

# Study on Damage Inference for Superstatic Trusses

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**Abstract.** Based on the damaged statically indeterminate truss, this study uses the Bayesian and Opensees methods to study and deduce the damage of damaged members. Multiple schemes are used for inference in order to compare multiple loading schemes to obtain the best loading scheme. By changing the error comparison, it can be found that the smaller the error, the more concentrated the posterior distribution, and the closer to the result. By changing the comparison of measuring points, it can be found that the closer the measuring points are to the damaged bar, the more concentrated the posterior distribution is, and the better the effect is. In combination with the prior distribution, increasing the number of cycles has little effect on the results. Through these comparisons, this study mainly finds out the key factors to infer structural damage in practical engineering, so that the damage inference of statically indeterminate truss can better serve the practical engineering.

**Keywords:** Damage inference, Hyperstatic truss, Bayesian.

## 1. Introduction

With the rapid development of the economy, more and more buildings have been built. In the process of using the building structure, due to the influence of the environment and load, it will cause the aging of the internal structure, which will bring about the potential safety hazards [1]. Therefore, the study of structural damage identification is of great significance. Severe overloading or working with damage may eventually cause serious damage to the whole structural engineering, resulting in serious economic losses and casualties. For example, on July 23, 2023, a roof collapse accident occurred in the gymnasium of a middle school in Qiqihar, China. It was investigated that the roof grid structure of the school gymnasium collapsed as a whole, and the perlite soaked with water and increased in weight under the influence of rainfall, which led to an increase in the roof load and triggered the collapse [2]. In order to study the safety of structures, it is necessary to study the damage identification techniques and methods, so that the damage can be detected in a timely manner and the location and extent of the damage, so that the structure can be repaired or strengthened in real time. In the actual engineering environment to identify the structure is divided into four stages, damage judgment (to determine whether the structure damage), damage localization (to determine the location of structural damage), damage quantification (to determine the degree of damage), damage prognosis (to determine the remaining life of the structure) [3]. In addition, by combining the current damage identification and detection methods, a structural health monitoring system is established to accurately monitor the structural condition in real time. It is of great significance to promote the practical development of structural damage identification methods by making fast and accurate diagnosis when structural damage occurs.

Structural damage identification is divided into two categories: deterministic methods and uncertainty methods. Structural damage identification deterministic method refers to the damage characteristics of the parameter as a deterministic quantity to establish a mapping relationship with the real damage, and through the reasoning and analysis of the calculation to achieve the purpose of structural damage identification. They include the following methods: (1) identification methods based on dynamic fingerprints; (2) identification methods based on model modification; (3) identification methods based on measured time-domain signals; (4) identification methods based on neural networks [4]. Using structural damage deterministic method, most of them are in a more ideal state, but due to the uncertainty of the theoretical model and the uncertainty of the measured data, the structural damage deterministic method has greater limitations. Therefore, the structural damage

uncertainty identification method has been gradually developed, which is mainly divided into three methods: (1) based on Bayesian model correction damage identification method (2) based on stochastic finite element model correction damage identification method (3) based on statistical model damage identification [3]. Among the basic principles of Bayesian methods Bayesian methods are based on Bayes' theorem, whose central idea is to make inferences by updating probability distributions. Based on the Bayesian model correction damage identification method will be considered as a random variable structural parameters, the use of measured data and Bayesian principle to modify the parameter a priori probability distribution, to obtain the parameter a posteriori probability distribution, by comparing the parameter a posteriori probability distribution before and after the damage, the probability of structural parameter changes in the statistical significance of the structural parameters are given to determine the location of the structural damage and the extent of the damage [3]. That is, with the accumulation of observation data, the information of the main body will be constantly updated [5]. Specifically, the Bayesian method utilizes the existing prior knowledge and new observation data to calculate the posterior probability, so as to infer and predict the unknown parameters or hypotheses. Currently, Bayesian theory has become one of the main analytical approaches in the field of statistics [6].

Hyperstatic truss has redundant supports, is characterized by light weight, high capacity to withstand pressure and bending moments, and has good deformation resistance and adjustability [7]. This makes it has a wide range of applications in many engineering fields. In this paper, a super-static truss is taken as an example, and the Bayesian updating method combined with a priori distribution is applied to measure the damage of the truss. The displacements of the points are observed by applying loads, and then the structural damage is recognized by Bayesian updating, and the efficiency of the load test is improved by the Bayesian recognition.

## 2. Methodology

### 2.1. Superstatic Truss Structure

The statically indeterminate truss structure is selected as the research object in this study, as shown in Fig. 1. Table 1 shows the stiffness data of the superstatic truss and the stiffness of the damaged rod. There is one structural damage caused by stiffness reduction on 4-11 (the member between Node 4 and Node 11) and 10-11 (the member between Node 10 and Node 11). What this research does is to use Bayesian update method and Opensees language to make damage inference.

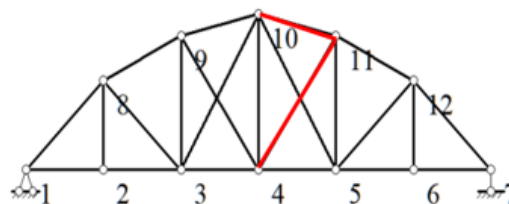


Figure 1. Statically indeterminate truss structure

Table 1. Stiffness of rods of superstatic truss structure

Rods (nodes)	EA ( $10^5 \text{ N}\cdot\text{m}^2$ )	Rods (nodes)	EA ( $10^5 \text{ N}\cdot\text{m}^2$ )	Rods (nodes)	EA ( $10^5 \text{ N}\cdot\text{m}^2$ )
1-2	1.4	1-8	1.54	2-8	1.26
2-3	1.4	8-9	1.428	3-8	1.19
3-4	1.4	9-10	1.428	3-9	1.19
4-5	1.4	11-12	1.428	4-9	1.19
5-6	1.4	3-10	1.134	4-10	1.33
6-7	1.4	12-7	1.54	5-11	1.19
5-12	1.19	6-12	1.26	5-10	1.134

## 2.2. Bayesian Update Modeling Approach

The Bayesian approach is based on Bayes' Fundamental Theorem, and its core idea is to make inferences by updating probability distributions. The Bayesian formula is as follows.

$$P(H|E) = P(E|H) * P(H)/P(E) \quad (1)$$

Where  $P(H)$  is the prior probability of hypothesis  $H$ ,  $P(E|H)$  is the probability of the occurrence of evidence  $E$  under hypothesis  $H$ ,  $P(H|E)$  is the posterior probability of  $H$  after the occurrence of evidence  $E$ , and  $P(E)$  is the marginal probability of evidence  $E$ .

The advantage of Bayesian model is that when estimating parameters, the posterior distribution combines the knowledge of prior and samples, and can make more reasonable estimates of parameters than the prior distribution. Its parameter estimates are all based on the posterior distribution. This method is particularly effective for studying situations where there is more information besides the observation data.

Although the Bayesian method is very different from the classical statistical method, under the condition of large samples, the parameters estimated by these two methods are consistent [8]. In the case of small samples, Bayesian methods can make full use of all kinds of information, and the results are more reliable. The Bayesian method is characterized by the ability to make full use of the available information, such as the overall information, empirical information and sample information, etc., and the statistical inference is based on the posterior distribution. In contrast to the traditional frequency school of thought (such as the great likelihood estimation method) [9] has many limitations, the data is too small (only 1 or a few), cannot explain anything, or because of 1 test produced a failure, failure probability of 100%, which is obviously not rigorous enough, while the use of Bayesian methods can be combined with the a priori distribution of the results of the test to update the introduction of the final result, can be Derive more deterministic parameter posterior distribution [8]. Can also be based on subjective experience or historical data to give the unknown parameter or model of the prior distribution, and based on the experimental data to update the prior distribution, to get the unknown parameter or model of the posterior distribution, for statistical inference [10].

## 2.3. Inferring Structural Damage in Hyperstatic Trusses Based on Bayesian Updating Theorem

In this study, by predicting the damage of two rods, measuring the displacement of relevant points under load, and updating them with Opensees language, the updated posterior distribution can be got, and then analyze the posterior distribution to get the damage of two rods. Four loading schemes are adopted in this study, as shown in Table 2. The best loading scheme can be obtained by comparing the loading schemes.

**Table 2.** Load scheme table

Program serial number	The loading point	Applied loads	Measuring points	Relative error
Option 1	9	100N	4, 5, 10, 11	5%
Option 2	9	100N	4, 5, 10, 11	2%
Option 3	9	100N	2, 3, 8, 9	2%
Option 4	11	100N	4, 5, 10, 11	2%

## 3. Results and Discussion

First, Scheme 1 applies a force of 100 N at 9 points, measures the lateral displacement of 4, 5, 10 and 11 points, sets the relative error as 5%, and the measured posterior distribution is shown in Figure 2 below.

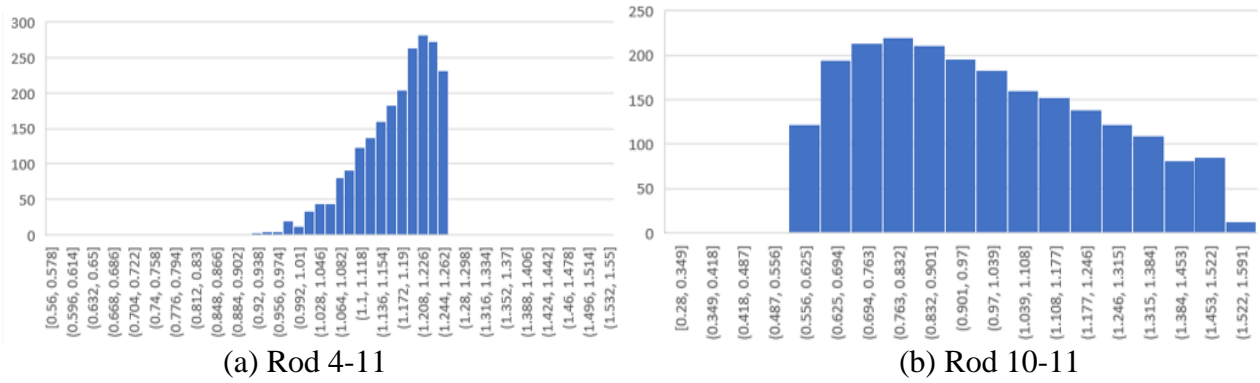


Figure 2. Scheme 1 posterior distribution

As can be seen from Fig. 2, the standard deviation of rods 4-11 and 10-11 are 0.065 and 0.255 respectively, the standard deviation of the two rods is relatively large, the results are very scattered, and the mean of the results of the two rods is also very different from the results, so this scheme should be further improved. Subsequently, all the conditions remain unchanged and only the error is changed to 2%, which is option 2, and the posterior distribution is obtained, as shown in Fig. 3.

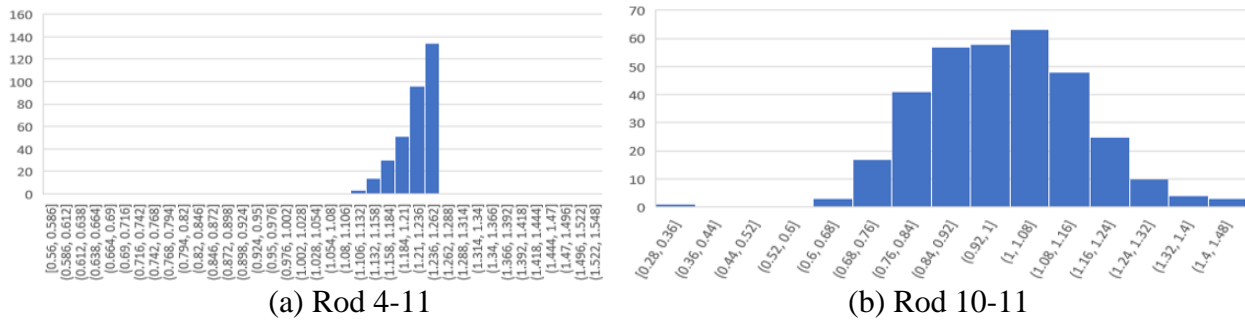


Figure 3. Scheme 2 posterior distribution

As can be seen from Fig. 3, the standard deviation of bars 4-11 and bars 10-11 are 0.03 and 0.15 respectively, and it can be found that the smaller the error is, the more centralized the posterior distribution is, and the closer the results are by changing the comparison of the errors.

Subsequently, in this study, all the conditions remain unchanged, and only the measurement points are changed, changing the measurement points to 2, 3, 8, and 9, which is option 3, and the posterior distribution is shown in Fig. 4.

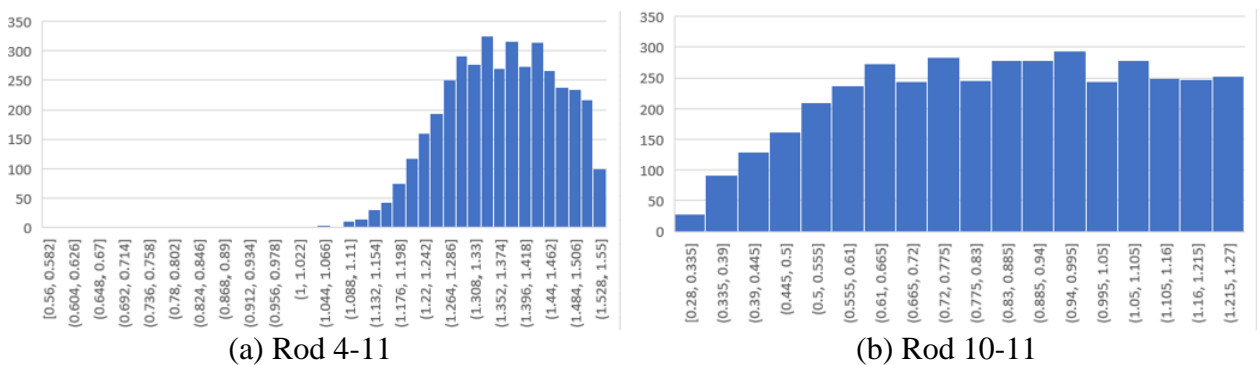


Figure 4. Scheme 3 posterior distribution

As can be seen from Fig. 4, the standard deviations of rods 4-11 and 10-11 are 0.09 and 0.24, respectively. it can be found that the closer the measurement points are to the damaged rods, the more concentrated the posterior distribution is, and the better the effect is by changing the comparison of measurement points.

Then this study changed the load application point, and finally found the best load application point, which was 11 points. 100N load were applied to 11 points, and measured the vertical

displacement of 4, 5, 10, and 11 points. The relative error was changed to 2%. The posterior distribution is shown in Figure 5 below.

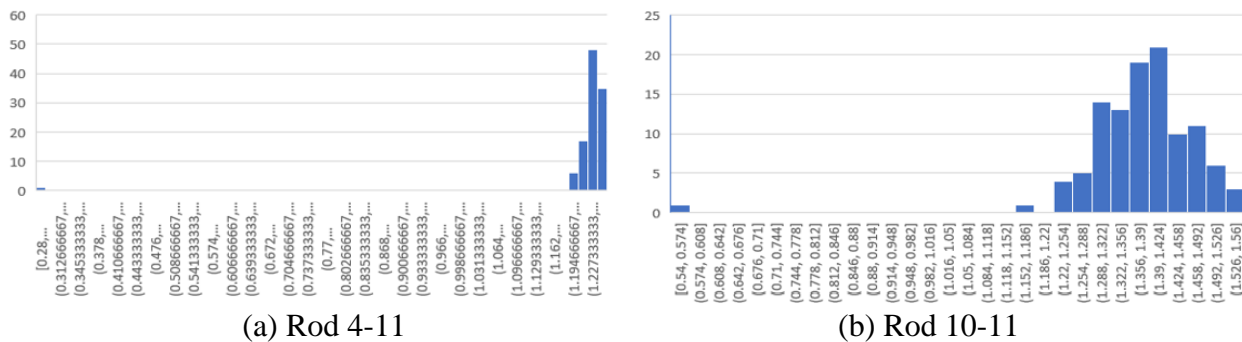


Figure 5. Scheme 4 posterior distribution

It can be seen from Fig. 5 that the standard deviation is 0.01 and 0.07 respectively. Because the loading effect at this point is the best, this study updated this loading scheme, measured the true displacement of these four points under the predicted damage condition, and combined with Openses to update, obtained the final damage results, measured the damage of two rods were 1.10041 and 0.669723, which is consistent with the actual damage, within reasonable error.

A priori distributions are initial assumptions or a priori knowledge about the damage state of a structure. The choice of different a priori distributions can have an impact on the results because the a priori distribution affects the shape and location of the posterior distribution. If an unreasonable or inaccurate prior distribution is chosen, it may lead to a biased estimate of the damage state of the structure. For example, if a prior distribution is chosen that favors the belief that there is no damage to the structure, the posterior distribution may be dominated by the prior distribution even if the observed data indicate the presence of damage, resulting in an inaccurate estimate of the damage state of the structure.

#### 4. Conclusion

This paper takes the statically indeterminate truss with two damaged members as the background, compiles the model of the secondary truss with the help of openses, and then deduces the damage of the secondary truss through the Bayesian update method. The main conclusions are as follows:

(1) Comparison of the results of the program can be seen: the lower the error, the more concentrated the a posteriori distribution of the damage of the measured rod, the closer to the actual damage. The closer the measurement points are to the damaged rods, the more concentrated the posterior distribution is, and the better the results are. The higher the number of cycles, the Bayesian updating process will more fully utilize the new observation data to correct the a priori information, so that the probability distribution gradually converges to a more accurate posterior distribution. Therefore, a higher number of cycles can improve the accuracy and reliability of the detection results.

(2) In this study, there are still some places that are not considered in the study. For example, when controlling the error variables, the relative error is unified, and the absolute error is not taken into account. Secondly, this study mainly simulates the damage and constraints of the truss on the computer by writing code. However, there are many factors to be considered in the actual engineering environment, such as weather conditions, and the actual construction process will produce certain errors in the measurement. Therefore, the actual engineering environment needs to be considered in many aspects, but the use of Bayesian update method is far more efficient and accurate than the traditional statistical method. Update the prior distribution based on the experimental data, and obtain the posterior distribution of unknown parameters or models, which can reflect the accumulation process of scientific research evidence.

## Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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