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# Damage Identification for Transmission Tower Structure Using Information Fusion Methods

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Structural damage identification can realize pre-warning, identify the location of the damage and improve reliability and safety of the structure. In this paper, at first, the damage identification of a simple steel framework model was presented by the modal curvature method, the modal flexibility method and so on. Then, the influences of the recognition effect and damage degree were analyzed. At last, the modal curvature difference (MCD) method and the modal flexibility curvature difference (MFCD) method, as better recognition methods, were introduced into an actual transmission tower model, and damage identification on main stressed ones of structure were valued under different conditions. The improved adaptive weighted fusion (IAWF) method was proposed. Recognition results of the MCD method and the MFCD method were processed by the IAWF method. Simulation results showed that IAWF method was more precise than any other methods. The information fusion technology is applied to fault monitoring, pre-warning and diagnosis system, which can obtain the estimation of structure under operating state more accurately and improve the confidence degree of diagnosis.

## 1. Introduction

Reliability and safety of critical infrastructures (Zio et al., 2012) have attracted more and more attention from scientists and engineers. The material or geometric properties of the whole high-rise tower structure or some parts of structure will be changed by the coupling of long-term environmental erosion, material aging and long-term effects of loads, which cause stiffness, intensity, and connection conditions to decline. Without timely measures, it will inevitably lead to the accumulation of damage and resistance attenuation, even structural collapse in extreme environments. To ensure structural safety, reliable operation, damage identification for the main stressed ones of structure is necessary.

Currently, damage identification of structure is mainly focused on single dynamic characteristic index, only a small amount of damage identification work is applied to the transmission tower. The mode shape difference (MSD) method and the modal flexibility change rate (MFCR) method have been used on the transmission tower to identify damage (Liu et al., 2012). The modal curvature change rate (MCCR) method had accurate damage identification ability on 500kV transmission tower (Liu et al., 2010). The generalized flexibility matrix change (GFMC) method on simply supported beam has been proposed (Li et al., 2010). The uniform load surface (ULS) method and the ULS curvature method have been proposed and verified by benchmark structures provided by IASC-ASCE Structural Health Monitoring Group (Zhang et al., 2013). The best achievable flexibility change (BAFC) method has been put forward and proved by Yang and Sun (2011). Modal strain energy for damage identification could identify the localization and quantification of plate-type structure (Fan and Qiao, 2011). However for complex structures, some methods will appear misjudgement, bad recognition effect and other failure phenomena. In this paper, damage identification of a simple steel framework model with the modal curvature and modal flexibility corresponding indexes will be presented. The recognition results of the MCD method and the MFCD method for transmission tower structure will be processed by the traditional adaptive weighted fusion (AWF) method and the improved adaptive weighted fusion (IAWF) method, hoping that IAWF would have a better recognition accuracy and anti-noise capability than other methods.

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## 2. Damage identification methods

### 2.1 Modal curvature index

**A. Modal curvature difference (MCD)**

MCD is a structural damage identification index (Pandey et al., 1991), which is given by the expression

$$\Delta_i = C_j^d(i) - C_j^u(i) \quad (1)$$

Where, $C_j^u(i)$ and $C_j^d(i)$ are the curvatures of structures before and after its damage of the $i$-th node of $j$-th order respectively, which can be calculated by the relationship of difference quotient, derivative and difference based on mode shapes, $i = 1 \sim n$, $n$ stands for measurement point number.

**B. Modal curvature change rate (MCCR)**

MCCR is defined on the basis of MCD, and its expression is as follows

$$MCCR = \Delta_i \Big/ \sum_i |\Delta_i| \quad (2)$$

It is noteworthy that modal curvature is directed to the single mode shape of structure, in the selection of mode, a mode to consider. In this paper, the simulation shows that *y* direction displacement and the first mode shape of structures have the better recognition effect, which can be used to identify damage later.

### 2.2 Modal flexibility index

**A. Modal flexibility difference (MFD)**

Modal flexibility matrix was proposed by Pandey and Biswas (1994), which can be expressed as

$$F = \Phi\Omega^{-1}\Phi^T = \sum_{i=1}^{n} \frac{1}{\omega_i^2}\phi_i\phi_i^T \ , \quad (3)$$

In (3), $\Phi=[\phi_1,\phi_2,\cdots,\phi_n]$ is the modal matrix, $\phi_i$ is the mode shape of the $i$-th order, $\Omega = diag(\omega_i^2)$ is the diagonal matrix, $\omega_i$ is the frequency of the $i$-th order. The flexibility change matrix before and after its damage is $\Delta = F^u - F^d$, with the absolute maximum value $\delta_j = \max|\Delta_{ij}|$ of the $j$ column in $\Delta$ for damage identification index, where $F^u$ and $F^d$ are modal flexibility matrix before and after its damage.

**B. Modal flexibility change rate (MFCR)**

MFCR was proposed by Ko et al. (2002), which is defined as diagonal elements of $\Delta$ are normalized by the corresponding diagonal element of $F^u$. And the formula of MFCR is

$$MFCR = (F_{ii}^d - F_{ii}^u) \Big/ F_{ii}^u \quad (4)$$

**C. Modal flexibility curvature difference (MFCD)**

Flexibility curvature is calculated based on the average value of the algebraic sum of each column of flexibility matrix $F^u$ and $F^d$ by finite difference method.

$$\Delta_{MFC} = MFC^u - MFC^d \quad (5)$$

$MFC^u$ and $MFC^d$ are Modal flexibility curvatures before and after its damage respectively.

**D. Modal flexibility curvature change rate (MFCCR)**

MFCCR is defined on the basis of MFCD, and its expression is as follows

$$MFCI = \Delta_{MFC} \Big/ \max|\Delta_{MFC}| \quad (6)$$

It should be emphasized that the low order modes are relatively easy to measure, and high order modes for modal flexibility effects is very small. So the lower modal information could achieve a better accuracy. Therefore, the first ten order modes are selected in the paper.

## 3. Example of simple steel framework model

A nine-story steel frame finite element model was established by ANSYS software, with beam188 unit, which is shown in Figure 1. The steel modulus of elasticity $E = 2.06 \times 10^{11}$ Pa and density $\rho$ = 7850 kg/m$^3$.

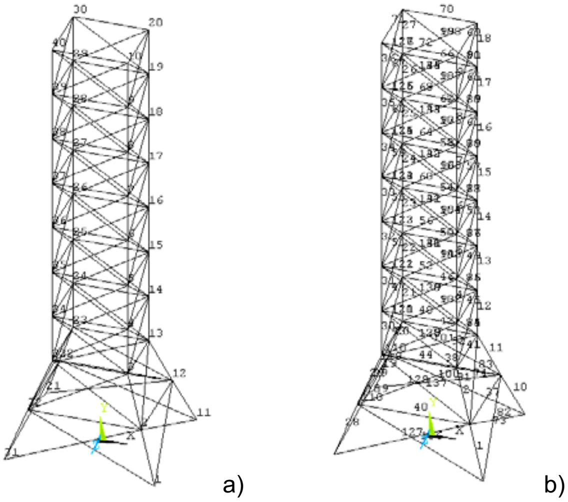


*Figure 1: Steel frame model: a) Node number; b) Element number*

### 3.1 Damage identification

The damage degree was simulated by the reduction of the elastic modulus, assuming that the local damage of the structure occurred, with no change of other factors outside of stiffness. In this paper, E23D50 (N: 25, 26) stands for Element 23 (corresponding nodes are 25, 26) occurred 50% damage (same as below).

For condition E23D50 (N: 25, 26), it can be seen from Figure 2 that the identification results of MCD, MCCR, MFCD and MFCCR are better damage identification methods, compared with MFD and MFCR.

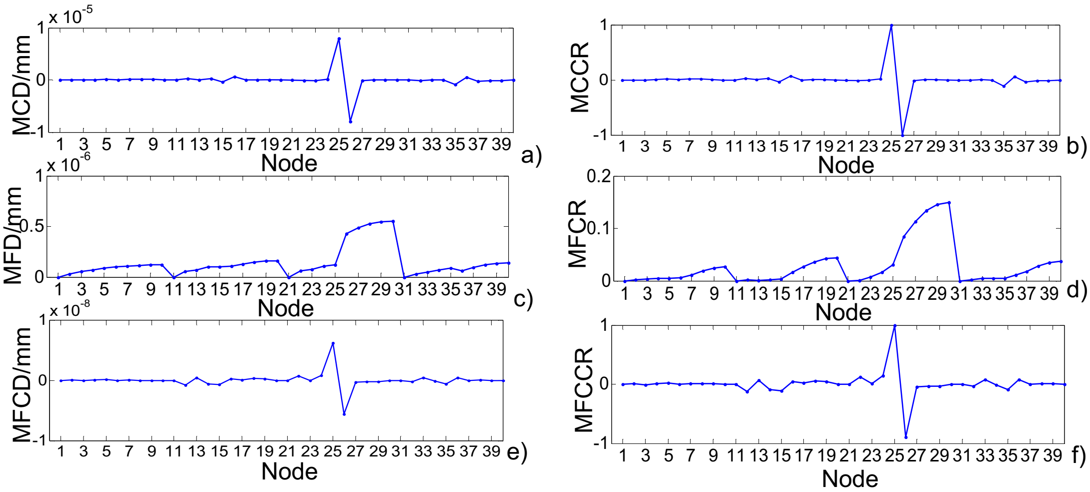


*Figure 2: Identification results of each method: a) MCD; b) MCCR; c) MFD; d) MFCR; e) MFCD; f) MFCCR*

### 3.2 Damage degree identification

Under conditions of E23D5, E23D50 and E23D95, the mutation values of MCD and MFCD in damage location increase with the increasing damage degree, while the values of MCCR and MFCCR remain almost constant, which are shown in Figure 3. It is proved that MCD and MFCD could identify the damage degree, while MCCR and MFCCR could not.

## 4. Information fusion methods

Information fusion technology is produced by combination with many traditional disciplines and emerging engineering fields. A structural damage identification method based on integration of information fusion and Shannon entropy was proposed (Li et al., 2008). Jiang et al. (2011) proposed a novel two-stage structural damage detection approach by fuzzy neural networks and data fusion techniques.

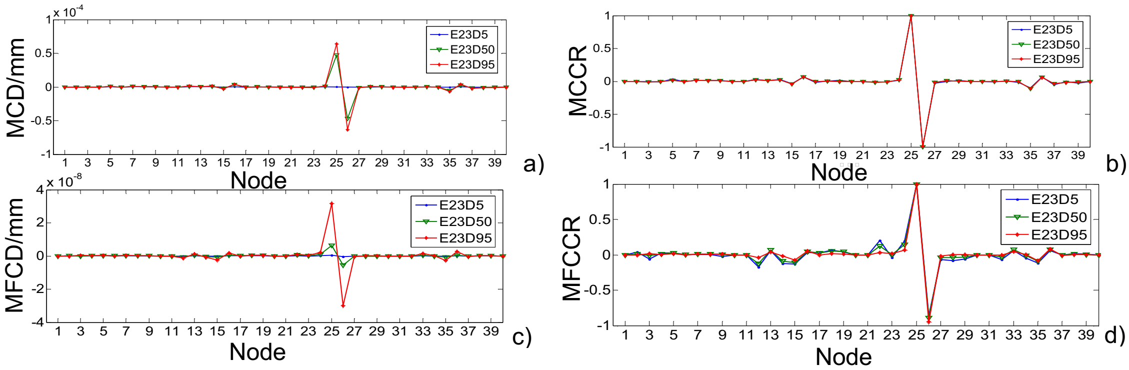


*Figure 3: Identification results of damage degree of each method: a) MCD; b) MCCR; c) MFCD; d) MFCCR*

Due to different characteristic parameters on the sensitivity degree of different modes are not same, so the recognition result of different characteristic parameters can be processed by AWF, which could integrate a variety of characteristic parameter identification sensitivity to improve recognition accuracy.
The identification number of characteristic parameters is $n$, the vector variance of the recognition result of each method is $s_i$, and the weighting coefficient of recognition result of each characteristic parameter is $\omega_i = 1/(s_i \cdot \sum_{i=1}^{n} 1/s_i)$. The AWF algorithm (Liang et al., 2009) is as follows

$$\bar{u} = \sum_{i=1}^{n} \omega_i u_i \tag{7}$$

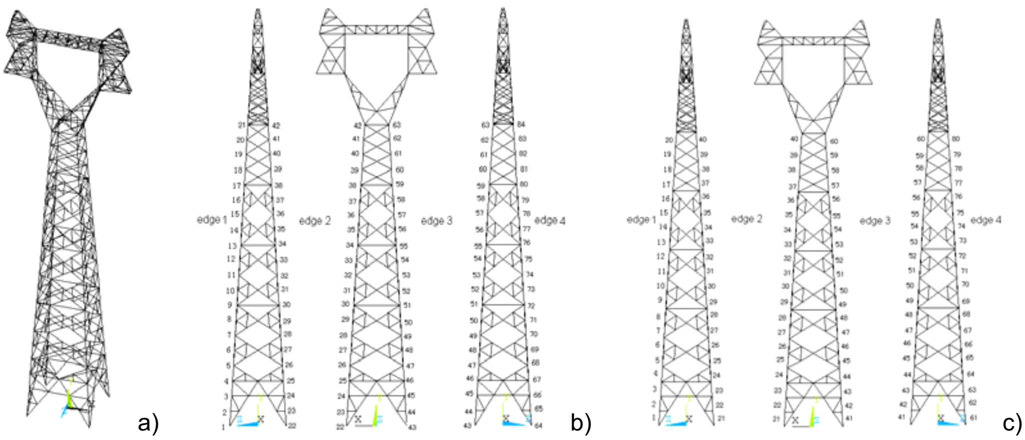


*Figure 4: Oxytropis transmission tower model: a) 3-D model; b) Node number; c) Element number*

In order to improve the precision and accuracy of damage identification, $|u_i|^2$ can be used to raise the values of the damage location and smooth out the values of remaining part in the study of formula (7), making sure that the values of the damage location are more prominent and the values of remaining part become not obvious, the AWF algorithm will be improved, and the IAWF algorithm is as follows.

$$\bar{u} = \sum_{i=1}^{n} \omega_i |u_i|^2 \tag{8}$$

### 4.1 Example of transmission tower

An oxytropis transmission tower model was established by ANSYS software, with beam188 unit, $E = 2.06 \times 10^{11}$ Pa and $\rho = 9\,420 kg / m^3$, as shown in Figure 4.

### 4.2 Damage identification

**A. Single condition: E30D50 (N: 31, 32)**

From Figure 5, identification results of MCD, MFCD, AWF and IAWF occur mutations in the location of nodes 31 and 32, and it is proved that the 30-th element is damaged without noise. From the point of view of the anti-noise capability, allowable noise level of MCD and MFCD are 0.1 and 0.075 respectively, and while the allowable noise level of AWF and IAWF are 0.15.

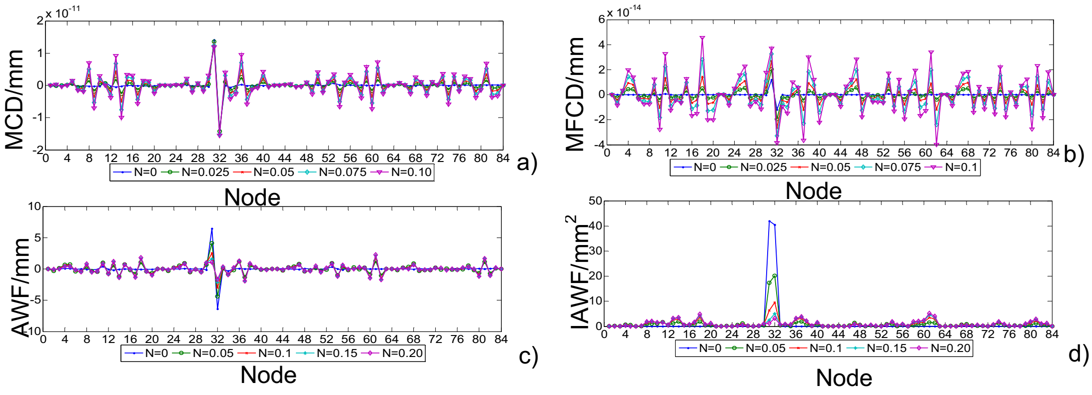


*Figure 5: Identification results of different noise levels under single condition: a) MCD; b) MFCD; c) AWF; d) IAWF*

**B. Composite conditions: E10D50 + E50D50 (N: 10, 11 & 52, 53)**

From Figure 6, MCD, MFCD and IAWF are able to identify damage in the 10-th and 50-th element, while AWF could not identify damage in the 10-th element. Because values of MCD and MFCD in the 10-th and 11-th node have opposite signs to each other, and they will be cancelled out by the fusion process. The allowable noise level of MCD and MFCD is 0.075, and while IAWF is 0.1, as shown in Figure 7.

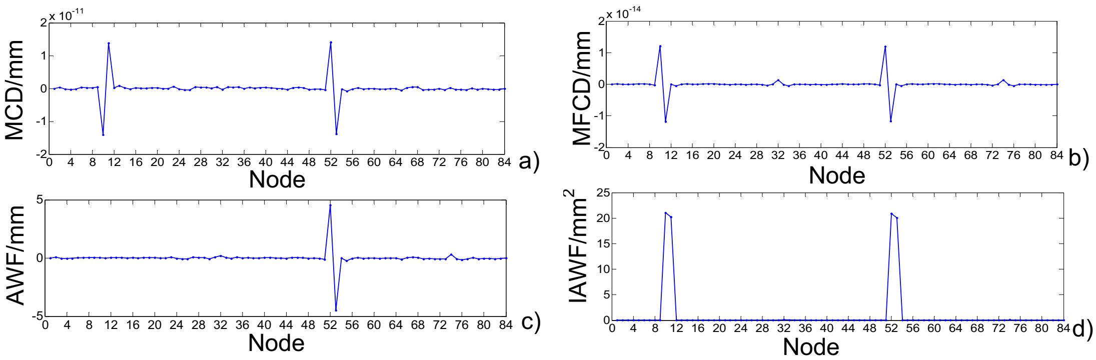


*Figure 6: Identification results under composite conditions: a) MCD; b) MFCD; c) AWF; d) IAWF*

## 5. Conclusion

In this paper, damage identification based on modal analysis of a simple steel framework model with the modal curvature and modal flexibility corresponding indexes were presented. Although MCD, MCCR, MFCD and MFCCR are good structure damage identification methods from the recognition results, only MCD and MFCD could identify the damage degree.

An IAWF damage identification method based on the MCD and MFCD was proposed and introduced into main stressed ones of the transmission tower model, and damage identification was presented under different conditions. Simulation results showed that the IAWF method is simple, easy to implement, and compared to the MCD, MFCD and the traditional AWF methods, it is able to overcome misjudgement drawbacks in the composite damage, with a better anti-noise ability and recognition accuracy. The IAWF method is applied to fault monitoring, pre-warning and diagnosis system, which can obtain the estimation of structure under operating state more accurately and improve the confidence degree of diagnosis.

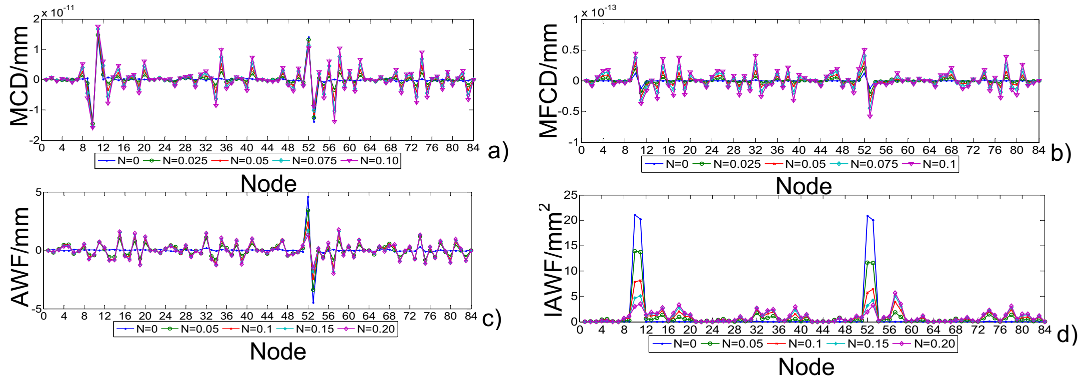


*Figure 7: Identification results of different noise levels under composite conditions: a) MCD; b) MFCD; c) AWF; d) IAWF*

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