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STUDY ON DAMAGE DETECTION OF SQUARE PYRAMID SPACE GRID STRUCTURE CONSIDERING INITIAL RANDOM DEFECTS

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Because of different types of load, material properties deviation and construction errors, structures have initial defects inevitably. Therefore structural damages emerge easily and have strong randomness. At the same time, the ideal design model often has difference with structure in service. To most structures, the initial testing dates cannot be obtained, while this initial model is very important to structural damage detection. So the ideal model needs to revise. In this paper, elastic modulus, Poisson ratio and link section area are given as initial random defects and these defects obey normal distribution which can be constructed by Monte Carlo probabilistic design method. Firstly, the sensitivity parameters to structural response will be received by PDS technology from Ansys. Next, the square pyramid space grid models with random defects were obtained. Finally, given link element damage, using the method combined curvature mode difference with wavelet transform, the link element damage can be determined. Through analysis, the effects about the initial defects to damage detection will be obtained.

Keywords: Probabilistic design method, Monte Carlo method, Curvature mode, Sensitivity parameters, Wavelet transform.

1 INTRODUCTION

Because of different types of loads, material properties deviation and construction errors, structures have initial defects with randomness. All these can cause different between model structure and structure in-service. With these initial random defects and many other unforeseen circumstances, structural damages are often unpredictable. Now many damage detection methods used well on model structures, but emerge less on practical application. The reason is that many initial random defects have been ignored. So the study began around damage detection of square pyramid space grid structure considering initial random defects. These solutions can deflect some influences from initial random defects.

2 MODEL OF SQUARE PYRAMID SPACE GRID STRUCTURE WITH INITIAL RANDOM DEFECTS

Structural random defects parameters and random model with initial random defects are two main problems. Firstly, three parameters (Elastic modulus, Poisson’s ratio, and link section area) were considered as the structural random defects parameters. Next, using probabilistic design system, the random defects model of square pyramid space grid structure was established. This method was achieved based on Monte Carlo statistical methods. Through analysis, the sensitivity of random defects was judged and the sensitive random defects were selected to establish random defect model. Given link element damage, using the method combined curvature mode difference with wavelet transform, the link element damage can be determined. Then, comparing the detection solutions of the ideal model and random defects model, the influences from random defects were obtained. All these study was valuable to the practical structural damage detection.

2.1 Probabilistic Design Method

Probabilistic design method (Wang 2009, Kaminski 2006, Qi 2012, Ge 2014) can execute probabilistic design and determine the possibility of invalid. This method can implement by PDS modules of ANSYS software. The analysis procedure is as follows:

- Assuming that random defects parameters (for example Elastic modulus, Poisson's ratio and link section area) and obeying normal distribution.
- Using Monte Carlo Method (Jin 2012), a series data about random defect parameters were obtained.
- To determine the sensitivity of random defect parameters, a method based on Latin hypercube sampling was selected.
- Selecting high sensitivity parameter as the random defects, the structural model with random defects was received.

2.2 Assuming Structural Random Defect Parameter

Table 1. Statistical characteristics of structural random defect parameters.

Random defect parameters	Distribution type	Mean value	Standard deviation
Elastic modulus E	Normal distribution	$2.1\times10^{11} N/mm^2$	$6.18\times10^{9} N/mm^2$
Poisson's ratio v	Normal distribution	0.3	0.009
Link section area r	Normal distribution	0.00005 m^2	0.00000005 m^2

2.3 The Sensitivity of Random Defect Parameters

To judge the sensitivity of random defect parameters to structural response, PDS method was used to do the probabilistic design by finite element. Random defects were input parameters, and the maximum displacement was the response parameters. The structural model was shown in Figure 1.

This model has 326 nodes, 1200 links, the chord member cross-sectional area is 50 mm^2, and the webs cross-sectional area is 25 mm^2. This structure bears uniformly distributed load and the edge lower chord nodes were used peripheral supports. Through analysis, the sensitivity of three parameters is shown in Figure 2.

From Figure 2, link section area and elastic modulus have big influences to structural response. But Poisson's ratio has less influence. So this parameter was invalid and was ignored in after analysis.

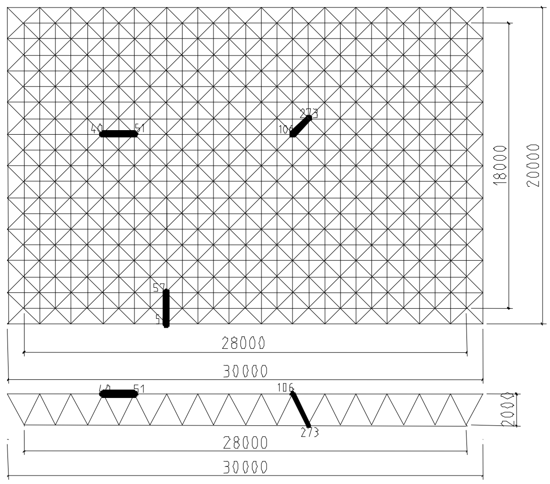

Figure 1. Square pyramid space grid structure.

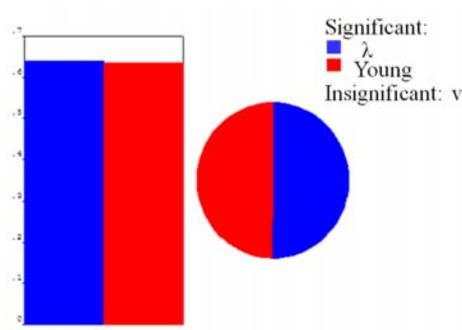

Figure 2. Sensitivity of random defect parameters.

2.4 The Model of Square Pyramid Space Grid Structure with Random Defects

Constructing 1200 sample values which along normal distribution (shown in Figure 3), this structure model with random defects can be obtained by Ansys software. Different link has different the value of elastic modulus or link section area.

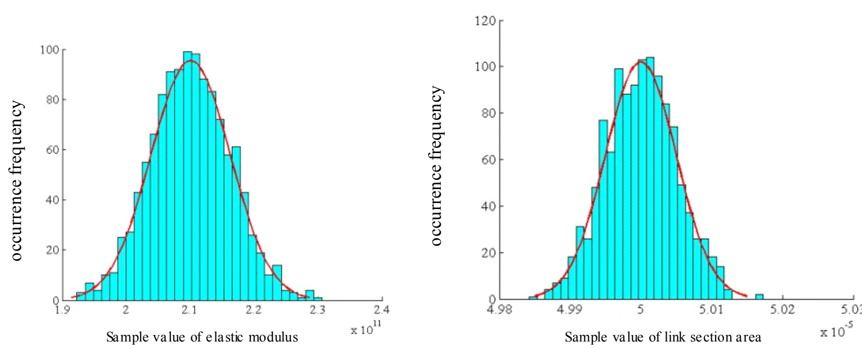

Figure 3. Normal distribution of elastic modulus and link section area.

3 DAMAGE DETECTION METHOD COMBINED CURVATURE MODE DIFFERENCE WITH WAVELET TRANSFORM

Link damage often occurs in local structure, which can change structural local parameter, for example stiffness EI, structural section area, etc. The change of EI can cause curvature mode change and these changes from pre and post damage can express the damage index to detect damage location. Structure vibration equation is written as:

$$M\ddot{v} + C\dot{v} + Kv = f(t) \tag{1}$$

While M, C, and K respectively represent matrix of mass, dampening and stiffness, v is vibration displacement, $f(t)$ is the structural exciting load. According to mode theory, the solution of Eq. (1) can be expressed as:

$$v = \sum_{i=1}^{n} \varphi_i q_i(t) = \Phi q \tag{2}$$

While φ_i is displacement modal vibration shape and $q_i(t)$ is modal coordinates, Φ is modal matrix. Curvature modes are often obtained by difference approximate calculation and can be written as:

$$\phi_i'' = \left(\phi_{i-1} - 2\phi_i + \phi_{i+1}\right) / \left(l_{i-1,i} l_{i,i+1}\right) \tag{3}$$

While, subscript i expresses the ith measuring point; $l_{i-1,i}$ express distance between measuring point i-1 and i. Then pre and post damage of curvature mode difference $\Delta\phi_{ki}''$ can be expressed as:

$$\Delta\phi_{ki}'' = \phi_{ki}''^{u} - \phi_{ki}''^{d} \tag{4}$$

While, k expresses the kth mode; $\Delta\phi_{ki}''$ is curvature mode difference of node i with the kth mode; $\phi_{ki}''^{d}$ is curvature mode difference of node i after structural damage; ϕ_{ki}'' is curvature mode difference of node i with intact structure, which was considered as input signal S. These signals were analyzed by specific wavelet function $\varphi(t)$ which have two basic parameters scale a and translation distance b. Through analysis, the wavelet transform coefficients C will be gained and this coefficient will be written as follows:

$$C = \left(W_\varphi S\right)\left(a,b\right) = \left\langle S, \varphi_{a,b} \right\rangle = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} S\varphi\left[\frac{t-b}{a}\right] dt, \quad a > 0 \tag{5}$$

While, $C = (W_\varphi S)(a,b)$ is wavelet transform coefficient, "< >" means inner product. This equation show that the minimal changes of wavelet function $\varphi(t)$ can lead to larger variety of wavelet coefficient C. The bigger the wavelet transform coefficient C means the larger the mutation degree of signal. So, with different wavelet function $\varphi(t)$, the analyzing signals will show huge difference. The db3 wavelet belongs to Daubechies group was selected in this paper because of its properties of fast transformation, better orthogonality and vanishing moment (Fan 2014, Li 2012, Law 2005).

4 DAMAGE DETECTION OF SQUARE PYRAMID SPACE GRID STRUCTURE WITH RANDOM DEFECTS

Firstly, four damage cases were determined in Table 2. Case 1 to 3 depress single link damage, case 4 depress multi damages. Damage location was shown in Figure 1. Next, considering three conditions (ideal structure, structure with random elastic modulus or link section area defects) and four damage cases, the first displacement modal was obtained by modal analysis in every condition.

Table 2. Damage cases.

Damage cases	Damage link (node number)	Damage degree	Link type
1	51（56—57）	10%	chord
2	200（40—51）	10%	chord
3	985（106—273）	10%	web
4	51, 985	10%	—

Based on Equation 4, the curvature mode difference of nodes can be received. Through wavelet analysis, the wavelet transform coefficients of every damage case by db3 wavelet can be acquired. The solutions show in Figure 4.

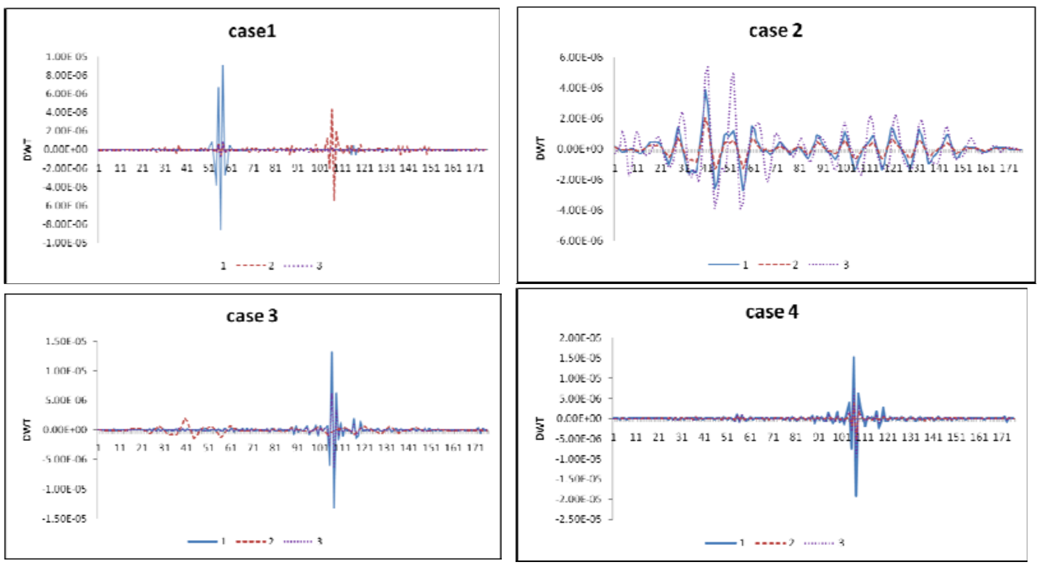

Figure 4. The wavelet transform coefficients of three conditions– Series 1: ideal structure; Series 2: structure with random elastic modulus defects; Series 3: structure with random link section area defects; DWT express discrete wavelet transform coefficients.

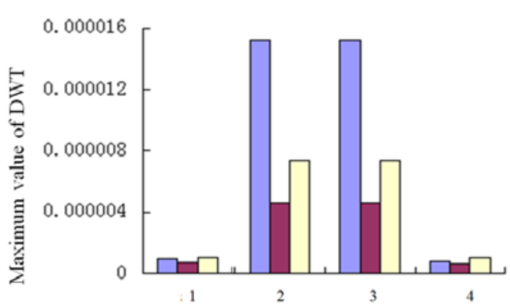

Figure 5. The maximum value of every damage case.

At the same time, the maximum wavelet transform coefficients value of every damage case was selected and compared in Figure 5. In addition, depress ideal structure, depress structure with random elastic modulus, depress structure with random link section area defects.

Through comparison, some conclusions were obtained and stated as follows:

(1) Random defects significantly affected damage detection from damage degree to degree location. From Figure 4, with random defects the wavelet transform coefficients significantly decrease in case 1, 3, and 4. However, in case 2, the wavelet transform coefficients increase with random defects.

(2) From Figure 5, in case 2 and 3 the maximum value of DWT of ideal structure was very bigger than structures with random defects. But in case 1 and 4, this value is close.

5 CONCLUSIONS

In this paper, elastic modulus, Poisson ratio and link section area are given as initial random defects and these defects obey normal distribution. Given link element damage, using the method combined curvature mode difference with wavelet transform, the link element damage can be determined. Through analysis, the effects about the initial defects to damage detection will be obtained.

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