# New Safety Assessment Model for Civil Engineering Structure

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## Abstract

*To find an effective model for safety assessment of civil engineering structures under the uncertainty and data lack, the unascertained set was introduced to measure the reliability and a safety assessment model with credible identification principle was set up. Then, engineering practice for the reliability assessment of a cable-stayed bridge showed that the model proposed here can complete the safety assessment systematically and scientifically without any assumption. The work has significance in theory and practice for structural safety assessment.*

## 1. Introduction

Safety assessment of civil engineering structure is more and more important in our society. How to measure the safety is an urgent question. Among the different measures [1-2], the Fuzzy Set is a popular method. Yet, it has following shortcomings: (1) the membership function of the Fuzzy Set is a function of a single variable and it cannot clearly point out the measurable space in its definition. (2) the calculation principles of Fuzzy Set are correct in sigma-algebra space, yet error in the different natures. To avoid these shortcomings, a new measure, the unascertained measure based on the unascertained mathematic was proposed and then it was introduced into the safety assessment of civil structure, which is an important work of civil engineering. Application results showed that it can complete the safety assessment systematically and scientifically without any assumption. It provides an effective method for safety assessment.

The paper is organized as follows. In the introductory part, attention was paid to the basic concepts of the unascertained set. In the following part, a reliability assessment model for civil structure assessment based on the unascertained measure was set up. Then, its application in practice was introduced. Finally, compared with the Fuzzy Sets, the advantages of the method we proposed were pointed out.

## 2. Brief introduction to unascertained set

The unascertained set, which is a new tool to quantitatively describe the subjective uncertainty, was proposed by G. WANG and K. LIU in 1990[3]. It mainly deals with the unascertained information. The unascertained information differs from the stochastic information, fuzzy information and grey information. It refers to the decision-making-demanded information that the message itself has no uncertainty but because of situation constrain, the decision-maker can not grasp the whole massage of them. Uncertainty was produced by the decision-maker itself. Since 1990s, it has been systemically and successfully used in many fields [4].

Difference between the Unascertained Set and Fuzzy Set:

On the space, the membership function of the Fuzzy Set is a function of a single variable, while the membership function of the Unascertained Set is function of two-variables.

On the definition, the Unascertained Set introduces the measure principles into its definition, it clearly points out the nature space and measurable space in its definition.

## 3. Safety assessment model proposed here

With the development of civil engineering technology, more and more large structures appear. But the catastrophic disasters related to these structures have caused enormous properties loss and environment pollution. The situation has signified the need for safety assessment of the civil engineering structures.

Up to date, most safety assessments have dealt with the maintenance, repair and retirement of the structures, few researches have been done on the reliability of the structure itself [5]. The methods employed, such as fuzzy sets, have many

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disadvantages. How to solve the problem of uncertainty and data lack and find out a new method for safety assessment of structures are urgent tasks in offshore engineering.

According to this, the unascertained mathematics is introduced to solve the unascertained problem of the assessment. The unascertained measure is proposed and the credible identification is set up for the safety assessment. We take the safety assessment of cable-stayed bridge as an example.

## 3.1. System of assessment indexes

The set up of the assessment index system should use the system engineering theory and method and be closely associated with the engineering practice. For the safety assessment of cable-stayed bridge, the state of the cable, girder, main Pylon, auxiliary Pylon, frusta, base and backstays constitute the main assessment indexes.

## 3.2 Model based on unascertained measure

Let $x_1, x_2, \cdots, x_n$ be the $n$ structures , $I_1, I_2, \cdots, I_n$ be the indexes for the assessment of $x_i$, $x_{ij}$ be the observed value of $x_i$ based on index $I_j$, $c_k$ be the $k^{th}$ comment ($1 \le k \le K$).

### 3.2.1. Single-index unascertained measure

Let $u_{ijk}$ be the degree of the subject $x_i$ belonged to the assessment rank $c_k$ under the index of $I_j$. $u_{ijk}$ is also called the measure result for the "degree". It must satisfy the "three principles for a measure" which means nonnegative and limited principle, additive principle and convergent principle.

The Delphi method is employed to get the scores of every factor. The number of the specialists is $k$. Every specialist should rank the degree that the index $I_j$ ($1 \leqslant j \leqslant m$) belongs to the rank $c_k$ ($1 \leqslant k \leqslant K$) using 0-10. If the $k^{\text{th}}$ specialist ranks the degree that the index $I_j$ of the object $x_i$ belongs to rank $c_k$ is $x_{ijk}$, then $u_{ijk} = x_{ijk}/10$ is the unascertained measure that the observed value $x_{ijk}$ makes $x_i$ located in rank $c_k$.

The single-index measure assessment matrix of $x_i$ is:

$$(u_{ijk})_{m\times k}=\begin{bmatrix} \mu_{i11}, & \mu_{i12}, & \cdots, & \mu_{i1k} \\ \mu_{i21}, & \mu_{i22}, & \cdots, & \mu_{i2k} \\ \vdots & \vdots & \vdots & \vdots \\ \mu_{im1}, & \mu_{im2}, & \cdots, & \mu_{imk} \end{bmatrix} \quad (i=1,2,\cdots,n) \tag{1}$$

### 3.2.2 Weight of every index

The weight of index refers to the influence degree of every factor to the classification of the plan. It is important to determine the weight of index. The common methods used to get the weight are Delphi method, Brainstorming, Analytic Hierarchy Process (AHP) and so on. In the paper, the unascertained measure matrix has been derived, the degree that every index belongs to the rank has been determined and the importance degree of every index to the plan classification has been given too. The information entropy can be used to give the weight of every factor.

### 3.2.3 Comprehensive assessment system

After the single index matrix and the weight are derived, we can definite the comprehensive assessment vector.

Let

$$\mu^i = \omega^i \cdot \left(\mu_{ijk}\right)_{m\times K} = \left(\omega_1^i, \omega_2^i, \ldots \omega_m^i\right)\begin{bmatrix} \mu_{i11}, & \mu_{i12}, & \cdots, & \mu_{i1k} \\ \mu_{i21}, & \mu_{i22}, & \cdots, & \mu_{i2k} \\ \vdots & \vdots & \vdots & \vdots \\ \mu_{im1}, & \mu_{im2}, & \cdots, & \mu_{imk} \end{bmatrix} \tag{2}$$

$u^i = (u_{i1}, u_{i2}, \cdots, u_{ik})$ describes the unascertained classification, in order to obtain the certainty classification, the identification is needed.

### 3.2.4 Principle of identification

Because the classification of the comment ranks is orderly, e.g. $c_k$ is "better" than $c_{k+1}$, the identification principle of "maximum measure" is not available. The credible identification principle is needed. Let the credible identification be $\lambda$, where $0.5<\lambda<1$, it is always 0.6 or 0.7.

If

$$k_0 = \min\left[\left(\sum_{l=0}^{k}\mu_{jl}\right) \ge \lambda, k = 0,1,\cdots,K-1\right] \tag{3}$$

then $x_i$ belongs to the rank $c_{k0}$.

# 4. Engineering practice

Using the method above, we finished the safety assessment of a cable-stayed bridge located in a city.

The scores of every factor given by the specialists are list in table 1.

Table 1 Scores of the factors given by the specialists

| ranks<br>factors | best | better | nor-<br>mal | worse | worst |
|---|---|---|---|---|---|
| cable state | 0.2 | 0.2 | 0.3 | 0.2 | 0.1 |
| girder state | 0.2 | 0.2 | 0.3 | 0.2 | 0.1 |
| main pylon state | 0.3 | 0.1 | 0.1 | 0.2 | 0.3 |
| auxiliary pylon state | 0.1 | 0.2 | 0.3 | 0.2 | 0.2 |
| frusta state | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| base state | 0.1 | 0.2 | 0.3 | 0.2 | 0.2 |
| backstays state | 0.2 | 0.2 | 0.3 | 0.1 | 0.2 |

The single-index unascertained measure $(u_{ijk})_{m\times k}$ can be obtained:

$$(\mu_{ijk})_{m\times k}=\begin{bmatrix} 0.2 & 0.2 & 0.3 & 0.2 & 0.1 \\ 0.2 & 0.2 & 0.3 & 0.2 & 0.1 \\ 0.3 & 0.1 & 0.1 & 0.2 & 0.3 \\ 0.1 & 0.2 & 0.3 & 0.2 & 0.2 \\ 0.2 & 0.2 & 0.2 & 0.2 & 0.2 \\ 0.1 & 0.2 & 0.3 & 0.2 & 0.2 \\ 0.2 & 0.2 & 0.3 & 0.1 & 0.2 \end{bmatrix}$$

The weight can be derived:

$w^i_j$ =(0.1，0.1，0.15，0.2，0.15，0.2，0.1)

The assessment result can be obtained by using format (2):

$u^i$ =(0.18，0.22，0.20，0.20，0.20)

Let $\lambda$=0.6, according to format (3), the final assessment results can be obtain: the bridge belongs to the third rank, which means “normal”.

Using the fuzzy comprehensive assessment [6], the bridge belongs to the second rank, which means “better”. All the specialists agree that the former is more rational. The practice also demonstrated its validity. The reasons are that the unascertained measure pays attention to the order of the assessment space and gives the rational rank and credible identification principles. All of those are not possessed by fuzzy comprehensive assessment.

## 5. Conclusion

The safety assessment is an important work in civil engineering. How to measure the safety effectively is a question for the scholars and engineers. In the paper, a model based on unascertained set was proposed. Then it was introduced into the fields of civil engineering safety assessment. The safety assessment of a cable-stayed bridge showed that the method proposed here had following characteristics:

(1) Using the qualitative and quantitative analysis, it overcomes the shortcomings of subjective and perceptual assessment.

(2) Employing the information entropy and credible identification principle, it overcomes the disadvantage of fuzzy comprehensive assessment and makes the result more objective.

(3) It is easy to realize the scientific and rational decision-making. It finishes the safety assessment in programmable methods. It is easy to realize the assessment without any assumption.

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