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Analysis and Identification of Chemical Composition and Performance of Steel Grid

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According to the stress characteristics of truss structure with steel as the chemical composition and the unit modal strain change before and after the damage, the square difference of the unit modal strain is taken as the damage identification indicator of the truss structure with steel as the chemical composition, and the damage level of the steel truss structure is determined by the square difference of the unit modal strain. The numerical simulation results show that, for truss with steel as its chemical composition, under the condition of complete low-order modal test, targeting on different damage conditions of single damage, multiple damage, minor damage and severe damage, this method can effectively identify the location of the damage on the structure, and determine the damage level of the steel truss structure according to the modal strain square difference of the damage units. It also has strong robustness under certain noise level, and is suitable for damage identification and location of truss with steel as the chemical composition under actual observation conditions.

1. Introduction

In recent years, many domestic and foreign scholars have studied the damage detection of structures. Main structure damage identification methods include: damage location method based on strain-type parameters (strain mode, modal strain energy, curvature mode, etc.), and damage location method based on displacement-based parameters (displacement, displacement mode, flexibility matrix, etc.), and the former is more advantageous. Shi et al (1998; 2002) proposed a damage detection method based on modal strain energy, and took the unit modal strain energy change as the damage location indicator to conduct numerical analysis and experimental study on the plane truss and frame structure.In addition, some scholars have conducted in-depth research on the unit modal strain energy method, which has been successfully applied to damage identification of various structures (Yan et al., 2011; Fan and Qiao, 2012). When the structure is damaged, the damage of the structure can be identified by the unit strain modal difference before and after the damage. Li et al. (2009; 2010) used the low-order unit strain modal difference before and after the damage of the structure as the dynamic fingerprint of structural damage location, and established a structural damage location method based on unit modal strain; Xiong and Zhao (2012), Zhang et al. (2013) also studied the unit strain modal difference from different directions. Taking a plane truss structure as an example, based on the strain mode, the unit modal strain square difference is proposed as the damage identification indicator, and the numerical simulation results show that this method can obtain better damage location and damage level prediction by using low-order modes. Basic theory for unit modal strain square difference damage identification method.

2. Basic theory for unit modal strain square difference damage identification method

From the basic assumption of the plane truss structure, it can be known that the rod pieces in the plane truss structure mainly bear the axial force and produces axial deformation. The two-node plane hinged rod unit is adopted, the rod unit is linear elastic, and the small deformation and nonlinearity (namely the terms of high orders) are neglected. The strain of the unit is $\varepsilon = (L' - L)/L$, L is the original length of the rod unit, L' is the

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deformed length of the rod unit, and the strain of the rod unit can be obtained by the displacement of the nodes at both ends of the unit:

$$\varepsilon_k = \left[\left(u_j - u_j\right)\left(x_j - x_i\right) + \left(v_j - v_i\right)\left(y_j - y_i\right)\right]/L^2 \quad (1)$$

In the above formula, x_i, y_i and x_j, y_j are the coordinates of the nodes i and j in the plane coordinate system, respectively; and u_i, v_i and u_j, v_j respectively represent the displacement of the node in the plane coordinate system. According to a certain order displacement mode of the measured plane truss, the corresponding unit strain can be obtained, which is called a certain order unit strain mode. We take the unit modal strain square difference as the damage indicator, which can be expressed as:

$$\Delta_\varepsilon^2 = \left|\varepsilon_{um}^2(k) - \varepsilon_{dm}^2(k)\right| \quad (\mathrm{k} = 1,2,\cdots \mathrm{N}) \quad (2)$$

In the above formula, $\varepsilon_{\mathrm{um}}^2$ and $\varepsilon_{\mathrm{dm}}^2$ represent the m-th order modal strain square of the structure before and after the damage, respectively. It can be concluded from equation (2) that if a single rod piece is damaged, the maximum unit modal strain square difference might be the damaged rod unit. If multiple rod unit damages occur, where the unit modal strain square difference changes obviously should be regarded as the locations of the damaged rod units. After the damage location is determined, according to the relationship between the modal strain square difference and the damage level of the damaged unit, we can preliminarily determine the damage level of the unit (Yang and Wu, 2018).

3. Numerical simulation

3.1 Structural model

The example adopts the plane truss structure model shown in Figure 1. The span is 20m and the height is 2m. The upper and lower chord members are 2m long. The cross-sectional area of all rod units is A=1860mm^2, the elastic modulus E=2.1X10^{11}Pa, and the material density is 7850Kg/m^3. In order to facilitate the analysis, each rod piece is divided into one unit, a total of 37 units and 20 nodes. In the damage identification analysis, the APDL language of ANSYS is used for programming to solve the problem, and the two-node linear plane rod unit LINK8 is used to simulate the truss rod pieces. Assuming that the structural damage won't cause changes in the mass, and the damage is simulated by the decrease in the elastic modulus E (generally simulated by the area change), and the influence of the damping is ignored. Consider eight kinds of damage conditions of the structure (see Table 1), which are working conditions of single damage, multiple damage, and coexistence of damages of different levels; calculate the modal parameters of each order under different working conditions, and then compile the corresponding programs by Matlab. The damage indicator is established by using the first 2 orders of modal strain parameters, and the proposed unit modal strain square difference damage indicator is used to identify the damage under various working conditions. The damage identification indicators corresponding to each unit under the first and second order modes are respectively calculated, and the damage identification results are shown in Figure 2 to Figure 5.

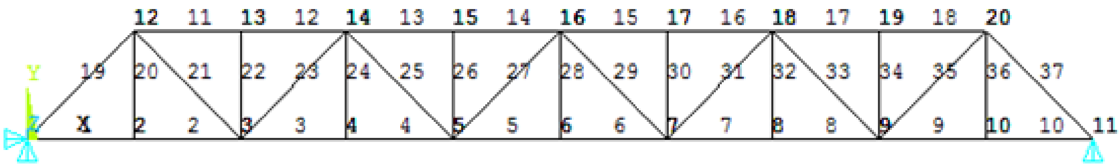

Figure 1: Plane truss structure model

Table 1: unit damage cases

Damage conditions	Damaged units	Damage level
1	Top chord 15	30%
2	Bottom chord 2	80%
3	Web member 23	90%
4	Web member 23	10%
5	Bottom chord 3, top chord 12	50%
6	Web member 23, web member 25	50%
7	Bottom chord 9, top chord 18, web member 23	30%
8	Bottom chord 8, top chord 16 Web member 31 and web member 29	50%

3.2 Single damage conditions

For different damage conditions 1~4 of a single rod piece, as shown in Figure 2 and Figure 3.
(1) The working condition of unit 23 when the damage is 10%. When using the second-order unit modal strain square difference damage identification indicator, except the damage in unit 23 has not been identified, at the location of the damaged bar piece units under other damaged working conditions, the damage indicator is significantly higher than the undamaged units, and all the locations of the damaged units can be identified.
(2) Although the second-order mode fails to identify the specific location of damage unit 23, for the first-order mode, the unit modal strain square difference of unit 23 is still significantly higher than other undamaged units, and the specific damage location of damage unit 23 can be identified. It can be seen that it is more effective to identify the location of the single damage by using only the unit modal strain square difference of the first two order modes.

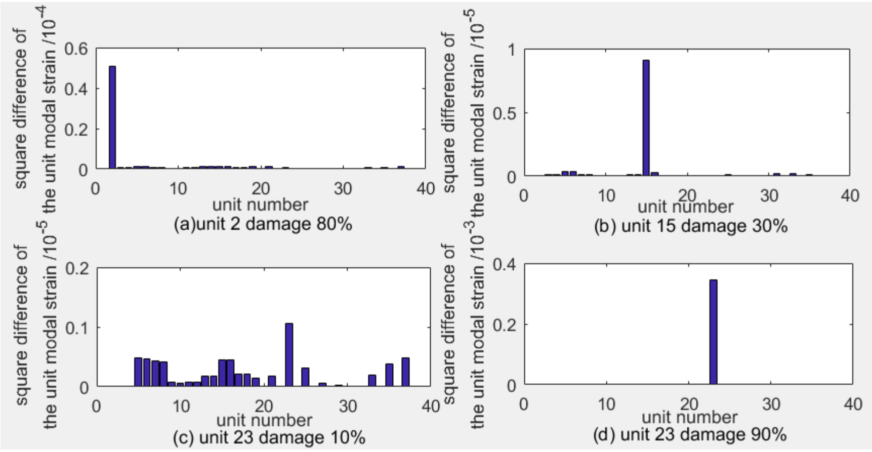

Figure 2: Damage identification for different damage levels of one unit (1st Mode)

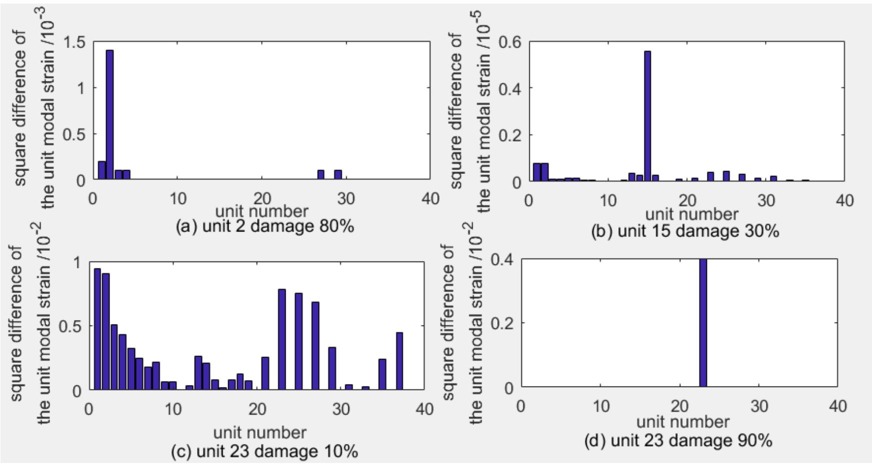

Figure 3: Damage identification for different damage levels of one unit (2nd Mode)

3.3 Multiple damage conditions

For the simultaneous damage conditions of multiple units 5-8, after numerical simulation, it can be obtained:
(1) First-order unit modal strain square difference damage identification situation is shown in Figure 4, second-order unit modal strain square difference damage identification situation is shown in Figure 5, when two to four rod units simultaneously have different level damages, it can be seen from Figure 4 that the specific location of the damaged unit can be identified by using the first-order unit modal strain square difference damage indicator.
(2) It can be seen from Figure 5 that when the damage unit is identified by the second-order unit modal strain square difference damage indicator, except from Figure 5(a) we can know that the damage indicator of unit 12

is too small to be identified and from Figure 5(c) we can see the damage indicator of unit 9 is too small to be identified, in other cases, the specific locations of the multi-unit damages can all be identified.
(3) It can be seen from Figure 4 and Figure 5 that the low-order modal strain squared difference indicators can effectively identify the specific locations of simultaneous damages at multiple units. Although the damage level of units that are damaged simultaneously is the same, the expressed modal strain square difference indicators are different, so the damage level of different units cannot be judged according to the value of the damaged unit modal strain square difference

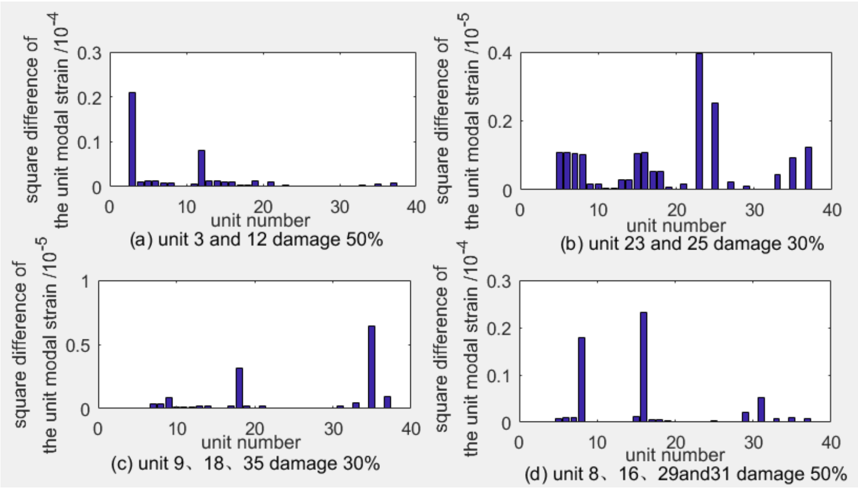

Figure 4: Damage identification for different damage levels at different locations (1st Mode)

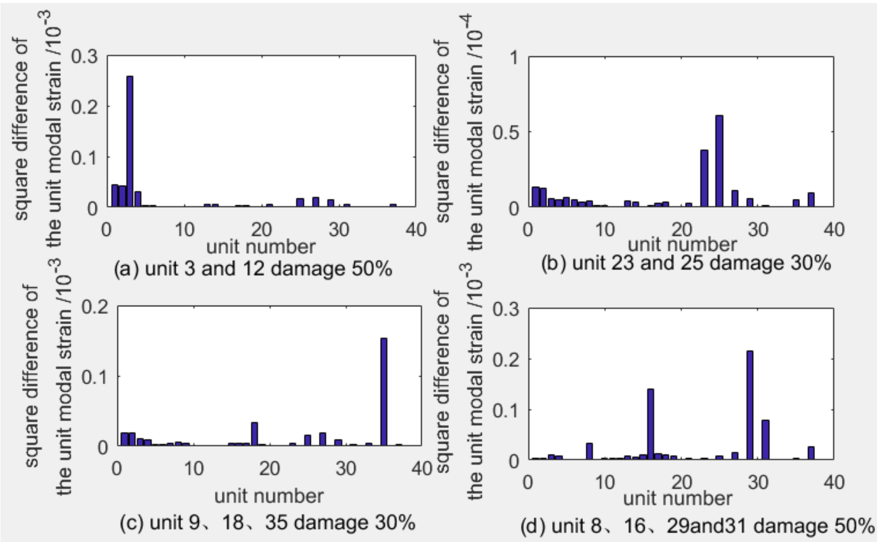

Figure 5: Damage identification for different damage levels at different locations (2nd Mode)

3.4 Damage identification under the influence of noise

The above numerical simulation verified the effectiveness of using unit modal strain square difference as the indicator for damage identification, but in actual modal displacement measurement, it's inevitable that the measurement would be affected by the accuracy of the equipment and the environmental noise. In order to investigate whether the method has certain robustness, the Gaussian white noise with zero mean is added to the modal shape of the numerical simulation to simulate the actual measured data. The displacement modal noise simulation equation is (Cao and Lin, 2010):

$$\varphi_{ij}^{Z} = \varphi_{ij} + \varphi_{max,j} \times randn \times \beta \tag{3}$$

In equation (3): φ_{ij}^{Z} and φ_{ij} represent the modal shape before and after the noise addition, $\varphi_{max,j}$ represents the maximum value of the j-order mode. randn represents a Gaussian white noise with a mean of zero and a standard deviation of 1, indicating the noise level of the modal shape in actual measurement.

In order to investigate the effectiveness of the environmental noise on using the unit modal strain square difference as the damage identification indicator, two working conditions are simulated, the single damage condition 9 of unit 15 with 10% damage, and the multiple damage condition 10 of unit 3 and unit 12 with 50% damage. For working conditions 9 and 10, the noise levels respectively are: no noise, 1% noise, 3% noise, 5% noise, the identification effect of the first-order unit modal strain square difference is respectively shown in Figure 6 and Figure 7. It can be seen from Figures 6a-6d and 7a-7d that although the modal strain square difference of the undamaged units increases with the noise level, the modal strain square difference indicators of the damaged units are significantly higher than those of the undamaged units, so that the location of the damage can be determined accurately. It can be seen that when the specific number of damaged units is known, the damage location method of taking low-order unit modal strain square difference as the damage indicator has certain anti-noise ability.

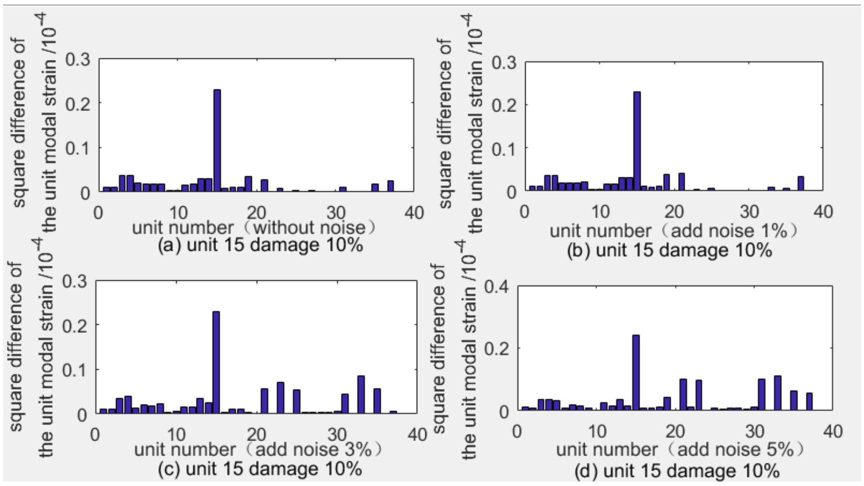

Figure 6: Damage identification with noise for different damage levels of one unit (1st Mode)

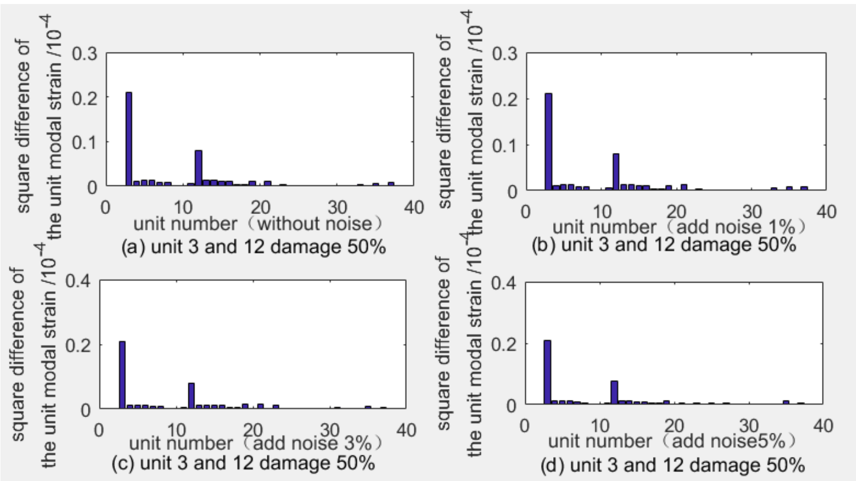

Figure 7: Damage identification with different noise for different damage levels at different locations (1st Mode)

3.5 Identification of unit damage level by unit modal strain square difference

After determining the location of the damage, the damage level of the unit should be judged according to the magnitude of the modal strain square difference of the unit. In the following passage, taking the truss damage rod unit 16 as an example, the relationship between the magnitude of the first-order and second-order modal strain square difference of the damage unit 16 and the level of damage is calculated and plotted, as shown in Figure 8. It can be seen that as the damage level of the truss unit 16 increases, the difference between the first-order and second-order modal strain squares also increases; and the greater the level of damage, the more obvious the square difference of the modal strain of the damaged unit, and the smaller the level of damage, the less the square difference of the modal strain of the damaged unit. According to this law, after determining the location of the damage, the damage level of the unit can be judged according to the magnitude of the unit modal strain square difference.

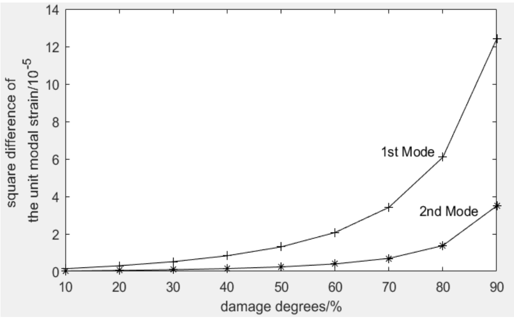

Figure 8: Strain Square difference in unit strain modal and different damage levels

4. Conclusion

(1) From the point of view of damage location, taking the unit modal strain square difference as the location indicator for damage on plane truss structure can accurately locate single damage and multiple damage in low-order mode.
(2) Taking unit modal strain square difference as the damage indicator can not only accurately identify the more serious local damage, but also can identify the minor damages well, which has certain practical significance for the early damage diagnosis of truss structures.
(3) The unit modal strain square difference method has strong robustness at a certain noise level, and is suitable for truss damage diagnosis under actual engineering detection conditions.
(4) From the point of view of damage level evaluation, the damage level of single damage can be judged according to the magnitude of unit modal strain square difference, but the judging effect of multi-damage situation still needs further study.

References

Cao H., Lin X.P., 2010, Noise simulation in structal damage identification, Joural of Vibration and Shock. 29(5), 106-109.

Fan W., Qiao P.Z., 2012, A strain energy-based damage severity correction factor method for damage identification in plate-type structures, Mechanical Systems and Signal Processing, (28), 660−678, DOI: 10.1016/j.ymssp.2011.11.010

Li Y.M., Gao X.Y., Shi S.Y., Zhou X.Y., 2009, Damage diagnosis of space truss based on change of elemental strain modal, Journal of building structures, 30(3), 152-159, DOI: 10.1109/CLEOE-EQEC.2009.5194697

Li Y.M., Guo L., Sun G.F., 2010, Identification of damages of truss Structures using elemental modal strain method, Journal of the China Railway Society, 32(6), 78-83, DOI: 10.3969/j.issn.1001-8360.2010.06.013

Shi Z.Y., Law S.S., Zhang L.M., 1998, Structural damage localization from modal strain energy change, Journal of Sound and Vibration, 218(5), 825−844, DOI: 10.1061/(ASCE)0733-9399(2000)126:12(1216)

Shi Z.Y., Law S.S., Zhang L.M., 2002, Improved damage quantification from elemental modal strain energy change, Journal of Engineering Mechanics-Asce, 128(5), 521−529, DOI: 10.1061/(ASCE)0733-9399(2002)128:5(521)

Xiong X.L., Zhao M., 2012, Strain-modal-shape index applied in Modal-free damage detection for flat space truss, Structural Engineers, 28(2), 59-65.

Yan W.J., Ren W.X., Huang T.L., 2011, Statistic structural damage detection based on the closed-form of element modal strain energy sensitivity, Journal of Central South University (Science and Technology), 42(1), 152−157, DOI: 10.1016/j.ymssp.2011.04.011

Yang L., Wu A., 2018, Research on effects of chemical erosion on mechanical properties of q235 steel weld seam, Chemical Engineering Transactions, 66, 55-60, DOI: 10.3303/CET1866010

Zhang L.M., Liu W.R., Zhang L.W., Du S.J., Zhang Y., 2013, Damage testing method of space truss based on elemental strain mode difference and RBF neural network, Journal of Hebei university of science and technology, 34(1), 79-85.