사회기반시설(부식된 강구조물)의 안전도 평가에 관한 연구
Safety Assessment of Corrosion-damaged Steel Structure

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요약

일반적으로 부식된 부재의 두께를 측정하는 데는 많은 불확실성이 존재하며, 부식의 진행정도에 따라 부재의 부식 두께는 측정 위치마다 다르므로, 기존의 신뢰성 해석 방법을 사용하여 모든 불확실성을 고려한 정량적인 안전도를 평가하는 것은 실질적으로 불가능하다. 따라서 본 논문에서는 불확실 신뢰도 기법을 적용한 안전도 분석 절차를 제안하였으며, 효율성과 적용성을 검토하기 위하여 국내 공용중인 사장교에 적용하였다. 심하게 부식된 부재의 잔존 두께의 불확실성은 부식이 진행되는 정도에 따라 증가하므로 부재의 부식 두께를 불확실 정도로 표현되는 불확실 구간으로 표현하였으며, 기존의 신뢰성 기법과 불확실 신뢰도 기법의 비교를 수행하였다. 이러한 불확실 신뢰도 기법은 주관적이거나 조건부 독립에 대한 통계적 판단을 이용하여, 부식된 구조물의 안전도 평가나 위험도 평가를 하는 경우에 유용하여 적용할 수 있을 것으로 판단된다.

Key words : Safety Assessment, Reliability, Corrosion Damage

1. Introduction

There is a high degree of uncertainty in measurements of the loss of thickness of corroded elements. Unfortunately, current inspection techniques for thickness or crack length measurement are far from perfection, and the spatial variability of corrosion makes the measurement even more difficult. The objective of this paper is to propose a procedure of safety assessment using imprecise reliability for corrosion-damaged structures. The suggested procedure could be effectively used to handle and analyze the uncertainties explicitly in quantitative terms for the safety assessment. The proposed safety assessment procedure is also applied to a cable-stayed bridge to demonstrate its effectiveness and applicability.

2. Imprecise Reliability Theory

In this paper, imprecise reliability theory well described in (Kozine et. al, 2000) are used for safety assessment procedure to handle and analyze the uncertainties. Unkile conventional reliability theory, the lower and upper probabilities, $\underline{P}(A)$ and $\overline{P}(A)$, of the unions an intersections (depending on the lower and upper probabilities of X and Y) can be obtained without the judgement of conditional dependence or independence(Kozine et. al, 2000). Important thing in this point, conditional dependence can be ignored. Thus, since precise probabilities cannot be obtatined for adequate and credible models of the real structures, imprecise reliability could be effectively used in many reliability applications. A general procedure for imprecise reliability is the following:

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1) eliciting any probability judgements that express the desirability of specific gambles.
2) checking that these judgements avoid sure loss.
3) then constructing coherent lower probabilities.

3. Corrosion-Damaged Structures

Generally the thickness of corroded elements varies from one location of the element to another depending on the degree of corrosion (Sarveswaran, 1998). Thus, in this paper, Saveswaren model (1996) for corroded thickness and varying thickness loss is used to generate an imprecise probability of failure. These models are described in detail in (Sarveswaran, 1998). The equation of corroded thickness is modeled as follow:

$$\overline{T}_C = [\overline{T}_{ca}, \overline{T}_{cb}] \tag{1}$$

where $\overline{T}_C$ is corroded element; $\overline{T}_{ca}$ and $\overline{T}_{cb}$ are the lower and upper bounds of the corroded thickness.

A corrosion decay model (varying thickness loss model) has also been developed by Sarveswaran (1996) using percentage thickness loss of elements.

$$\overline{T}_C = \overline{T}_N - c\xi\overline{T}_N \tag{2}$$

where $\overline{T}_N$ is the as-new thickness of the element; c is a constant (0.7~1.3); $\xi = \%LT/100$, and %LT is the average percentage loss of thickness. In this paper, it has been emphasized that a practical approach is to estimate the value of ξ on some basis.

4. Procedure of Safety Assessment Using Imprecise Reliability

Safety assessment using imprecise reliability can be performed by the following procedure as shown in Fig. 1.

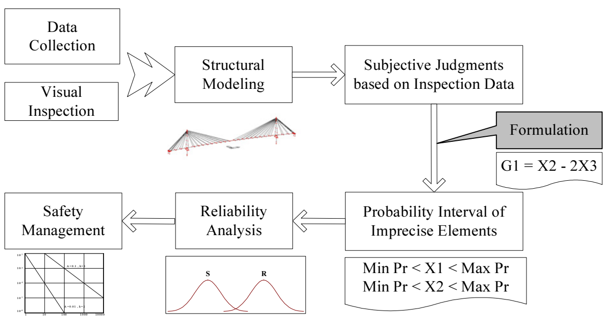


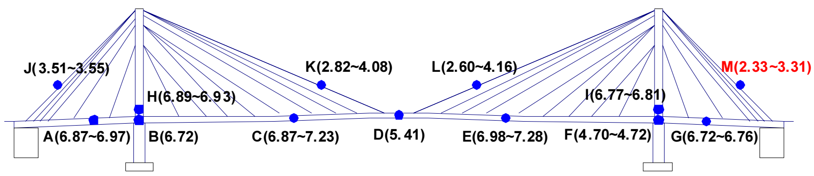
Fig. 1. Procedure of Safety Assessment Using Imprecise Reliability

As shown in Fig. 1, the first step is to collect the data such as the general description of the selected structure, the state of the deterioration, and the previous inspection data, etc. Structural modeling is performed at the second step. Next, if imprecision which has upper and lower probabilities such as corroded thickness are determined, subjective judgments based on the inspection data is made. That is, expert's estimation with simple visual inspection based on the previous data of nondestructive test or visual inspection at near point can be used. Then, reliability analysis is carried out using probability interval of imprecisions by simply converting the qualitative expert's estimation to quantitative terms in this proposed procedure. At this step, the numerical values of random variables and the limit state functions should also be investigated for structural analysis. Finally, it is determined whether safety maintenance action is needed or not depending on the results of reliability analysis and the risk acceptance criteria described later in this paper.

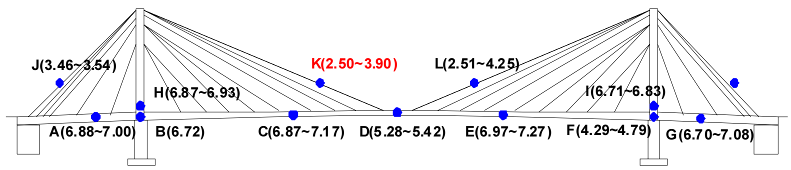
As described earlier, the procedure of safety assessment is proposed when the data for safety analysis are insufficient or when a decision for safety management is urgently required in hazardous environments such as typhoon or where data collection for deterioration is very difficult. The resulting interval reliability index will be helpful to decide safety management options such as urgent repair of critical point or to decide whether more exact and precise safety analysis including NDT inspection is needed or not, if available.

5. Application

In this study, the safety assessment of cable-stayed bridge using imprecise reliability is performed based on the corrosion-damaged varying thickness model. The results of safety assessment for the applied bridge based on the subjective judgment and the probability intervals described previously are presented in Table 1 and Fig. 2. As shown in Table 1 and Fig. 2, it can be expected that the back-stay cable at M point shows the lowest reliability bounds (e = 2.33~3.31). Based on these observations, it may be stated that the cable at M point governs the element reliability in this application. Moreover, the critical point using the partial ETA model at the Level 2 is point K after cable M is virtually collapsed.



(a) Element Reliability Index (Level 1)



(b) Reliability Index (Level 2: Cable Fracture at M)

Fig. 2. Results of System Reliability Analysis with Corrosion

The results of the failure probability based on the system reliability assessment for the cable-stayed bridge are summarized in Table 2. It can be clearly observed that the difference exists between the results of system reliability with no corrosion (7.99E-8) and with corrosion (6.27E-5 ~ 2.18E-8). These results indicate that the imprecise reliability may be used as an alternative rational method in case where the precise information such as corrosion are not available because of the limited data or inevitable situation, etc. In fact, the level of uncertainty about the structural performance increases due to inherent uncertainty of the deterioration process. Therefore, in many of practical situations, we can hardly expect precise reliability assessments of a specific structure because it is difficult to obtain precise data. As described in imprecise reliability example, the resulting range of imprecise reliability assessment is relatively wide.

Table 1. Element Reliability Indices of No Corrosion and Corrosion damage

Point	No corrosion		Corrosion Damage (Imprecise Reliability)			
	Level 1	Level 2	Level 1		Level 2	
			Lower	Upper	Lower	Upper
A	6.97	6.88	6.87	6.97	6.88	7.00
B	6.72	6.72	6.72	6.72	6.72	6.72
⋮	⋮	⋮	⋮	⋮	⋮	⋮
K	4.22	4.10	2.82	4.08	2.50	3.90
L	4.40	4.56	2.60	4.16	2.51	4.25
M	3.42	-	2.33	3.31	-	-

Table 2. Summarized Results of No Corrosion and Corrosion damage

	No Corrosion	Corrosion Damage (Imprecise Reliability)
System failure probability	7.99E-8	6.27E-5 ~ 2.18E-8
System reliability index	5.24	3.84~5.48

6. Conclusion

This study is to propose a methodology and a procedure of safety assessment using imprecise reliability for corrosion-damaged structures. The suggested procedure could be effectively used when the data for safety analysis are insufficient or when a decision for safety management is urgently required in hazardous environments such as typhoon or where data collection for deterioration is very difficult. The proposed safety assessment procedure is also applied to a cable-stayed bridge in Korea to demonstrate its effectiveness and applicability. Based on the results from the application of the imprecise reliability of corroded elements to the safety assessment of a cable-stayed bridge, the main observations and findings of this study can be summarized as follows:

1) Since it is almost impossible to exactly estimate the remaining thickness in the field investigation within a limited time, in the case of the greater degree of uncertainty such as corrosion, imprecise interval reliability can be practically applied while maintaining the appropriate safety.
2) The system reliability-based safety assessment may then be performed approximately but rationally by simply converting the qualitative expert's estimation to quantitative terms in this proposed procedure.
3) As described in imprecise reliability example, the resulting range of imprecise reliability assessment is relatively wide. However, it is observed that the interval of conventional reliability is included in interval of imprecise reliability. That is, although the interval of imprecise reliability is relatively wide, it may be stated that the results of imprecise reliability analysis is rational and reasonable.

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