SYMMETRICAL SIGNAL METHOD AND ITS APPLICATION IN STRUCTURAL DAMAGE DETECTION

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ABSTRACT:

It is well known that a baseline is necessary in most cases for structural health diagnosis, and it is very difficult to obtain a proper baseline for a given structure. But for some special types of structure, such as truss, cable-stayed and suspension bridges, there are a lot of pairs of elements, which are symmetrical both for geometry and boundary conditions. The vibration signal of these elements should also be symmetrical under symmetrical excitation; the Symmetrical Signal Method (SSM) is based on this idea. With respect to structures composed of slim elements, it is assumed that the same damage occurring simultaneously in the symmetric pairs is an event with small probability. Therefore, transversal flexible vibration of each pair if elements is easy to measure, and a frequency difference between symmetrical components indicates that there may be some problem with the one which has a lower frequency. Detailed inspection can be employed for the suspicious element. Analytical and truss model tests results show that SSM is very effective for detecting local damage in structures composed of pairs of slim elements.

KEY WORDS: Damage Detection; Health monitoring; Vibration Based; Symmetrical Signal Method; Local Damage.

1. INTRODUCTION

A lot of research shows that (Robert Y. Liang, etc., 1992, Yong Gao and B.F. Spencer, 2002) vibration frequencies can be used to detect structure damages. Usually the frequency variation is not sensitive to damages (Andrew D. etc., 1996, H. Sohn and K.H.Law, 2001). The premise for using this method is that the frequencies before the structure is damaged should be known as a comparing baseline. But this is quite difficult in practice; also the finite element analysis results on the frequencies of a specific structure are usually questionable. These arguments imply that a baseline is very important for structure damages detection by applying the vibration frequencies method. The Symmetrical Signal Method (SSM) (Guo Xun, etc., 2007) was proposed to meet this requirement. Symmetrical members in a structure can be regarded as baseline each other, any or some of them which are abnormal (especially take lower frequencies) maybe damaged and should be experienced detailed checking.

Damages in members (such as cracks, rust deterioration, connection loosening etc.) will lead decrease of flexible vibration frequencies of the member itself. Symmetry criterion is widely adopted in structural design.

For example a steel truss is usually composed of two panels (named as left panel and right panel); each member in left panel can find a symmetrical one in the right panel. In fact, any members in a truss with identical cross section, length and boundary conditions are defined as symmetrical, even if they are not in the spatially symmetrical position. Members in a truss are usually subjected principally to tension or compression, each member can be regarded as a single span beam restrained at it's end; the transverse flexible vibration under specific excitation of such a beam can be easily measured, and modal parameters of all those symmetrical beams should be symmetrical, this method is defined as Symmetrical Signal Method (SSM) here. In suspension Bridges and Cable-Stayed Bridges, there are also a lot of symmetrical members, such as cables, suspension rods etc.

2. TEST SETUP

Fig.1 shows the structure of the simply supported steel truss model which takes the size of 8.0 meters long, 0.5 meter wide and 0.8 meter high. In this model many pairs of symmetrical members can be founded, such as all the 8 pairs of members of lower chord and 6 pairs of members of upper chord. These upper chord or lower chord members take the same length, cross section and same hinged ends conditions respectively; so they should be symmetrical each other. Similarly, symmetrical members can also be found in groups of vertical and diagonal members. The cross section of each member in this model is listed in table 1.

Structural damage is simulated by either small cross section member or making cutting at the center of some members. One pair of symmetrical diagonal members (i.e. 26 and 26s) is selected for damage simulating. Member 26 belongs to the front panel, and member 26s belongs to the back panel. Four kinds of member as listed in table 2 are used alternatively in E26 or E26s. There are 8 cases of combination of two members out of A, B, C or D in table 2, which are listed in table 3. Damage profiles of member A and B are shown in photo 1. For example, in case2, “C+B” means member of C and B will be placed at 26 and 26s of figure 1 respectively. All the measurements are taken in the vertical plane and vibration is excited by tiny initial displacement (free vibration).

Instruments used for this experiment are: Accelerometers (Model-LC0405T, Lance, USA, Frequency range: 5-4000Hz, Mass: 77 gram); Charge Amplifier (Model-2635, B&K, Denmark); Data Logger (Siglab 20-42, Spectral Dynamics, USA, 16 bit with good anti aliasing filter).

As shown in photo 2, accelerometers are attached by magnetic units at the span center of the whole truss or the tested member, and perpendicularly to each of the member axis.

3. GLOBAL VIBRATION MEASUREMENTS

Initial displacement is induced by a weight of 2.0Kg, which is placed on the top center of the truss. Quickly release the weight will excite vibration of the truss, and this vibration is measured by accelerometer and Siglab data logger. Records are analyzed both in time domain and frequency domain.

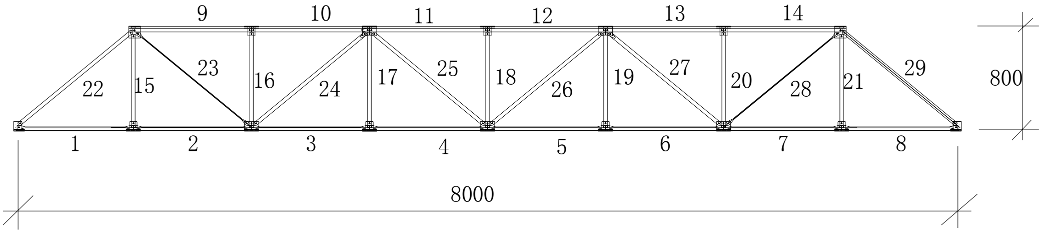

Fig. 1 Outline of the tested truss model

Table 1 Dimension of truss members

Member	Cross section (mm^2)	Member	Cross section (mm^2)
Upper chord	30×10	Diagonal chord	30×10 or 10×8
Lower chord	10×8	Transverse chord	30×10
Vertical chord	30×10	Transverse diagonal chord	30×2

Photo 1 damage profile of member A (left) and member B (right)

Photo 2 Accelerometer is attached perpendicularly to the middle of the member

Table 2 Dimension and description of elements used for damage simulating

Member	Cross section (mm^2)	Length（mm）	Description
A	10×8	1209	Standard member, no damage
B	10×8	1209	One central cutting with 2mm of depth and 3mm of width
C	10×8	1209	One central cutting with 6mm of depth and 25mm of width
D	10×30	1209	cross section is 3 times of A

Table 3 Cases of combination of the any two members out of A, B, C or D

Case No.	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Member combination	A+A	C+B	C+A	B+A	C+D	B+D	A+D	D+D

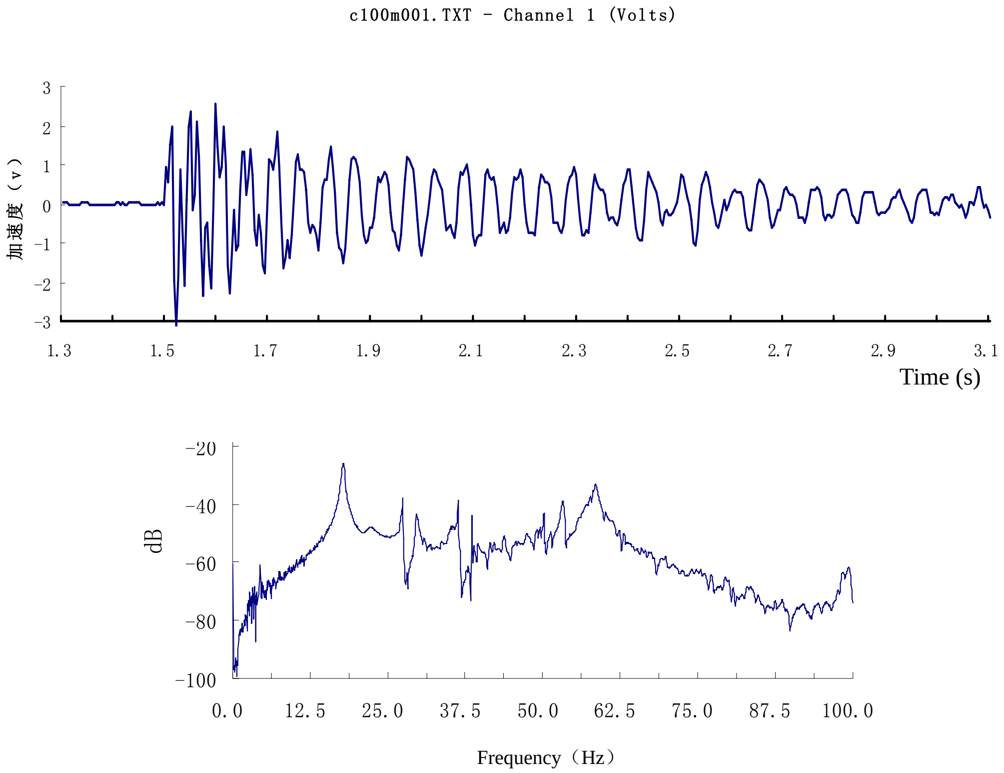

Figure 2 Global vibration time history and power spectrum in case 1

Figure 2 shows the measured free vibration time history and power spectrum in case 1, the global vertical vibration frequency of the whole truss model can be read as 19.63Hz. Global vibration frequencies of all 8 cases are summarized as table 4. Even though there is obvious local damages in some cases, only small frequency shift is related to such damages.

Table 4 Global vibration frequencies in different cases

Case No.	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Frequency (Hz)	19.63	19.63	19.56	19.69	19.63	19.56	19.56	19.75

4. LOCAL VIBRATION MEASUREMENTS

A tiny initial displacement on member E26 or E26s is induced by a weight of 100 gram and released manually perpendicular to each of the diagonal members; free vibration is measured by accelerometer and Siglab data logger. Local vibration frequencies of each case are summarized in table 5.

In case 1, there are no damages in E26 or E26s, only small primary frequency difference exists (Figure 3); in case 2 and 3, large local damages differences are revealed by obvious frequency difference (Figure 4 and Figure 5); in case 4, small local damage is also identified the comparison of the symmetrical pair of members (Figure 6).

Table 5 Local vibration frequencies of one pair of diagonal members (Hz)

Member	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
E26	33.25	24.50	23.63	31.63	24.25	34.81	33.25	68.13
E26s	33.56	32.00	34.13	33.88	68.13	35.38	68.13	68.13

5. DAMAGE IDENTIFICATION

In case 1 there is no damage in E26 or E26s, almost all symmetrical requirements are satisfied and this case is regarded as a baseline. The local vibration frequencies of E26 and E26s, showed in figure 3 are 33.25Hz and 33.56Hz respectively in case 1. In case

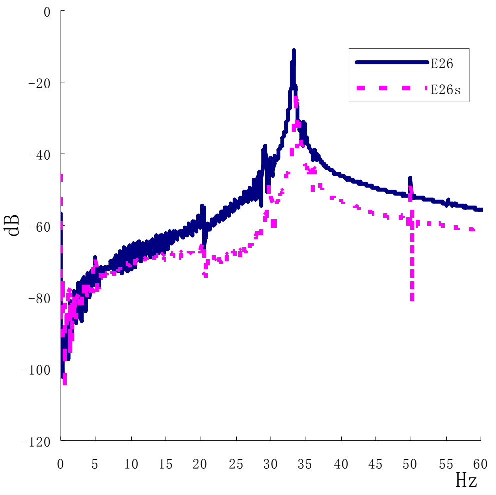

Figure 3 Local frequency comparison in Case 1 (no damage in E26 or E26s)

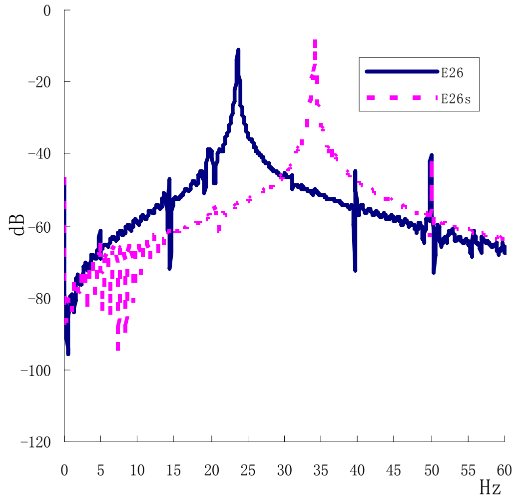

Figure 4 Local frequency comparison in Case 2 (member B in E26 and member C in E26s)

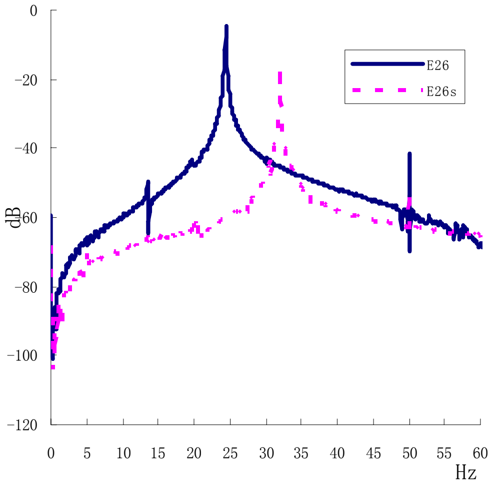

Figure 5 Local frequency comparison in Case 3 (member C in E26 and member A in E26s)

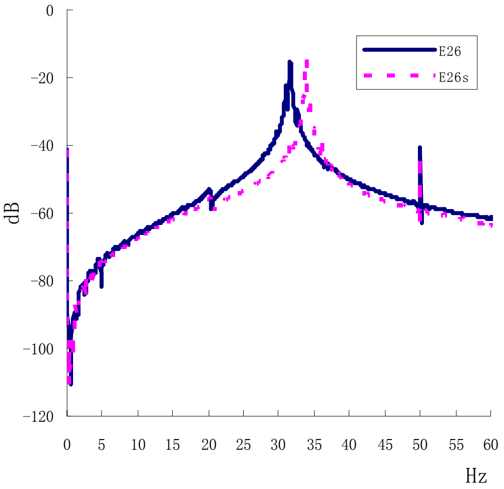

Figure 6 Local frequency comparison in Case 4 (member B in E26 and member A in E26s)

2, there is large cutting in E26 and small cutting in E26s, the local vibration frequencies of E26 and E26s, showed in figure 3 are 24.50Hz and 32.00Hz respectively. Frequencies for other cases are listed in table 6. Data in this table show that the global frequency change is not sensitive to the designed damages, however, when symmetrical signal method is used, the frequency shift is much more sensitive to member damages (both cross section reducing and cross section cutting). Figure 7 gives a clear comparison of the sensitivity between SSM and the traditional global frequency shift.

Table 6 Frequency change comparison of global and local frequency

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Global Frequency (Hz）	19.63	19.63	19.56	19.69	19.63	19.56	19.56	19.75
Global frequency shift (%)	0.0	0.0	-0.4	0.3	0.0	-0.4	-0.4	0.6
Local frequencies of E26/E26s (Hz)	33.25 33.56	24.50 32.00	23.63 34.13	31.63 33.88	68.13 24.25	68.13 31.31	33.25 68.13	68.13 68.13
Frequency difference of symmetrical members （Hz）	0.31	7.50	10.50	2.25	43.88	36.82	34.88	0.0
Frequency difference of symmetrical members (%)	0.9	23.0	31.0	6.6	64.4	54.0	51.2	0.0

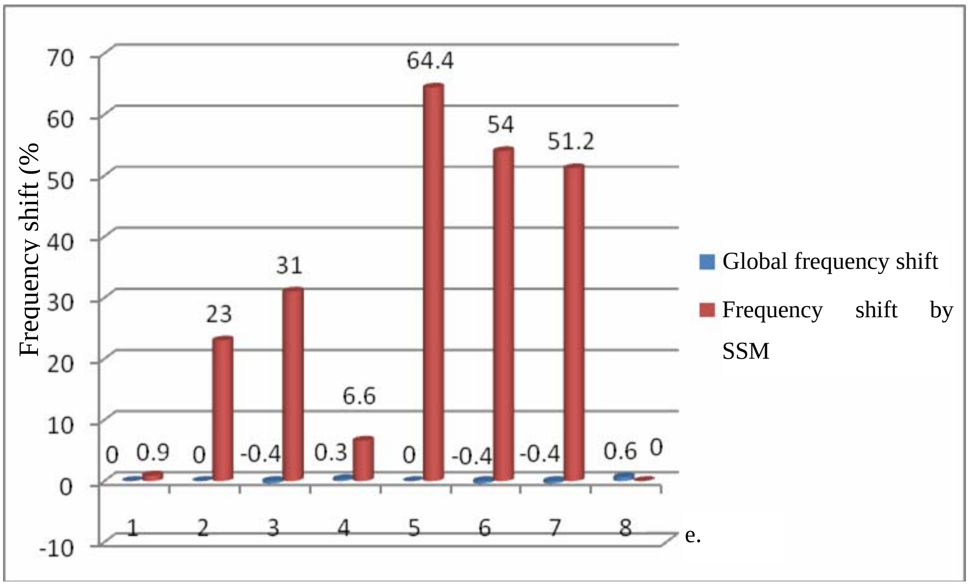

Figure 7 Frequency shift comparison of global and symmetrical difference

6. CONCLUSIONS

Symmetrical Signal Method (SSM) used for structural damages detection is proposed here. Free vibration test on a steel truss model are carried out, global vibration frequencies and local vibration frequencies of some members with different degree of damages are measured. Results show that SSM is much more sensitive to structural damages than the traditional method which is based on variations of global vibration frequency.

However, SSM can only be used for structures with many symmetrical flexible members such as steel truss, cable stayed bridge or suspension bridge. During the application of SSM, local flexible vibration of symmetrical members can be excited by shaker in the same time. After the global vibration frequencies are eliminated, frequency differences between symmetrical members will be clearly displayed, members take lower frequency are suspected to be damaged and need to be checked in detail.

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