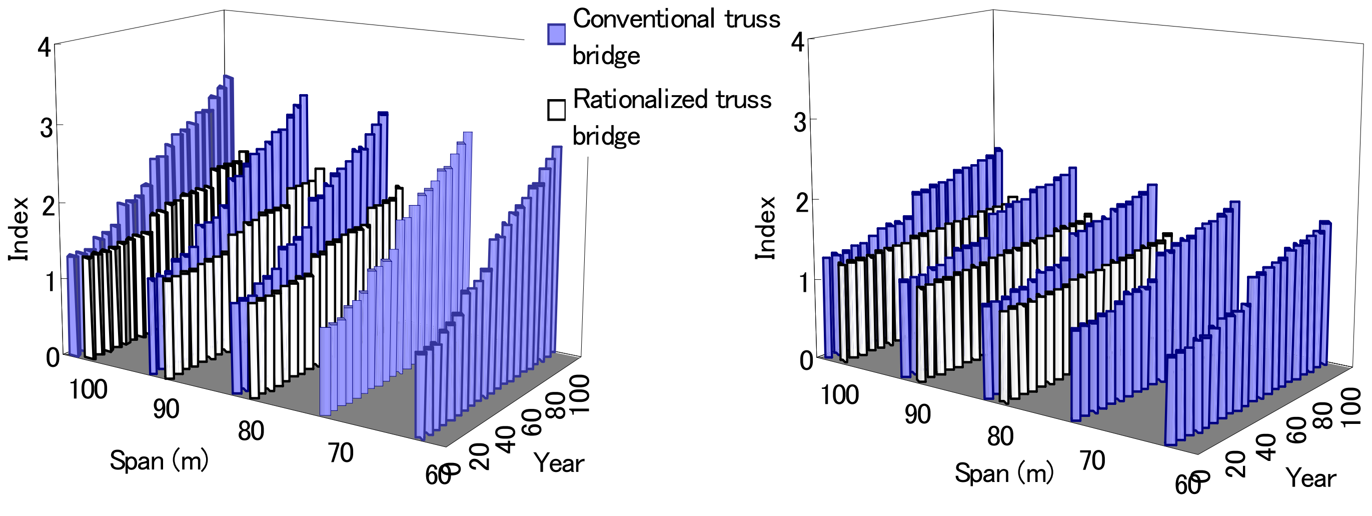
Figure 2 LCC and $LCCO_2$ of the I-girder bridges



a) LCC

b) $LCCO_2$

Figure 3 LCC and $LCCO_2$ of the box-girder bridges



a) LCC

b) $LCCO_2$

Figure 4 LCC and $LCCO_2$ of the truss bridges

LCA APPLICATIONFORCONVENTIONALBRIDGESANDNEWTYPEOFBRIDGES

Calculated Results of Conventional Bridges and New Types of Bridges in each Structural Type

The calculated LCC and $LCCO_2$ are shown in Figures 2, 3 and 4 respectively, with the results, divided by area of deck and written in dimensionless form. The vertical axis of these figures represents the relative values by taking the CO_2 emission and cost of conventional bridge at the construction stage as one. Reference span length of the conventional I-girder bridge is 30m, the box-girder bridge is 50m and the truss bridge is 60m. It is confirmed from these figures that both LCC and $LCCO_2$ of the newly developed bridges are less than the conventional ones.

CONCLUSIONS

In this study, both the conventional and the newly developed types of bridges in Japan were applied to the lifecycle assessment. Three types of bridge, I-girder, box-girder and truss bridges, were taken into consideration. The following conclusions are obtained:

1) The cost (LCC) and environmental impact ($LCCO_2$) of the new types of bridge are less than those of the conventional bridge. The LCC and $LCCO_2$ of the newly developed truss bridge during the 100 years after construction were reduced by 35% and 30% respectively, as compared with those of the conventional truss bridge. The reduction of whole LCC and $LCCO_2$ of the bridge is resulted from the maintenance stage of the bridge.
2) The $LCCO_2$ of the conventional bridge depended on the span length, but no significant effect of the span length on LCC and $LCCO_2$ of the newly developed bridges was observed.
3) Fragility curves are originally developed for steel bridge piers on the basic of synergistic use of bridge damage data obtained from the 1995 Hyogo-ken Nanbu earthquake and nonlinear dynamic analysis results using a hysteretic model with the peak ground acceleration. Thus, a probability-based evaluation approach for seismic damage risk is made possible for steel bridges according to fragility curves in combination with seismic hazard curves.
4) As far as the environmental impacts and costs of seismic recovery operations vary with the discount rates, fragility curves, and hazard curves, it was found from the numerical example that they are generally small compared to those from the construction stage. In addition, the cost distribution over seismic damage states presents that about one-half of lifecycle cost for seismic recovery operations is spent on one damage category state (category B) because of the probabilistic distributions of both seismic hazard and fragility curves.

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