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P.S.C 철도교량의 잔존수명 예측

Lifetime Prediction of a P.S.C Rail Road Bridge

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Abstract

The biggest challenge bridge agencies face is the maintenance of bridges, keeping them safe and serviceable, with limited funds. To maintain the bridges effectively, there is an urgent need to predict their remaining life from a system reliability viewpoint. In this paper, a model using lifetime functions to evaluate the overall system probability of survival of a rail road bridge is proposed. In this model, the rail load bridge is modeled as a system. Using the model, the lifetime of the rail road bridge is predicted.

Keywords : Rail Road Bridge (철도교량), System Reliability (시스템 신뢰성), Lifetime Function (생애함수)

1. Introduction

The bridges are designed to serve the public. And no matter how well these are designed, they are deteriorating with time. One of the main concerns is whether the reliability of the bridge remains above the required safety level or not at the end of expected lifetime. To increase the service life, it is necessary to properly maintain the bridge, and the most effective maintenance strategy is required because of limited funds.

In this paper, the program "LIFETIME", which was developed using system reliability and lifetime functions, is used to predict the remaining life of the rail road bridge.

2. System Reliability and Lifetime Function

2.1 Structure Function and Reliability Function

Structure function [1] is a useful tool to describe the state of a system with n components. Structure function defines the system state as a function of the component state. In addition, it is assumed that both components and the system can either be functioning or failed. The state of component i, xi, is assumed as

$$x_i = \begin{cases} 0 & \text{if component } i \text{ has failed} \\ 1 & \text{if component } i \text{ is functioning} \end{cases} \quad (1)$$

for i = 1, 2, ..., n

The n component system can be expressed as a system state vector as following.

$$x = \{ x_1, x_2, \ldots, x_n \} \quad (2)$$

Structure function, ø(x), expresses the system state vector x to zero or one. The structure function ø(x) for a given system state vector is

$$ø(\mathbf{x}) = \begin{cases} 0 & \text{if the system has failed} \\ 1 & \text{if the system is functioning} \end{cases} \quad (3)$$

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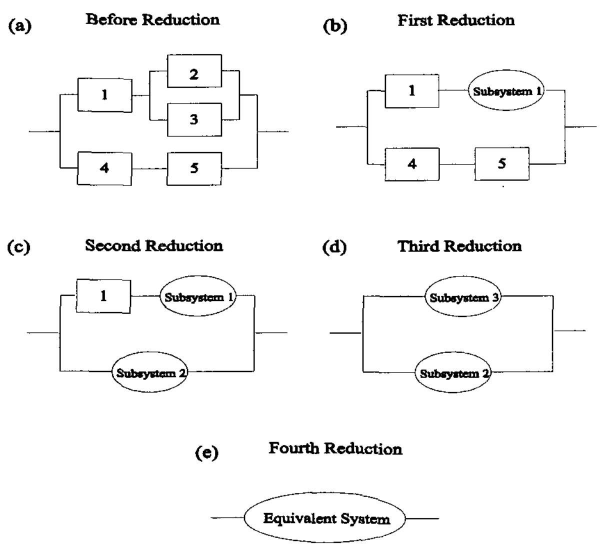

Fig. 1. Sequential Reduction Procedure

As an example, the structure function is obtained for a 5-component system shown in Fig. 1. Also, Fig. 1 shows the reduction steps. These reduction steps are also expressed as functions through Eq. (4) to Eq. (7).

The first reduction step is a parallel system between components 2 and 3. Using the first reduction, the subsystem 1 is obtained and expressed as following.

$$\phi_{S1}(\mathbf{x}) = 1-(1-x_2)(1-x_3) \tag{4}$$

The second reduction is a series system between components 4 and 5. This is expressed as following.

$$\phi_{S2}(\mathbf{x}) = x_4 x_5 \tag{5}$$

The third reduction is also a series system between subsystem 1 and component 1.

$$\phi_{S3}(\mathbf{x}) = x_1\phi_{S1} \tag{6}$$

Using the fourth reduction, the structure function of this 5-component system is obtained.

$$\phi(\mathbf{x}) = 1-\{1-x_1[1-(1-x_2)(1-x_3)]\}(1-x_4x_5) \tag{7}$$

The structure function is deterministic. This assumption may be unrealistic for certain types of components or system. So, reliability functions [1] are necessary to model the structures. x_i was defined to be the deterministic state of component i. Now, x_i is a random variable. The probability that component i is functioning is given by

$$P_i = P[x_i=1] \tag{8}$$

Where

p_i = Probability that component i is functioning

In order to obtain the reliability function for a 5-component system shown in Fig. 1, the same procedure is necessary. But the component reliability function, p_i, is used in each step instead of component state x.

2.2 Lifetime Function

There are several lifetime functions to describe the evolution of the probability of failure. In this paper, survivor function is introduced and explained. The survivor function can be applied to both discrete and continuous lifetime.

The survivor function is the generalization of reliability because the survivor function gives the reliability that a component or system is functioning at one particular time. The survivor function is expressed

$$S(t) = P[T \geq t] \qquad t \geq 0 \tag{9}$$

It is assumed that when $t \leq 0, S(t)$ is one. The survivor function has to satisfy three conditions. These are

1) $S(0) = 1$
2) $\lim_{t\to\infty} S(t) = 0$
3) S(t) is non-increasing without any maintenance

Exponential distribution, Weibull distribution, Log-ogistic distribution, and Exponential Power distribution are used as survivor functions. These are shown in Table 1.

Table 1. Survivor Functions

Distribution	Survivor function
Exponential	$\exp(-\lambda t)$
Weibull	$\exp[-(\lambda_s t)^{\kappa}]$
Log-logistic	$[1+(\lambda_s t)^{\kappa}]^{-1}$
Exponential- power	$\exp[1-\exp(\lambda_s t)^{\kappa}]$

where

λ = Failure rate
κ = Shape factor
t = Time, $t \geq 0$
λ_s = Scale factor

3. Data Collection

Each lifetime distribution has each its parameters (failure rate, scale factor and shape factor), and these should be obtained from data analysis to predict the failure probability of real bridges.

The data from Maunsell Ltd. [2] is used for bridge components. In Maunsell's report [2], the serviceable life is defined to be the time taken for a significant defect requiring attention to be recorded at an inspection. According to defect severity, four levels are classified.

- Severity1: no significant defects
- Severity2: minor defects of a non urgent nature
- Severity3: defects which shall be included for attention within the next annual maintenance program
- Severity4: the defect is severe and urgent action is needed

Data analysis was conducted for severity 3 and 4. Weibull distribution was selected as best fit for each bridge component and its parameters were summarized in the report [2].

4. System Failure Probability with Time

The bridge has simple span and a length is 24.9 m. The deck consists of 35 cm of reinforced concrete. The slab is supported by six P.S.C concrete girders. The design load is L22. The cross section of the rail road bridge is shown in Fig. 2.

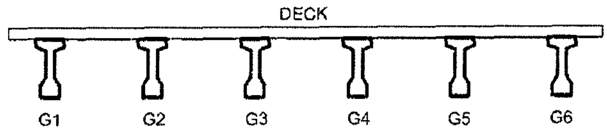

Fig. 2. Cross Section of the Rail Road Bridge

Due to nonlinearity in multi-girder bridge types, single girder failure doesn't cause the bridge failure. If one girder fails on bridge, the load redistribution takes place and the bridge is capable to carry additional loads. The multi-girder bridges are modeled as combination of series and parallel systems in system reliability analysis. The following failure modes are considered.

- System I: Any one girder failure or deck failure causes the bridge failure.
- System II: Failure of any external girder or any two adjacent internal girders or deck failure cause the bridge failure.
- System III: Any two adjacent girder failures or deck failure cause the bridge failure.
- System IV: Any three adjacent girder failures or deck failure cause the bridge failure.

These failure models are shown in Fig. 3 for the rail road bridge. With these failure modes, the reliability analysis is performed.

Where
D = Deck failure
G1 and G6 = Exterior girder failure
G2, G3, G4, G5 = Interior girder failure

When the system failure probability was computed, it is assumed that components are statistically independent. This assumption makes the mathematics simpler. However, this assumption cannot be applied to every system. The correlation between the components in a system affects the system failure probability. For a series system, an increase in the correlation between the components decreases the

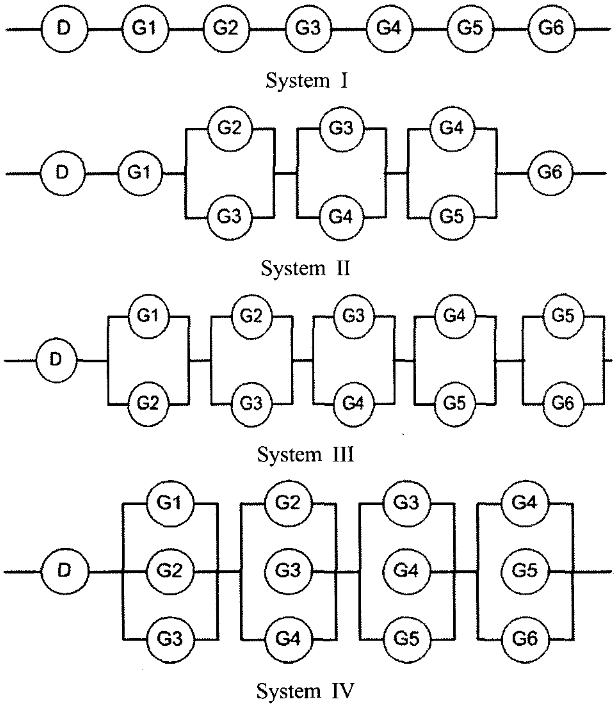

Fig. 3. System Failure Modes

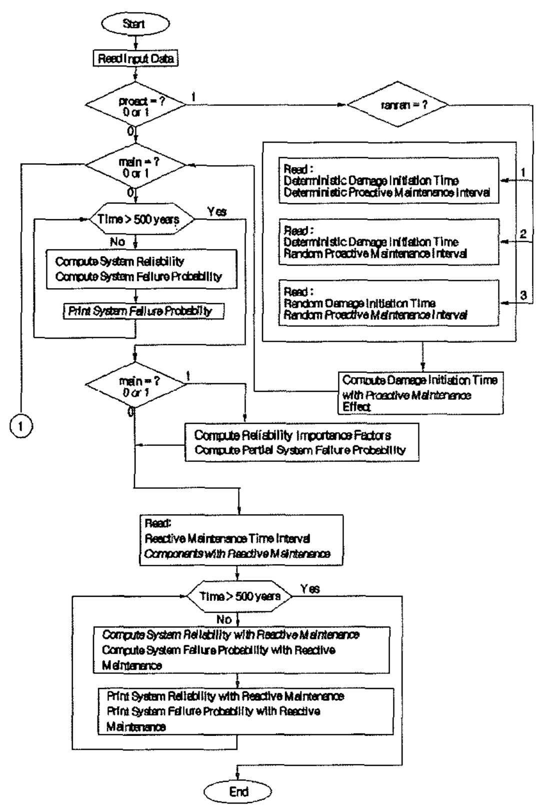

Fig. 4. Flowchart of the Program

system failure probability. Whereas, the increased correlation between the components of a parallel system increases the system failure probability. The calculation of a system failure probability is very difficult and approximation is almost always necessary and, upper and lower bounds of the corresponding probability are useful [3].

The program LIFETIME was developed by using lifetime functions and system reliability concepts. The flow chart of the program is shown in Fig. 4.

Using the program LIFETIME [4-6], the probability of system failure for each failure mode is predicted and shown in Fig. 5, Fig. 6, Fig. 7, and Fig. 8. That of all systems are shown in Fig. 9.

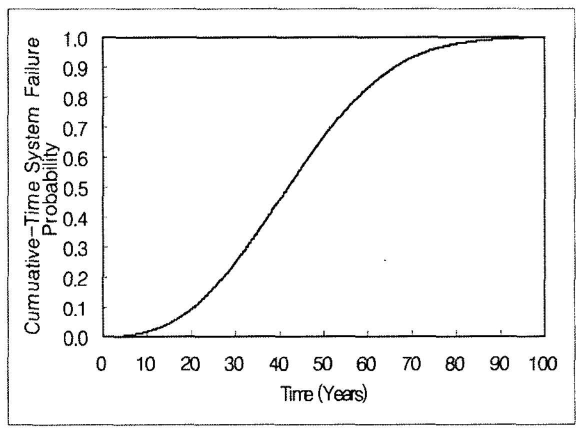

Fig. 5. Failure Probability of System I

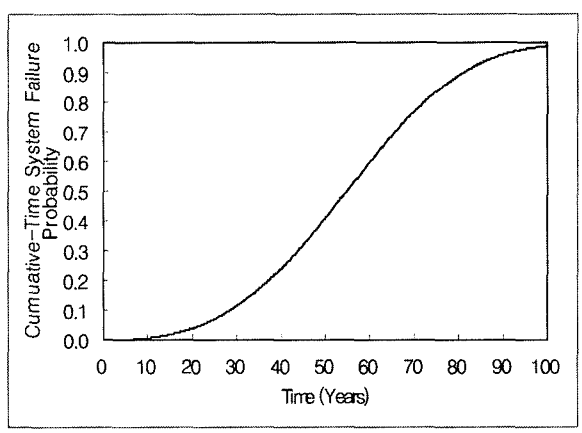

Fig. 6. Failure Probability of System II

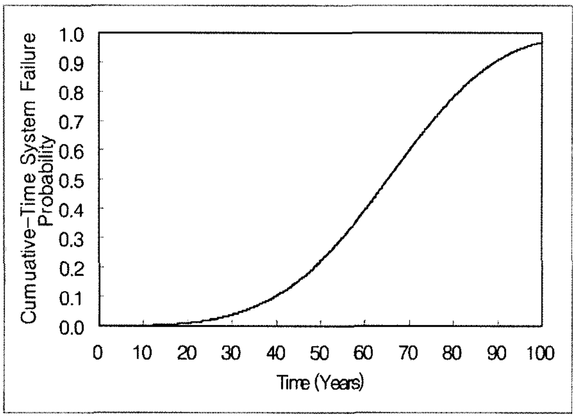

Fig. 7. Failure Probability of System III

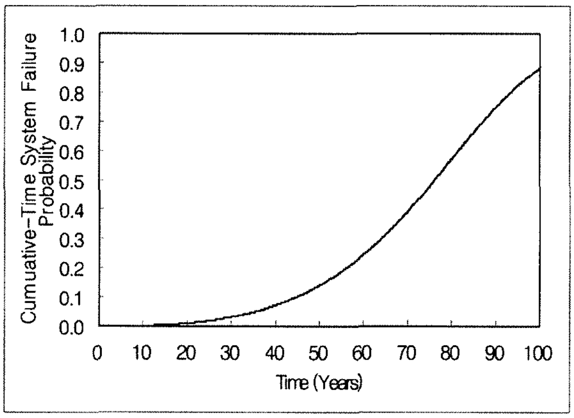

Fig. 8. Failure Probability of System IV

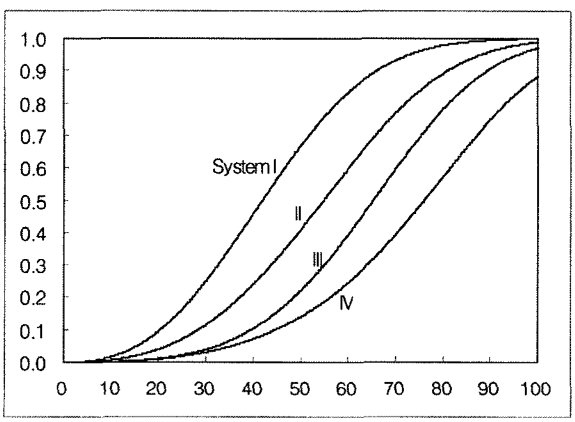

Fig. 9. Failure Probability of All Systems

5. Conclusion

The main purpose of this paper was to predict the time-dependent component and system failure probability. Lifetime functions and system reliability models were used. Finally, the rail road bridge was used to predict the time-dependent system failure.

(1) Using structure function and reliability function, the system can be expressed as a combination of series-parallel components.
(2) The program "LIFETIME" can be applied to any structural system which can be expressed as a combination of series-parallel components, to predict the system failure probability. The program "LIFETIME" can be applied to a bridge network.
(3) Because the program "LIFETIME" gives the time dependent system failure probability, the result can be used for making the plan of the repair or maintenance with a target system failure probability.

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