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Damage evaluation in earthquake events by nonlinearity extraction from video data

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1. INTRODUCTION

Structural damage is defined as a weakening of a structure which may cause local or global displacements, vibrations, or even catastrophic consequences (Das et al, 2016). It severely affects the safety and resilience of civil structures when suffering from various nature disaster, e.g. earthquake. The damage detection of structures at early stage can improve safety and extend their serviceability. Most damage scenarios may cause a previously linear structure to exhibit nonlinear behavior (Farrar et al, 2007). Therefore, identifying and extracting these nonlinear behaviors is a good way to detect structural damage. Common nonlinear behaviors in engineering structures include cracking, crushing, sliding, yielding, fracture, boundary conditions nonlinearity. The main challenges in structural damage detection are to distinguish between linear and nonlinear types of damages and between nonlinear damage and inherent nonlinearities in 'healthy' structure. If structural nonlinearities are mistaken for damage, then diagnoses are inaccurate are even false identification occur. The traditional detection methods usually need to use sensors; however, densely instrumenting a structure requires high cost, and it is difficult to get close to some damaged structure for safety especially in the disaster events. On the other hand, non-contact methods overcome these difficulties and they are being researched intensely for the purposes of the structural health monitoring. The vision technology-based damage identification is one of the significant non-contact methods, which has so many advantages, such as low-cost data acquisition, high spatial resolution, simultaneous, and so on (Yang et al, 2017). It also has a great potential to be applied to the damage detection of real-world engineering structures. In this study, the video data-based technology is used for nonlinearity damage identification of structures in earthquake events.

2. VIDEO DATA ACQUISITION AND INTRODUCTION

For the first step study, one of video data opened in E-defense, NIED was used for the nonlinearity detection. This video data is a full-scale 4-story steel building that was repeatedly subjected to ground shaking until it collapsed. And in this video, there are various nonlinear events (cracking, yielding, crushing, etc.). Here, the event of wall cracking is selected for analysis because it is one of the most common nonlinear events in engineering structures. Fig. 1(a) and 1(b) show the wall before and after cracks respectively. It can be clearly seen that there are some cracks appear in the red cropped area and the occurrence time is about 8th second.

(a) (b)

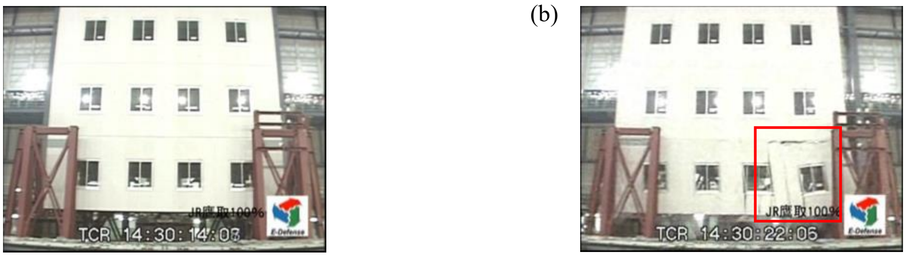

Fig. 1 Screenshot of the video data: (a) nominal state; (b) with cracks

3. NONLINEAR EVENT IDENTIFICATION OF OCCURRENCE TIME

Normally, the structural damages of civil engineering structures in service are a gradual process with the degree of damage varying from minor to severe. Thus, compared with the damage localization, it is also an important problem to identify the occurrence time of damages (nonlinear events) in order to control the expansion of damages. In this research, singular value entropy (SVE) is selected as index to reflect the occurrence of nonlinear events. Singular value decomposition is an orthogonal transformation. For any row or column linear correlation matrix, the original matrix can be transformed into a

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diagonal matrix by multiplying one left and right by an orthogonal matrix. The equation for singular value decomposition of X is the following (Michael et al, 2002):

$$X = USV^T \tag{1}$$

where X is an $m \times n$ matrix, S is an $n \times n$ diagonal matrix, and V^T is also an $n \times n$ matrix. Here, the diagonal value of matrix S is singular value. Then, singular value entropy can be calculated. Information entropy can be employed to measure the amount of information. And the more orderly a system, the lower the information entropy; Conversely, the more chaotic a system, the higher the information entropy. After the normalization process, the equation of entropy is as follows:

$$E = -\sum \alpha_k \, ln\,(\alpha_k) \tag{2}$$

where α_k are the singular values after normalization.

Here, the luminance part of wall cracking images are analyzed and the results of singular value entropy in whole image and red cropped area (Fig. 1(b)) are shown in Fig. 2(a) and 2(b) respectively.

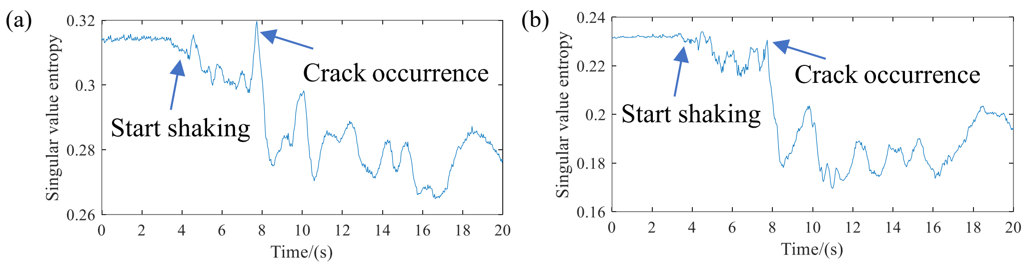

Fig. 2 The results of singular value entropy: (a) the whole image; (b) the cropped area

As shown in Fig. 2, the value of SVE start to fluctuate at near 4 s due the shaking occurrence. And both SVE in Fig.2 (a) and (b) show the reductions at near 8 seconds. It reflects that there are pixel value changes occur in video data currently, which coincides with the occurrence time of cracks on video in Section 2. However, the SVE cannot detect the reason that causes the pixel value to change. In addition, Fig. 2(b) has a greater difference value at 8 s compared with Fig. 2(a). The main reason is that only the cracking area is analyzed in Fig. 2(b), thus the change will be more obvious. Therefore, it is proved that the index of SVE can identify the occurrence time of nonlinear event (crack).

4. CONCLUSIONS

This research aims to identify and classify these nonlinear events and final realize the purpose of visualizing the real-time tracking results on the original video data. The analysis results in this paper showed that the index of singular value entropy has the potential to identify the occurrence time of nonlinear event. The future work is to apply CNN to localize and classify nonlinear events and RNN will be used to achieve the real- time visualization of multiple nonlinear events on the original video data.

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Video data: https://www.bosai.go.jp/hyogo/research/movie/movie-detail.html#7

