A STUDY ON ESTIMATION FOR LIFE CYCLE COST OF RC BRIDGE PIERS

Hajime ITO, Takayuki OBARA, Tetsuya MISHIMA
Maeda Corporation

***ABSTRACT*:** In the sustainable society, reinforced concrete (RC) structure should retain safety performance to the future. In order to keep the safety performance, it is necessary to use the durable material and premeditate maintenance.

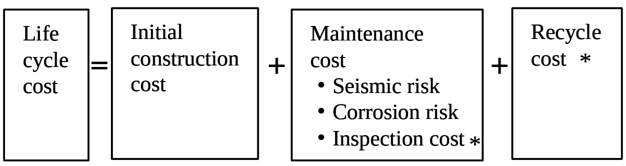
In this study, the estimation method of the life cycle cost (LCC) was presented. This paper described the estimation methods and the case study for LCC of RC bridge pier. The LCC was calculated in consideration of the seismic and the chloride corrosion risk. The performance deterioration from the risks of the RC structure were predicted in consideration of material and construction method. One RC bridge pier in the road bridge was selected and the service life was set as 100 years.

***KEYWORDS*:** life cycle cost, seismic risk, chloride corrosion risk

1. INTRODUCTION

In Japan, recently, the deterioration of the RC structure has begun to stand out, and expenses for the repair are increasing. In future, in order to fulfill the sustainable society, the maintenance plan of RC structure will become more important. Accordingly, the estimation of life cycle cost of RC structure is attracted the attention.

This paper presents the estimation method of the life cycle cost of the RC pier. The LCC was calculated in consideration of seismic and corrosion risk. Based on the proposed method, nine case studies was carried out. The influences of design details of RC bridge pier were evaluated in the case study.



* Their cost were not included in this study

Figure 1 Concept of life cycle cost

2. ESTIMATION OF LIFE CYCLE COST

2.1 Concept of life cycle cost

Life cycle cost is defined as the sum of initial construction cost and estimated maintenance expense as shown Figure 1. In this study, the recycle cost is not included.

Figure 2 presents the flow of LCC estimation. For estimating the maintenance cost, repair and rebuilt expenses by currency are calculated in terms of steel corrosion and probabilistic earthquake induced damage.

2.2 Estimation method of chloride corrosion risk

The costs of corrosion risk consists of initial costs and recovery costs as shown Figure 2. The initial costs spend to avoid the deterioration. The recovery costs spend to recover the corrosion damage.

The corrosion risk assessment was conducted with following equations of the JSCE Standard Specifications according to the thickness of cover layer and the quality of concrete. The density of chloride ion at cover layer is calculated by finite element analysis.

$$\frac{\partial u}{\partial t} = D_d \frac{\partial^2 u}{\partial x^2} \quad \text{(equation of diffusion)} \quad (1)$$

$$C_d \geq C_{\lim} = 1.2 kg/m^3 \quad \text{(judging standard)} \quad (2)$$

where,

u = Density of chloride ion (kg/m^3) at x=0, u=C_0

t = Time (s)

x = Distance from concrete surface (cm)

D_d = Diffusion coefficient of chloride ion (cm^2/s)

C_0 = Density of chloride ion at concrete surface (kg/m^3)

C_d = Density of chloride ion at steel bar (kg/m^3)

C_{lim} = Corrosion limit density of chloride ion (kg/m^3)

In this study, patching and surface protection were adopted as the recovery measure methods. As for the patching, the concrete is removed from the position at 20mm of the back of re-bar to the surface. Patching concrete is cast at the removed position. As for the surface protection, The performance that intercepts salinity is considered by the diffusion coefficient of the analysis.

2.3 Estimation method of seismic risk

The repair cost to recover the function after earthquake can be estimated with the possibility of seismic event of different magnitudes and corresponding damage magnitude of the structure. The damage level can be computed by conducting nonlinear dynamic analysis under the estimated seismic action.

Figure 3 shows the probability density and the recovery costs corresponding to the response. The probability density is calculated according to the relationship of the seismic kinds and the excess probability as shown Table 1. The recovery costs are calculated according to the relationship of the damage level and the recovery method as shown Table 2. Recovery costs of seismic damage per year are conducted with following equations.

$$\int_{\theta_y}^{\theta_{L2I}} C(\theta)\cdot p(\theta) d\theta + C(\theta_{L2II})\cdot p(\theta_{L2II}) \quad (3)$$

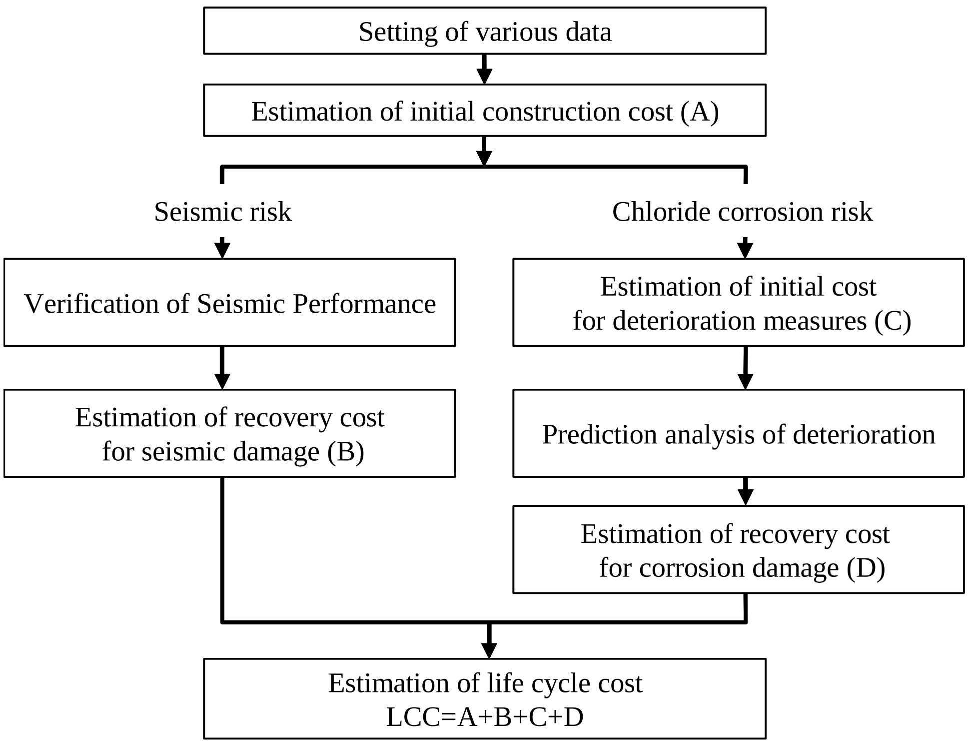


Figure 2 Estimation flow

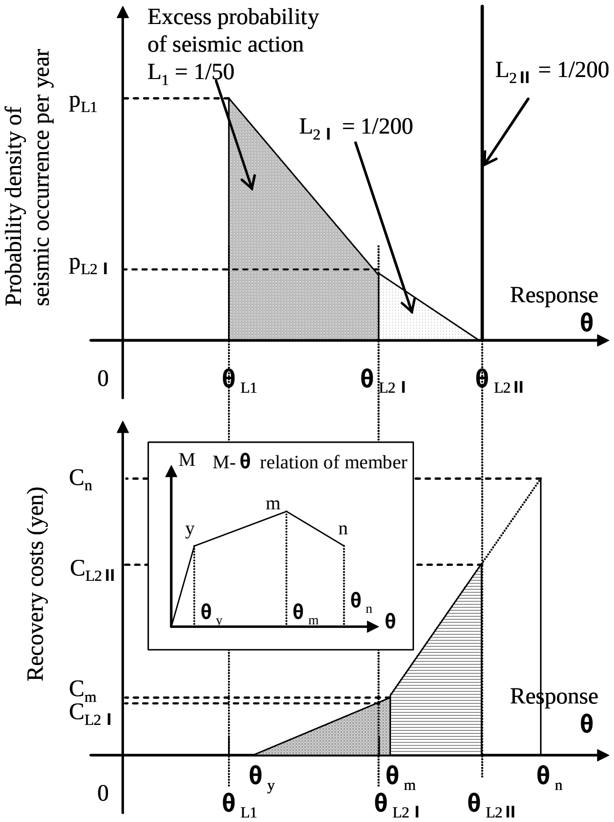


Figure 3 Evaluation of seismic risk

2.4 Characteristic of LCC

As for estimation of LCC, if much reinforcement is placed, the recovery cost may be less even under great seismic loads, but the initial cost will be increased. If we itemize high quality concrete, larger initial cost will be demanded, but the maintenance cost can be compressed. Then, the material and the structural capability, which have much to do with initial cost, are trade-offs of maintenance cost.

3. CASE STUDY

3.1 Examination case

In order to clarify the influential material and method for reducing life cycle cost, the LCC was compared with 9 design details of a RC bridge pier located close to the sea (See Figure 4). In the fundamental case (No.1), the sectional size was 5m ×2.2m, and the thickness of cover layer was 12cm, the concrete strength was 24N/mm^2 (W/C=55%).

Table 1 Seismic kinds and excess probability

Seismic kinds	Excess probability
L1	1 /50year
L2-Ⅰ	1 /200year
L2-Ⅱ	1 /1000year

Table 2 Damage level and recovery method

Damage level	Position on graph	Recovery method
1	*y* : yield	-
2	*m* : maximum	Injection into crack
3	*n* : ultimate	Receiving bridge Injection into crack Patching Adding re-bar

The density of chloride ion at concrete surface was 13kg/m^3 as assuming splash zone.

Nine cases of design details are discussed as listed in Table 3. Three kinds of concrete covers, C of 8, 12, 15cm, three kinds of re-bar area to concrete sectional area ratios, P of 0.38, 0.48, 0.61% and three kinds of chloride ion density at concrete surface, C_0 of 4.5, 9, 13kg/m^3 were employed as the main parameters.

In addition, No.6 case of super quality concrete (SQC) was calculated. SQC use high strength concrete and high strength reinforcing bars. And the concrete used to SQC possessed the characteristics of self-compacting concrete. In the No.6 case, the sectional size was reduced 3.5m×1.7m.

All cases satisfied the requirements of the design code specification for road bridges in Japan.

3.2 Unit price

Table 4 shows the unit price of construction works. Table 5 shows the unit price of recovery cost. The detail of surface protection assumed as thickness 1mm, diffusion coefficient 0.00183 cm^2 /year, and service life 30years.

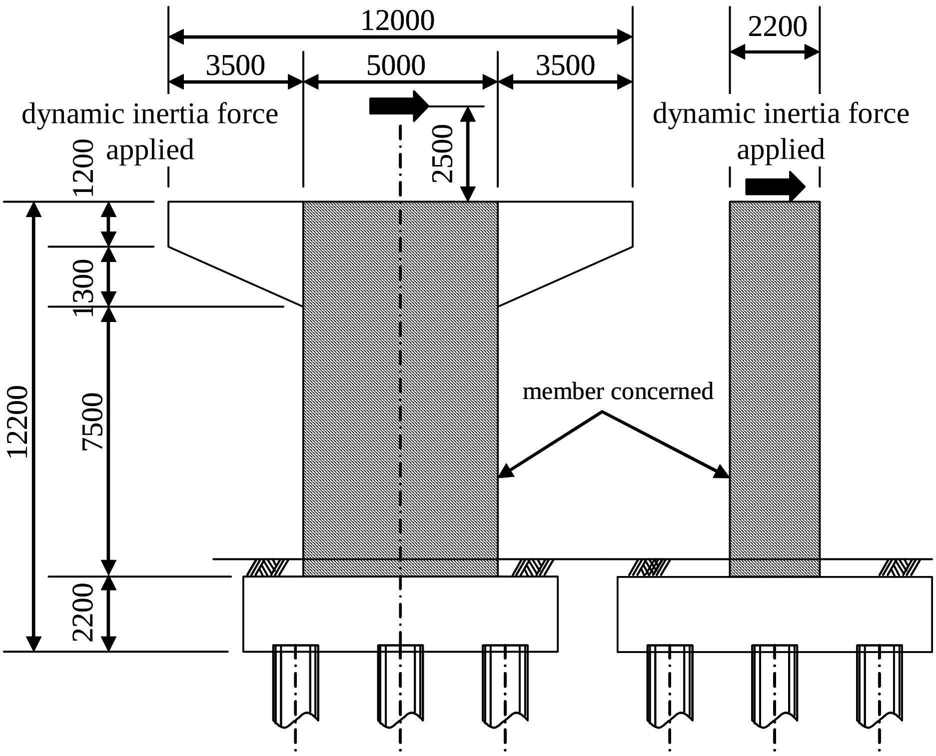


Figure 4 Model bridge pier

Table 3 Examination case

No.	Section		C	Type	f_c'	W/C	Main reinf.		Web reinf.		Chloride	Measure	
	Height	Width					type	P%	type	P%	C_0	initial	repair
1			12cm					0.48					
2			8cm					0.47		0.16			
3	2.2m	5.0m	15cm	Conv.	24 MPa	0.55	SD295	0.49	SD295		13.0 kg/m^3		
4								0.61		0.19		NO	
5								0.38		0.16			rebuilt
6	1.7m	3.5m		SQC	60MPa	0.35	USD685	0.91	USD785	0.27			
7			12cm								4.5		
8	2.2m	5.0m		Conv.	24 MPa	0.55	SD295	0.48	SD295	0.16	9.0		
9											13.0	surface	

Table 4 Unit price of construction works

Work kinds	Unit price
Concrete (24N/mm^2)	17,500yen/m^3
Concrete (60N/mm^2)	32,500yen/m^3
Form work	3,000yen/m^2
Curing	500yen/m^2
Re-bar (Normal strength)	90,000yen/ton
Re-bar (High strength)	125,000yen/ton
Scaffolding	2,000yen/m^2

Table 5 Unit price of recovery cost

Work kinds	Concrete strength	Concrete Cover	Unit price
Patching	24N/mm^2	80mm	10,388yen/m^2
		120mm	12,180yen/m^2
		150mm	13,497yen/m^2
	60N/mm^2	120mm	14,345yen/m^2
Surface protection	—	120mm	10,000yen/m^2

Table 6 Examination results

<table>
<tr><td rowspan="3">No.</td><td colspan="4">Seismic Performance:Pa／Khc W</td><td rowspan="3">No. of repair</td><td rowspan="3">LCC million \</td><td colspan="2">Initial cost mill \</td><td rowspan="3">Earthquake Recovery Cost mill \</td><td rowspan="3">Chloride Damage recovery</td></tr>
<tr><td colspan="2">longitudinal</td><td colspan="2">transverse</td><td rowspan="2">main structure</td><td rowspan="2">Chloride prepare</td></tr>
<tr><td>Type I</td><td>Type II</td><td>Type I</td><td>Type II</td></tr>
<tr><td>1</td><td>1.43</td><td>1.15</td><td>2.77</td><td>2.07</td><td>5</td><td>12.60</td><td>4.16</td><td rowspan="8">0.0</td><td>0.76</td><td>7.68</td></tr>
<tr><td>2</td><td>1.48</td><td>1.18</td><td>2.80</td><td>2.09</td><td>12</td><td>21.40</td><td>4.17</td><td>0.67</td><td>16.57</td></tr>
<tr><td>3</td><td>1.39</td><td>1.13</td><td>2.74</td><td>2.07</td><td>3</td><td>9.81</td><td>4.15</td><td>0.85</td><td>4.81</td></tr>
<tr><td>4</td><td>1.77</td><td>1.43</td><td>3.16</td><td>2.38</td><td>5</td><td>12.46</td><td>4.49</td><td>0.29</td><td rowspan="2">7.68</td></tr>
<tr><td>5</td><td>1.25</td><td>1.07</td><td>2.60</td><td>1.99</td><td>5</td><td>12.92</td><td>3.98</td><td>1.27</td></tr>
<tr><td>6</td><td>1.52</td><td>1.14</td><td>2.84</td><td>1.95</td><td>2</td><td>7.05</td><td>4.33</td><td>0.39</td><td>2.32</td></tr>
<tr><td>7</td><td rowspan="3">1.43</td><td rowspan="3">1.15</td><td rowspan="3">2.77</td><td rowspan="3">2.07</td><td>2</td><td>7.43</td><td>4.16</td><td rowspan="3">0.76</td><td>2.51</td></tr>
<tr><td>8</td><td>4</td><td>10.74</td><td>4.16</td><td>5.82</td></tr>
<tr><td>9</td><td>3</td><td>10.68</td><td>4.16</td><td>5.76</td><td>0.00</td></tr>
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3.3 Result

LCC of nine cases shown as Table 3 were calculated, and the corresponding LCC estimation is lined up in Table 6. LCC of SQC case (No.6) was cheapest in all cases, and LCC of least cover thickness case (No.2) was the most expensive.

Figure 5 shows change of costs in No.1 case. The cost for seismic damage recovery was 0.76 million yen, it corresponded to 20% of initial construction cost. The cost for corrosion damage recovery accounted for 60% of LCC, and it was three times of initial construction cost. It is obvious that the reduced maintenance cost relies greatly on the enhanced durability rather than the reduced seismic risk.

3.4 Influence of concrete cover

Figure 6 shows the relationship between the concrete cover thickness and the cost of No.1, No.2, and No.3. The value of ‘n’ means the frequency of corrosion damage recovery in this figure. The smaller cover thickness was, the more the repair frequency was. And as the costs of corrosion damage recovery increased, LCC increased.

On the other hand, because the section size of the pier was same, the smaller cover thickness was, the more the earthquake risk had decreased.

3.5 Influence of reinforcing bar ratio

Figure 7 shows the relationship between the reinforcing bar ratios and the cost of No.1, No.4, and No.5. As the reinforcing bar ratio increased, the seismic performance was improved. Then the LCC of No.4 was the least in these three cases.

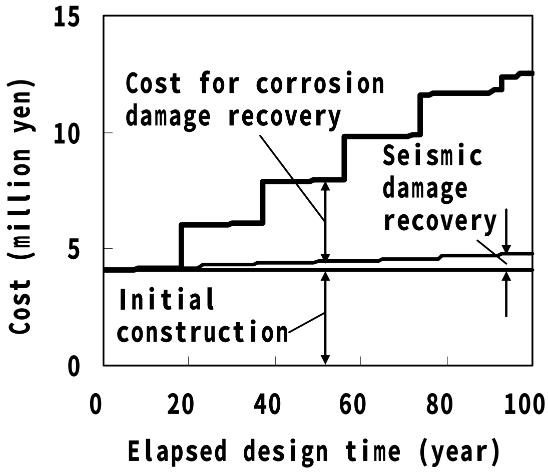

Figure 5 Change of costs

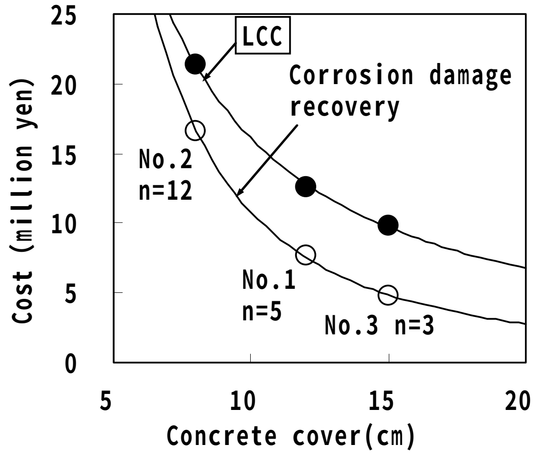

Figure 6 Concrete cover depth vs. cost

3.6 Influence of concrete strength

Figure 8 shows the relationship between the concrete strength and the cost of No.1 and No.6. No.6 is the case of SQC. This figure presents the sensitivity of the concrete strength to the cost configuration. Dramatic cost reduction was obtained when the strength of concrete was increased.

3.7 Influence of chloride condition

Figure 9 shows the relationship between the density of chloride ion at concrete surface and the cost of No.1, No.7, and No.8. As the density of chloride ion decreased, the repair frequency was decreased. Then the LCC of No.7 was the least in these three cases. And the ratio of cost of corrosion damage recovery decreased from 61% (No.1) to 34% (No.7).

4. CONCLUSIONS

As the result of this study, the following findings were obtained.

(1) The estimation method of the life cycle cost of RC pier could be established in consideration of the seismic risk and the corrosion risk.

(2) In the corrosion condition of this study, when the concrete strength was high and the concrete cover was thick, the LCC was decreased.

(3) As the seismic risk was set lower, the initial construction cost was higher. But then the recovery cost of seismic damage was lower.

(4) As for the corrosion condition, the frequency and the cost of corrosion damage recovery were different. Therefore the proportion of the cost of corrosion damage recovery in LCC was different.

REFERENCES

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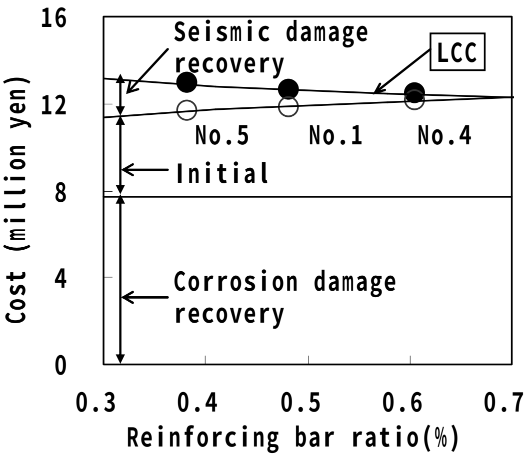

Figure 7 Reinforcing bar ratio vs. cost

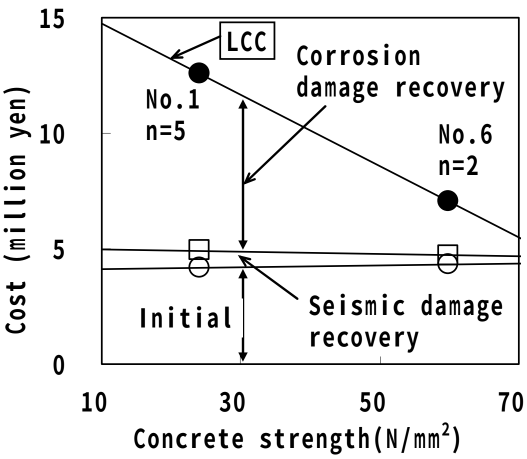

Figure 8 Concrete strength vs. cost

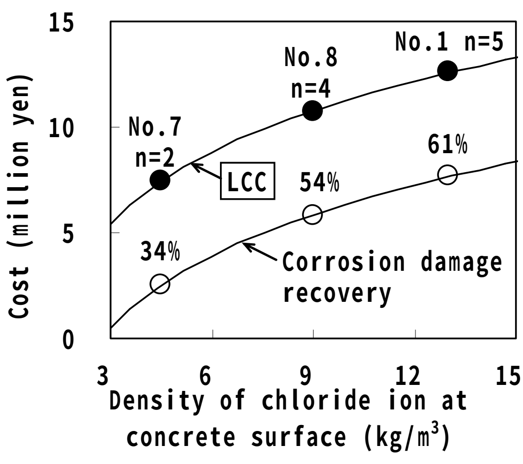

Figure 9 Chloride condition vs. cost