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Conference Paper · April 2018

DOI: 10.32548/RS.2018.024

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ABSTRACT

This article introduces a new approach for performing preliminary assessment for seismic damages and their severity by tracking the Fundamental Frequency of Damage (FFoD). Conventional damage assessment approaches monitor the global-behavior of the structure to capture anomalous structural responses. This requires for the damage to be sever enough to affect the overall structure behavior. The approach introduced in this article shifts from monitoring global structure, to monitoring the dynamic characteristics of the damage, namely the Fundamental Frequency of Damage (FFoD). The presence of structural damage will create a high-frequency oscillation, which characterizes the damage. FFoD is the frequency is of this oscillation. Identifying this oscillation is the recorded vibration is quite challenging since it is often has a low amplitude. To overcome this issue, the authors will utilize a new filtering technique that is capable of amplifying feeble signals by suing rather than suppressing the noise, namely Underdamped Pinning Stochastic

Resonance. With this filter, the signal is monitored at the FFoD to identify whether the damage present or not. A case study for a seismic moment frame is presented in this article.

1 INTRODUCTION

Buildings are a major investment in the United States where they impact our lives in many aspects including shelter, security, and safety. The sociological structure of burgeoning urban areas endorses the necessity of a massive repository of tall structures. Extreme seismic events induces significant damages 15→30 stories structures, that often requires a complete structural replacement. However, some of these facilities remains “apparently” intact and may not experience visible structural damages. For instance, the 6.7 earthquake which occurred on 17 January 1994, at Northridge led to sever damages for the moment-resisting frames connections of steel frame buildings [1-3]. The incipient detection for these damages after earthquake is essential for the structural safety and survivability. However, traditional assessment approaches require immense manpower and sophisticated processes that may require complete facility shutdown to perform the inspection. Therefore, for an extended time, researchers investigated the feasibility of utilizing Structural Health Monitoring techniques to infer about damages once they become permanent. The Fundamental Frequency of the structure had been intensively investigated as metric for structural damages [4-21]. However, the results indicated that this approach is effective only if the building is severely damaged. Therefore, this article aims to shift to an alternative approach, by monitoring the frequency of the damage, that exerts when the damage takes place, which will be introduced as the Fundamental Frequency of Damage (FFoD). FFoD, is the frequency of the oscillation of the damaged element. For instance, for a gusset plate in compression, the frequency of the buckling oscillation is the FFoD for this connection, since gusset plate buckling is what controls the design of the connections [22]. The frequency associated to the buckling mode can be easily identified from the plate geometry; this will be the FFoD for the connection. For standard mode of failures, the FFoD could be computed and tabulated with the aid of FEA software. The main dilemma is that damages oscillation are often high-frequency oscillations and have a considerably low amplitude, that cannot be easily identified in recorded signal. Therefore, we will explore using the Stochastic Resonance phenomenon which extract the signal of a targeted frequency by using rather than suppressing the noise.

Stochastic Resonance (SR) is a model for weak response detection from the response of a global system. In this approach feeble signals can be amplified and optimized by using instead of suppressing the noise in the signal. The approach was introduced by Benzi, Sutera and Vulpiani [23] as an explanation of the observed periodicity in the ice ages on earth. Since then, the approach has spurred interest, and many researchers have investigated applying this hypothesis in different disciplines [24]. Several studies have investigated the cooperative effect of noise in bi-stable/overdamped systems in detecting weak signal corrupted by a heavy background noise [25-31]. Recently, Zhang, He and Kong [32] for the first time introduced a SR model with the capability to detect mono-stable (i.e. the weak property is stable at one particular point) and bi-stable system. In this article we will investigate using the UPSR for its flexibility to provide mono and bi stable systems.

2 UNDERDAMPED PINNING STOCHASTIC RESONANCE (DUPSR)

The UPSR is a single degree of freedom filter that extract the signal when resonance approached. Eq. (1) present the general format of SR, where "*x(t)*" is the targeted feeble signal feeble signal, $V'(x)$ is the potential function, $\{s(t) + n(t)\}$ is the input signal with the noise. The weak signal "*x(t)*" can be extracted if resonance is approached in Eq. (1). This is done by changing the parameters of the potential function till resonance approached.

$$\frac{d^2x}{dt^2} = -V'(x) - \gamma \frac{dx}{dt} + \{s(t) + n(t)\} \tag{1}$$

The potential function of the UPSR model has been introduced by Zhang, He and Kong [32] is presented in Eq. (2).

$$V(x) = V_0 - V_d \left(\exp\left(-\frac{(x + x0)^2}{L^2} \right) + \exp\left(-\frac{(x - x0)^2}{L^2} \right) \right) \tag{2}$$

where, V_0 is a constant and will not be considered since it will turn into zero after differentiating the function as shown in Eq.(1) , V_d is the depth of the pinning, L is the length between the two pinning $\pm x0$ is the center of each pinning. The UPSR is governed by three parameters (i.e. V_d, L and *x0*) ascribing to efficient representation for mono-stable and bi-stable systems. Zhang, He and Kong [32] provide a numerical discretization for Eq. (1) considering the potential function given in Eq. (1). The numerical solution is illustrated in the following equation;

$$V'(x) = \frac{dV(x)}{dx} = -V_d \left(\frac{2(x + x0)}{L^2} \exp\left(-\frac{(x + x0)^2}{L^2} \right) + \frac{2(x - x0)}{L^2} \exp\left(-\frac{(x - x0)}{L^2} \right) \right)$$

$x(0) = 0; \frac{dx}{dt}(0) = 0$

For i = 2 : end

$$k_{x1} = \frac{dx}{dt}(i - 1) \tag{2}$$

$$k_{y1} = -V'\big(x(i - 1)\big) - \gamma \frac{dx}{dt}(i - 1) + \{s(i - 1) + n(i - 1)\}$$

$$k_{x2} = \frac{dx}{dt}(i - 1) + \frac{h}{2} k_{y1}$$

$$k_{y2} = -V'\left(x(i - 1) + \frac{h}{2} k_{x1} \right) - \gamma \left(\frac{dx}{dt}(i - 1) + \frac{h}{2} k_{y1} \right) + \{s(i - 1) + n(i - 1)\}$$

$$k_{x3} = \frac{dx}{dt}(i-1) + \frac{h}{2}k_{y2}$$

$$k_{y3} = -V'\left(x(i-1) + \frac{h}{2}k_{x2}\right) - \gamma\left(\frac{dx}{dt}(i-1) + \frac{h}{2}k_{y2}\right) + \{s(i) + n(i)\}$$

$$k_{x4} = \frac{dx}{dt}(i-1) + hk_{y3}$$

$$k_{y4} = -V'(x(i-1) + hk_{x3}) - \gamma\left(\frac{dx}{dt}(i-1) + hk_{y3}\right) + \{s(i) + n(i)\}$$

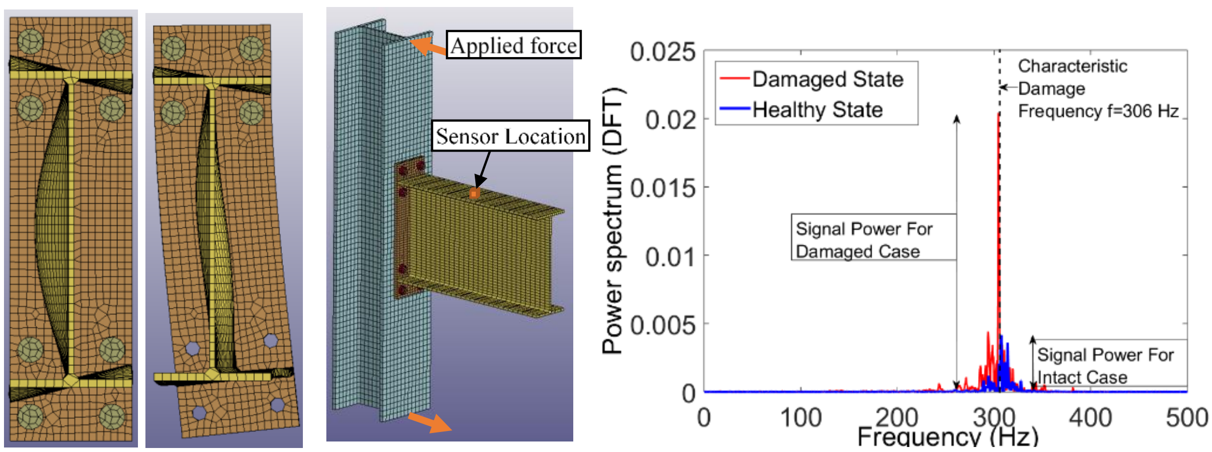
$$x(i) = x(i-1) + \frac{h}{6}(k_{x1} + 2k_{x2} + 2k_{x3} + k_{x4})$$

$$\frac{dx}{dt}(i) = \frac{dx}{dt}(i-1) + \frac{h}{6}\left(k_{y1} + 2k_{y2} + 2k_{y3} + k_{y4}\right)$$

where h is the calculation step which equals *R*dt* (dt is the time step and R is a rescaling factor).

3 CASE STUDY

The Fundamental Frequency of Damage (FFoD) is the frequency of the signal accompanied the presence of certain damage. To demonstrate the concept, the failure of the beam column connection as presented in Figure 1 (a) produces a mode of vibration associated with that damage as depicted in Figure 1(b). The FFoD associated with that mode was found equal to 306Hz. As this mode of failure approached, the power of the signal at that frequency will increase dramatically, which is pointing towards the presence of this specific mode of failure. To verify the effectiveness of the proposed method, a defected beam column connection will be used as a test sample. The column ends have been applied to a predefined motion to mimic a cyclic load. The simulation was carried out twice for the intact and the damaged connection. The UPSR technique is utilized to monitor the specified Fundamental Frequency of Damage. The objective is simple; if damage present, the power of the signal at the monitored frequency will increase dramatically. Figure 1 depict the difference between the intact and the damaged cases with a clear-cut identification that the damage has occurred in the second case.



(a) (b) (c) (d)

Figure 1 Monitoring the Characteristic Damage Frequency associated with the lower connection failure (a) Intact connection Model (b) Damaged Connection, the frequency of that specific Damage is (f=306 Hz) (c) loading configeration (d) Spectra of the signal extracted usng the UPSR Filtering Algorithm.

4 CONCLUSION

This article investigates a new concept for monitor the structural integrity of buildings by monitoring the Fundamental Frequency of Damage rather than monitoring the change in the fundamental frequency of the building. The Fundamental Frequency of Damage (FoD) could be pre-determined using Finite Element Modeling software, by modeling the expected damage and identify its natural frequency. The main issue is that the damage signal essentially feeble, thus to monitor this signal a robust filtering approach is needed. To this end, we exploited the use of Under Damped Pinning Stochastic Resonance UPSR, to amplify feeble signals by using rather than suppressing the background noise. The UPSR is used to amplify the signal at that targeted frequency, to monitor the damage. To illustrate the concept a simple connection has been utilized to represent and intact and a damaged state for a steel moment frame connection. The signals of the intact and damaged connections have been processed using the UPSR filter. The damage has been successfully identified in the acceleration spectrum of the beam vibration.

5 ACKNOWLEDGEMENT

The authors wish to express their gratitude for the financial support received from the National Science of Foundation (NSF-CNS-1645863). Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the sponsors.

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