1 Case study structure

The hypothetical structure used for this study is a prestressed, single-span slab bridge located about 100 meters from the shoreline. The assumed dimensions of the bridge are as follows:

- **Bridge length:** 20.76 m
- **Span arrangement:** single span
- **Width:** 8.2 m
- **Bridge area:** 170.2 m^2
- **Angle of skew:** 90°
- **Bridge class:** 1st class (TL25: design live load of 25 tf)
- **Protection from chloride damage:**

Category I (cover depth of 52 mm, outer prestressing steel located 70-mm deep)

Category III, when CFRM is used to reinforce (cover depth of 32 mm, outer prestressing CFRM located 50-mm deep)

Fig. 1. General diagram of bridge beam (elevation)

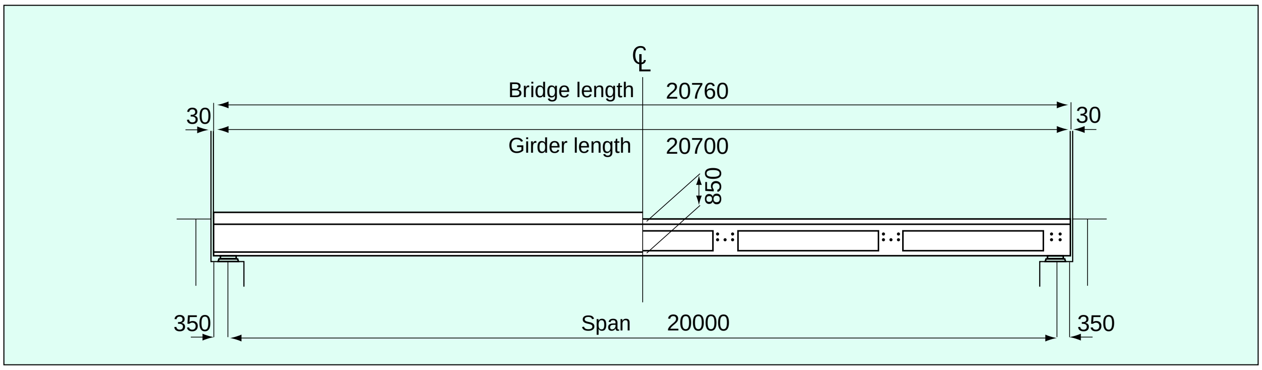


Fig. 2. General diagram of bridge beam (cross section)

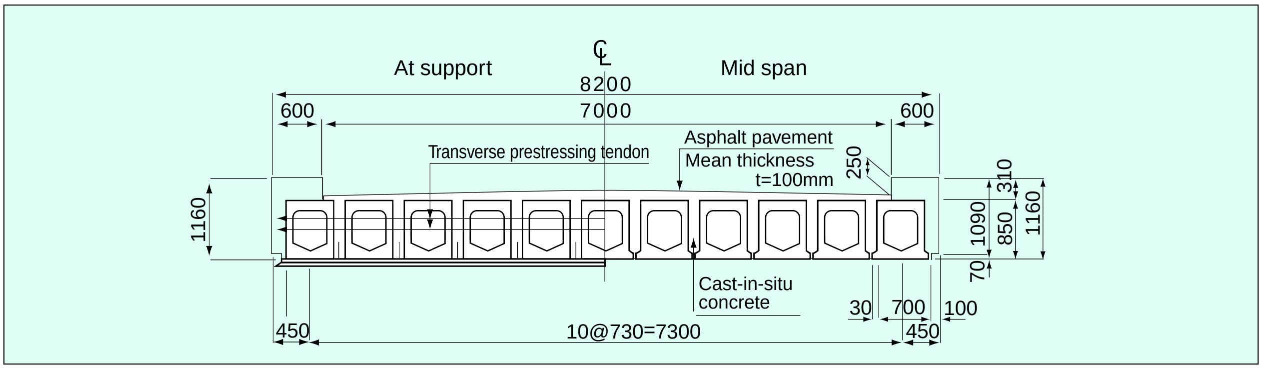
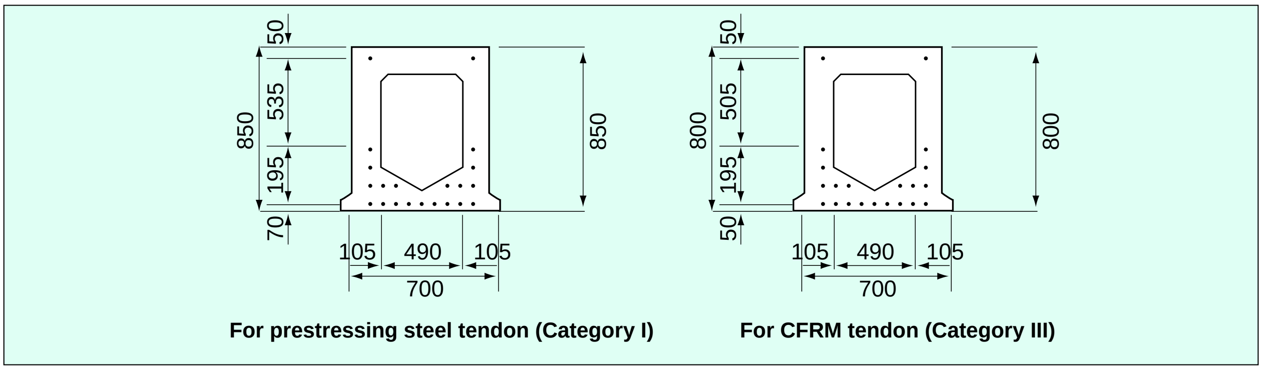


Fig. 3. Beam cross section



ACC

2 Degradation estimation

Chloride damage and carbonation (neutralization with C02) are believed to be factors responsible for promoting the corrosion of reinforcing steel. However, the water/cement ratio for the concrete used in major civil engineering works is estimated to be 50% or lower. Therefore, in accordance with "JSCE: Standard Specification for Design and Construction of Concrete Structures", we eliminated carbonation from consideration, and focused on chloride damage as the factor responsible for degradation.

The estimated diffusion of chloride ions led the authors to estimate that corrosion would start on steel reinforcing bars at a depth of 52 mm after about 18 years. In this study, therefore, the authors assumed that from the initial construction, there would be a latent period of 18 years before corrosion would begin, followed by a period of developing corrosion until year 25, and then a period of accelerated corrosion until year 50. Figure 4 is a graph of the theoretical progression of degradation due to chloride damage. Figure 5 shows the change in the distribution of chloride ion concentration over time under the analysis conditions described below.

■ Analysis conditions

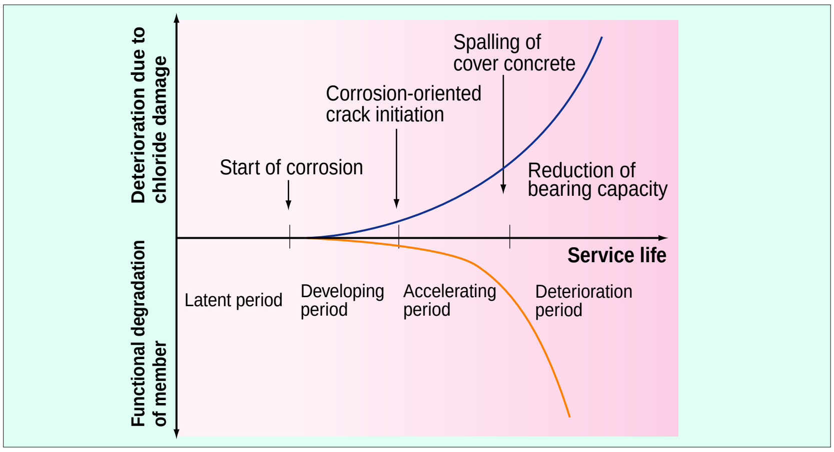
Concentration of chloride ions on the concrete surface -------------------------------- $C0 = 4.5\ kg/m^3$

Chloride ion concentration at initial period -- $C(x, 0) = 0.3\ kg/m^3$

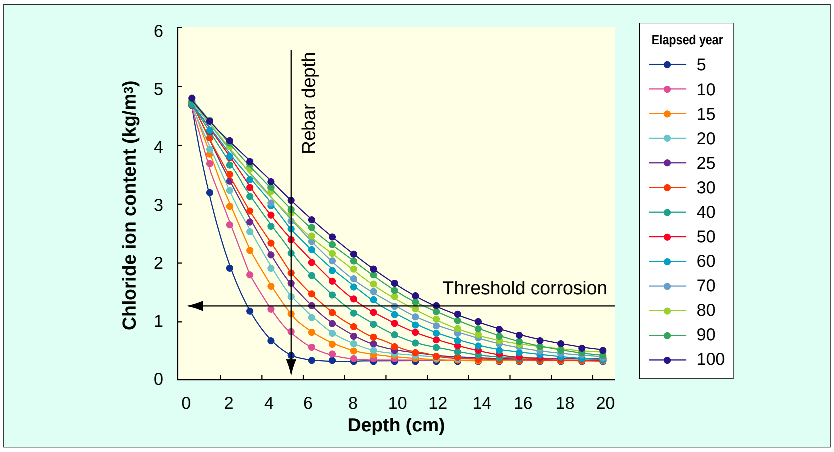
Water/cement ratio of the concrete -- W/C = 36%

Chloride ion concentration at the point when corrosion is about to begin (Threshold corrosion) ------------------------------ $Ccr = 1.2\ kg/m^3$

■Fig. 4. The progress of degradation due to chloride damage



■Fig. 5. Results of analysis of the distribution of chloride ion concentration over time



3 LCC comparison

Figure 6 shows a chart of rehabilitation and strengthening methods that the authors studied, together with the durability of each method. Looking at the 100-year mark, it was assumed that the first method that involved measures to prevent the permeation of chloride ions or to eliminate chloride ions from the concrete would maintain the concrete structure in a sound condition.

On the other hand, in the second method where the structure would be left until the onset of degradation and then reinforced, it was assumed that the service life of the structure would be over by the 100-year mark.

For the third method of cathodic protection, although it is more difficult to predict its outcome, the authors estimated the soundness of the structure would be maintained at the 100-year point.

The case where the structure would use epoxy coated reinforcing steel is included solely as a reference for two reasons: First, there are currently several technical issues in the manufacture of prestressed concrete beams that contain epoxy-coated prestressing tendons; Second, the relationship between pinholes in the epoxy coating and the corrosion of the steel is not well understood.

Figure 7 shows the outcomes of the LCC calculations. The figure shows that in an environment with a high chloride ion concentration, the LCC to preserve and maintain the structure is high. The construction costs shown in the figure are estimates of direct construction costs at today's rates. It should be noted that the complex interrelationships of several factors, such as future technology, interest rate trends, the residual value of the structure, as well as risk and risk management make it impossible to make a simple comparison among the various methods.

■ Preventive maintenance against chloride damage

In the approach where preventive maintenance against chloride damage is undertaken at the initial construction of the structure, the LCC at the 100-year point is estimated to range from 1.6 to 2 times higher than the initial construction cost of bridge beams using Category I chloride damage prevention measures. Of these approaches, the cheapest (at 1.63 times) is to use CFRM for all reinforcement of the pretensioned beams. Use of CFRM seems highly advantageous in an environment with a high chloride concentration even taking the following two factors into consideration: a) unforeseen degradation that could occur in CFRM-reinforced bridges, and b) inspection and other necessary maintenance and management.

The cost of repainting is high in the method where the surface of the concrete is repainted with waterproof paint every 16 years, pushing the LCC up by 1.9 times. It is hoped that highly durable concrete paints will be developed in the future. The recently well-publicized cathodic protection method appears expensive, due to high initial system costs and renewal costs.

■ Rehabilitation methods

The approaches that involve repairs during the latent period or at an early stage of corrosion development result in an LCC that is three times higher than the initial construction cost, due to the high concentration of chlorides remaining in the concrete, and are more costly than the preventive maintenance against chloride damage. Although these repair methods, if repeated, can maintain a structure in a sound condition for more than 100 years, the frequency of inspections, maintenance and management will likely increase over time. For structures in which chloride damage is expected to advance, methods that involve preventive maintenance against chloride damage are probably more suitable.

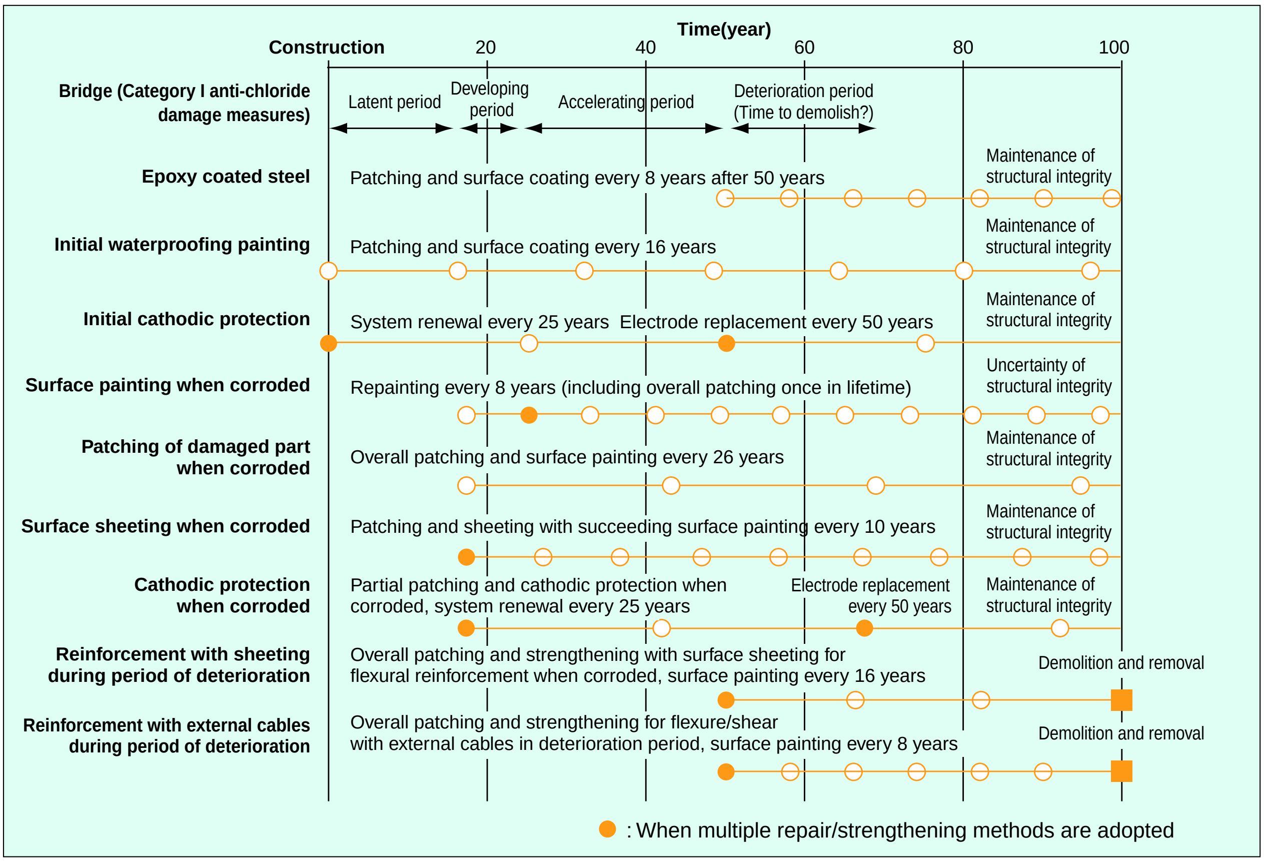
■ Strengthening methods

Approaches that advocate strengthening of structures during the latent period or during the period when corrosion accelerates require risk management to enable the continued service of the structure, since it is assumed that damage or degradation will occur in the structure from time to time. Reinforcements are comparatively costly; moreover, even after they are applied, a bridge beam may still not meet all the performance requirements. If the structure is demolished and removed after 100 years, then the LCC is from 2.6 to 3.7 times higher than the initial construction cost, plus there are the costs of constructing a new structure to replace the old one.

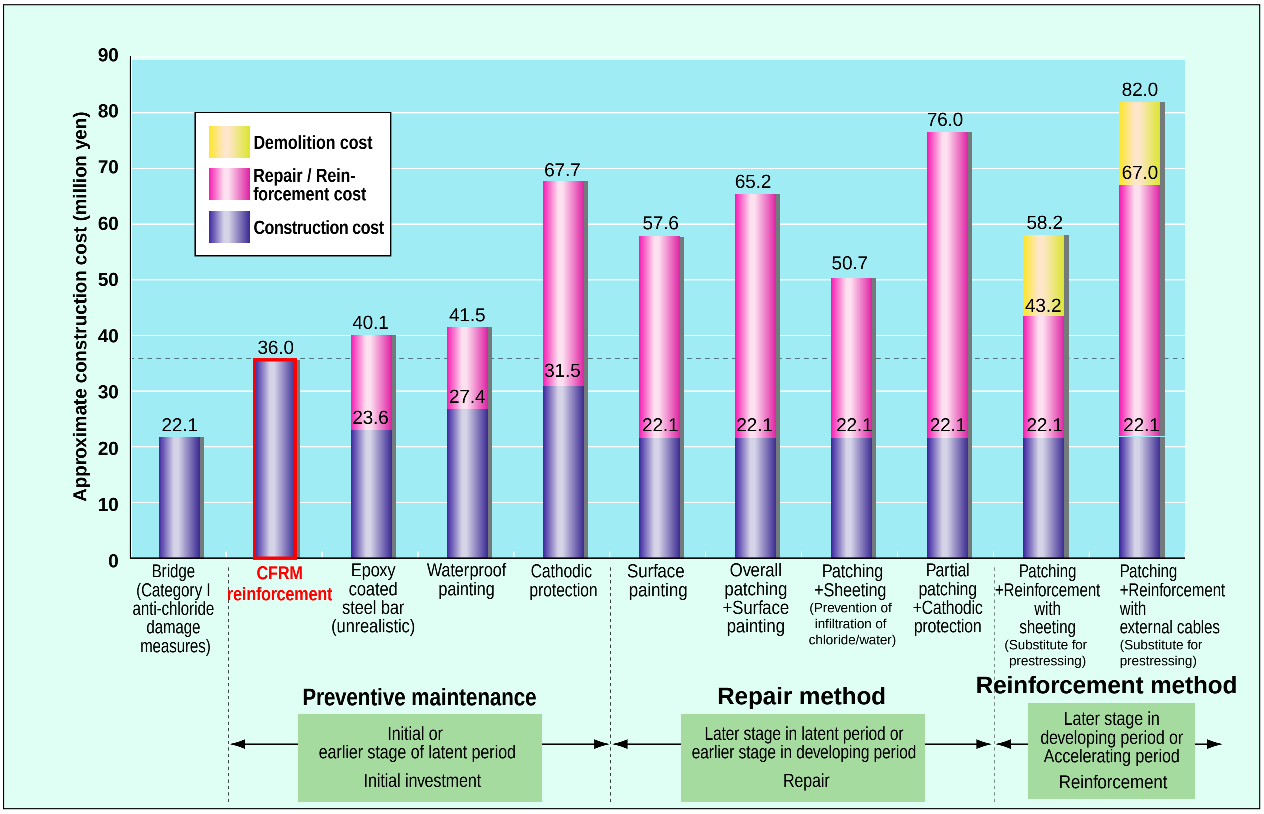
A Case Study on the Lifecycle Cost of a Concrete Structure using CFRM

3 LCC comparison (fig)

■ Fig. 6. Summary of rehabilitation methods



■ Fig. 7. Outcomes of the LCC calculations



4 Conclusions

In an environment where the concentration of chloride ions is high, the application of preventive maintenance results in the lowest lifecycle costs. Of these preventative approaches, one of the best choices is to use CFRM reinforcement to construct a structure that will neither rust nor degrade. It is hoped that the wider adoption of CFRM-reinforced concrete will contribute to the development of a sustainable society.

This study was conducted by the ACC's LCC Application Study Group. The Group hopes that this pamphlet will serve as a reference for further CFRM studies. For further information about this study, please refer to the "ACC LCC Application Study Group Report, June 2002."

■ Bentenbashi (Benten bridge)

Bentenbashi, located at Hattachi Beach in Iwaki City (Fukushima Prefecture, Japan), uses CFRM for all its reinforcing tendons in the superstructure (reinforced concrete hollow deck bridge) and the substructure.

■ CFRM used to reinforce concrete structures