OPTIMIZATION OF LIFE-CYCLE MANAGEMENT ON PORT MOORING FACILITIES

Hokkaido University Student Member ○Surya Dewi Puspitasari
Port and Airport Research Institute Member Yuichiro Kawabata
Hokkaido University Fellow Hiroshi Yokota

1. INTRODUCTION

Reinforced concrete (RC) structures are subjected to various mechanical and environmental actions throughout their service life resulting in the degradation of structural performance. Port mooring facilities are among such RC structures suffering from chloride-induced corrosion owing to its exposure to harsh marine environments (Kawabata et al. 2018). Port mooring facilities have essential roles for seaborne shipping; therefore, it is necessary to prevent the severe damages. Ensuring structural performance requirements of the facility with the concept of life-cycle management can stimulate sustainable social and economic activities at the same time. However, it is deniable that the great amount of money is required to maintain these facilities, and benefit loss cannot be avoided if corrective repair or replacement of structural components is conducted. Since an environmental aspect is a global issue, an optimization of life-cycle management strategy is required to minimize the repair cost and/or to maximize the benefit as well as to reduce global environmental impact. This paper discusses how to define the optimum life-cycle management strategy of port mooring facilities by comparing the preventive and corrective strategies. The following four indicators are selected for the comparison in the paper: (1) structural performance degradation, (2) life-cycle cost (LCC), (3) net present value (NPV), and (4) CO_2 emission.

2. ANALYTICAL PROCEDURES

2.1 Target facility

An open-type wharf that was built in 1988, particularly for coal handling, is chosen as a case study. The total surface area and concrete volume of its structural members are 6910 m^2 and 2480 m^3, respectively. The most recent close visual inspection was done in 2013, which calculated the overall grade (D_p) of 2.206 that is defined in Eq. (1). The annual net benefit was estimated to be around 1.63 billion yen (Kawabata et al. 2018).

2.2 Prediction of structure performance degradation

The progress in performance degradation was predicted by using the Markov chain model, in which the deterioration moves from one grade to the next one according to the transition probability, p_x (Ng and Moses, 1997). The conditions of each structural member there were evaluated with four deterioration grades: grades d, c, b and a. Grade-d refers to the sound condition while grade-a represents the most severe condition. These deterioration grades are consolidated as the overall grade (D_p) by using Eq. (1), in which the proportion of deterioration grades (P_d, P_c, P_b and P_a for grades d, c, b, and a, respectively) with weighting factors 1.0, 2.0, 3.0 and 4.0 for the corresponding grades (Yokota et al. 2016). The transition probability of the facility is p_x=0.054 based on the latest inspection results.

$$D_p = 1.0\times P_d + 2.0\times P_c + 3.0\times P_b + 4.0\times P_a \tag{1}$$

2.3 Calculation of LCC and NPV

Delving the influence of the repair method of the mooring facility on LCC and NPV, the repair strategies and corresponding repair methods and their specifications are defined in Table 1 (Kawabata et al. 2018). LCC and NPV are estimated for the service life of 100 years. NPV can be estimated using Eq. (2).

$$NPV = \sum_{i=1}^{j} \frac{B_i - C_i}{(1+r)^i} \tag{2}$$

Where B_i is the benefit at i-th year, C_i is the cost at i-th year, r is the social discount rate (=4%), and j is the service life.

Table 1 Repair method, repair cost and benefit loss

Range	Repair strategy	Repair method	Unit	Unit cost (yen)	Benefit loss
$1.7 \le D_p < 2.0$	Preventive	Surface coating	m^2	24 000	0%
$2.0 \le D_p < 2.3$	Corrective	Surface coating (SC)	m^2	22 500	30%
$2.3 \le D_p < 2.6$					50%
$2.6 \le D_p < 3.0$		SC + Small section repair	m^2	16 500	70%
$3.0 \le D_p < 3.5$		SC + Large section repair	m^2	205 000	100%
$3.5 \le D_p$		Replacement	m^3	300 000	100%

Unit costs for repair include temporary work (9 000 yen/m^2)

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Contact address: Kita 13, Nish 8, Kita-ku, Sapporo, Hokkaido, 060-8628, Japan, Tel: +81-11-706-6204

2.4 Environmental impact

Maintenance work is one of the ways how engineering and policy can associate with a sustainable environment. Construction work, either maintenance or building a new structure, will emit a considerable amount of CO_2 that globally affects the environment. The previous study provided CO_2 emission-related inventory data on construction work, such as concrete plant: 7.7 kg-CO_2/t, concrete mixer (3 m^3): 0.6 kg-CO_2/m^3 (Kawai et al. 2005), section repair: 56.30 kg-CO_2/m^2, and surface coating: 4.69 kg-CO_2/m^2 (Japan Society of Civil Engineers, 2012). The environment impact in this paper only focuses on CO_2 emissions from raw materials production and above-listed construction work.

3. ANALYSIS RESULTS

Figure 1 shows LCC estimated for preventive and corrective repair strategies without considering the social discount rate. Prediction of performance degradation suggested that it is necessary to do surface coating every 20 years in the preventive strategy or section repair about every 30 years in the corrective strategy during the service life. Since the overall grade (D_p) already reached the range of preventive strategy, surface coating should be done at the beginning. The first section repair is planned at 27 years because D_p reaches 2.3. The preventive strategy looks more beneficial to be applied in the early maintenance time than the corrective strategy, because the cost for the former is lower than that for the latter. At 56 years, the LCC of the corrective strategy goes up significantly over that of the preventive strategy. At the end of service life, the gap between the two strategies are rather big, and the LCC of the preventive strategy becomes lower than that of the corrective strategy. As mentioned earlier, the deterioration rate of this facility is large, and the overall grade (D_p) at the beginning is 2.206. That is, the overall grade remains in the range of corrective strategy at the beginning. It means, if the section repair will be applied later, the damage is predicted to be more severe, which needs higher cost.

Figure 2 points out that NPV of the surface coating is slightly higher from the beginning than that of the section repair. The section repair work disrupts the daily port operations more or less, which causes benefit loss from 50% to 100%. On the other hand, the surface coating provides less benefit or revenue loss from the port operation. The longer the facility is used, the more difference in NPV's between the surface coating and the section repair is estimated.

The CO_2 emission trend reveals that surface coating emits less CO_2 than the section repair, even though the surface coating is applied earlier in the service life. The surface coating is applied more often than the section repair, but the total amount of CO_2 emission of the surface coating is much lower. In other words, the more structure is damaged, the more CO_2 will be emitted. Preventing severe damage in the facility is necessary to protect our life, ecosystem and earth from the sustainability point of view.

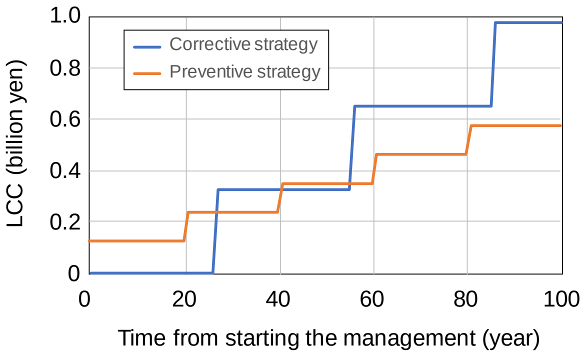

Fig. 1 Calculated LCC

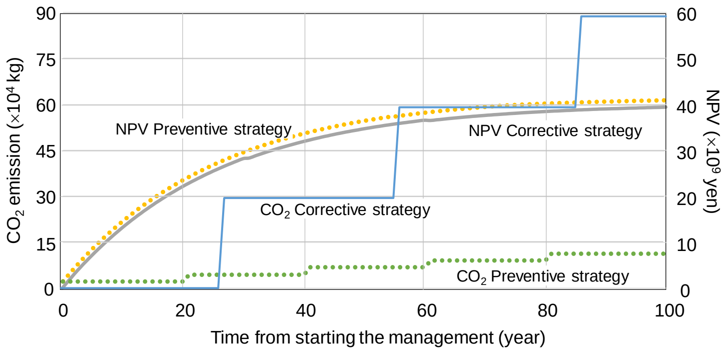

Fig. 2 Calculated NPV and CO_2 emission

4. CONCLUSIONS

NPV's of the preventive and corrective strategies are almost the same, but CO_2 emission is considerably saved when the preventive strategy is taken. A multi-objective optimization maintenance strategy of the facility is intended to optimize NPV and LCC and to minimize environmental impact under ensuring the performance requirements of the facility.

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