XI International Conference on Computational Plasticity. Fundamentals and Applications
COMPLAS XI
E. Oñate, D.R.J. Owen, D. Peric and B. Suárez (Eds)

PREDICTION OF DAMAGE INTENSITY IN MOMENT FRAMES BY USING WAVELET ANALYSIS

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Key words: damage detection, wavelet transform, plastic hinge, moment frame

Abstract. After occurrence of an earthquake, one of the most important applications of recorded information in instrumented buildings is using these data in observation and estimation of damage in the structural systems of the building. A method using plastic hinge formation and wavelet analysis has been presented which directly makes use of rotational response history of frame nodes (rotation, angular velocity, angular acceleration) for extracting information of damage.

1 INTRODUCTION

The estimation of severity of the damage has two main goals: (a) determining the stability and serviceability of structures after the earthquake, (b) getting timetable and its priority scheme for the damaged parts repairing. Topic of intensity of damage in structures subject to earthquake is a matter of major interest in most papers. The reason for this interest is that estimating the severity of damage with respect to onset and its position is difficult. One of the problems is that estimation of damage is a relative issue. In other words, although the damage severity of a member can be judged relative to the other members, but the damage influence and its severity, for example in a section of the structure cannot be estimated, correctly. Also, as these estimates are often based on vibration responses of system, substantive changes in response - for example, frequency of the lower modes - is the basis for damage detection. These changes are functions of intensity and distance of damaged part to the measured position. This means that small damage at the closer distance may have similar effects as a large damage at farther away which makes the detection more complicated. In some cases, relative damage estimation is also useful because it can be a basis for choosing a strategy to repair damaged areas. For calculating structural damage in members we can use Joint plastic rotation in beams and columns of a frame. First of all moment-curvature diagram is determined, and then the level of plastic rotation capacity is calculated. Campbell has presented a similar damage index [1].

2 WAVELET

Wavelet is now a well known tool to detect damages. It defines a group of mathematical functions that are used to break down a signal to its frequency components. Wavelet functions have a limited bandwidth in time domain and frequency domain. Wavelets are transferred and scaled samples obtained by affecting a wavelet mother function on the main signal.

Wavelet coefficients contain much information about the contents of the signal. Eqs. 1 to 4 show main equations of wavelet transform method. Using a selected analyzing or mother wavelet function ψ(t), the continuous wavelet transform of a signal f(t) is defined as (M. Misti et al., 2007) [2]:

$$C(a,b)=\int_{-\infty}^{+\infty} f(t)\psi_{a,b}(t)dt \tag{1}$$

$$\psi_{a,b}(t)=a^{-\frac{1}{2}}\psi\left(\frac{t-b}{a}\right) \tag{2}$$

Discrete wavelet transform is similarly defined as follows:

$$C(a,b)=c(j,k)=\sum_{n\in z} f(n)\psi_{j,k}(n) \tag{3}$$

in which $\psi_{j,k}$ is a discrete mother wavelet, which is defined as follows and sometimes also called binary analysis:

$$\psi_{j,k}(n) = 2^{-j/2}\psi(2^{-j}n - k) \tag{4}$$

Selection of proper mother wavelet function is the first step in the wavelet analysis. The choice depends on the desired issue and can have a considerable effect on the results. In this study, discrete wavelet transform (DWT) employing "Bior 6.8" [3], is used. In DWT, scale parameter 'a' is chosen as a= 2^J where J is an integer values J ϵ Z. For a function f(t) ϵ L2-space with a Fourier transform F(ω), a change in scale factor J is followed by a change in scale of frequency domain given by a= 2^J. Signal decomposition in wavelet analysis is carried out by projecting the signal into a subspace of scaling and wavelets basis functions at different scales and their transmission.

3 METHODOLOGY

Based on the definition of the Federal Emergency Management Agency (FEMA 356) [4] plastic formation at a joint of a steel frame in a Moment-Rotation curve has a clear transition point, "point A" in Fig. 1, that the member's elastic behavior ends and its inelastic behavior starts. After that, there is "point B", in which the member cannot carry more loads. In this situation the member has been sustained severe damages. In other words, there are two clear stages: (a) Passing from point "A" and (b) Passing from point "B". Transition from point A is considered as the beginning of the plastic behavior and actually is the criterion for determining starting time of damage, while passing from point B can be considered as a criterion for determining severity changes, which leads to destructive damages.

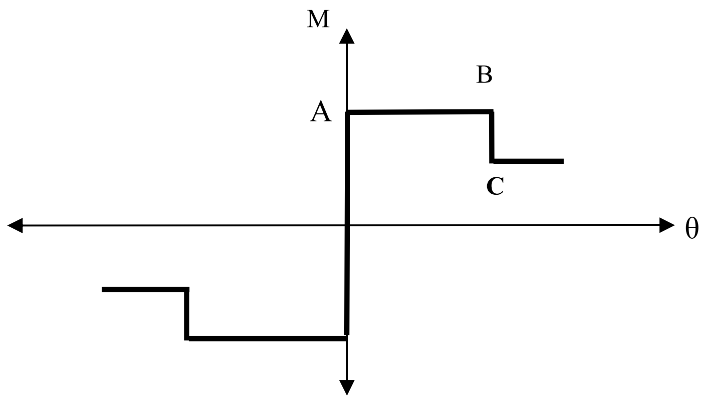

Fig.1. Moment - rotation behavior

Moving from point A to C can be estimated from response history of the nodes adjacent to the hinge. These changes cause permanent alteration in the responses of the joint and it would lead to a shift in the response base line of the adjacent node. For determining the value of this shift, using wavelet analysis, details can be removed from the response and an approximation can be achieved. Details will contain information for computing time of damage [5] and approximation will have information about the severity of damage. Details demonstrate passing from point A and approximation demonstrates if the response falls between A and B or it has passed B.

To further clarify the above mentioned method, consider the frame shown in Fig. 2 under the loading shown in Fig. 3. Two cases are assumed: First, all members behaves within their elastic ranges such that no plastic hinges would be formed by increasing external load, F(t). In this case, the rotation time history response of node P, such as loading, has a linear gradient and increases constantly. Second, it is permitted that by increasing external load a plastic hinge initiates to form at a member. Again we analyzed the rotation response of node P. As it can be seen in Fig. 4, after plastic hinge formation, slope of the response function increases clearly. Also for this frame the occurrence time and their related values of the rotation for the end section of member AP in each states: A, B and C are speciifed in Fig. 4.

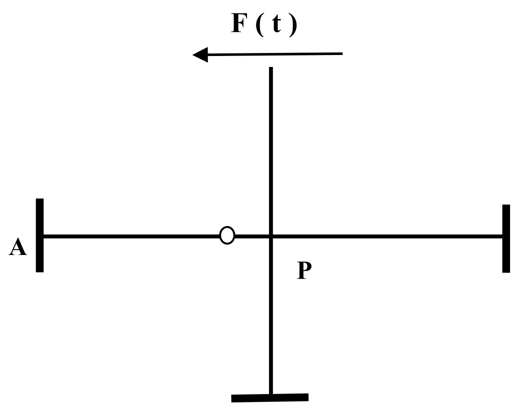

Fig. 2. Simplified model of Plastic hinge formation (on the frame subjected to a horizontal load)

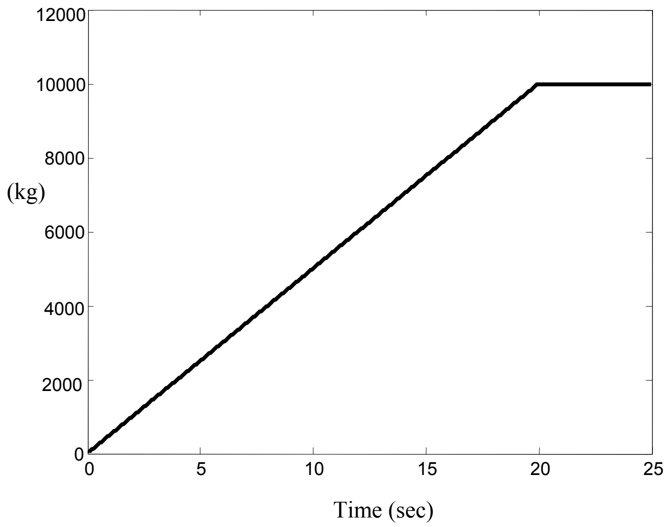

Fig. 3. Monotonic loading

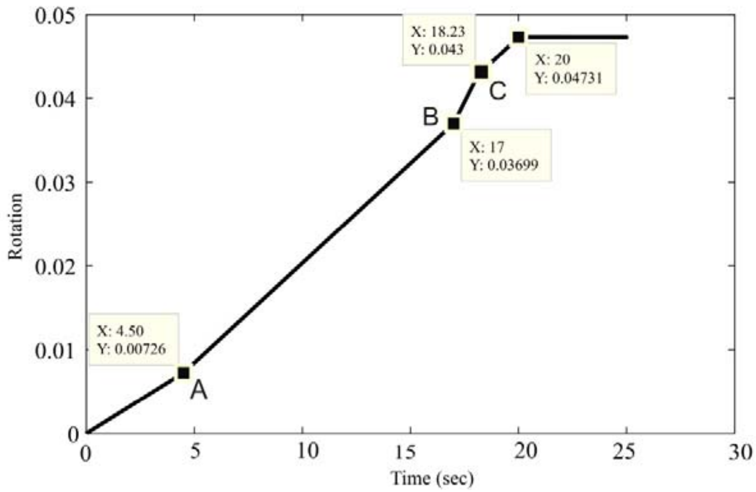

Fig. 4. Time history response of node B in case of plastic hinge formation in a member

4 NUMERICAL ANALYSIS AND RESULTS

Now, we aim to examine this procedure to a moment steel frame, Fig. 5, subjected to a random support excitation like an earthquake. This frame is a 5 meter length, 3 meter height simple frame with fixed bases and a uniform dead load about 2000 kg/m. Fig. 6 shows the strong ground motion recorded at Tabas, Iran. This earthquake was a huge earthquake measuring 7.8 on the Richter scale, which struck on September 16, 1978 in central Iran.

Fig. 5. Schematic representation of main damage in the studied frame subject to Tabas excitation

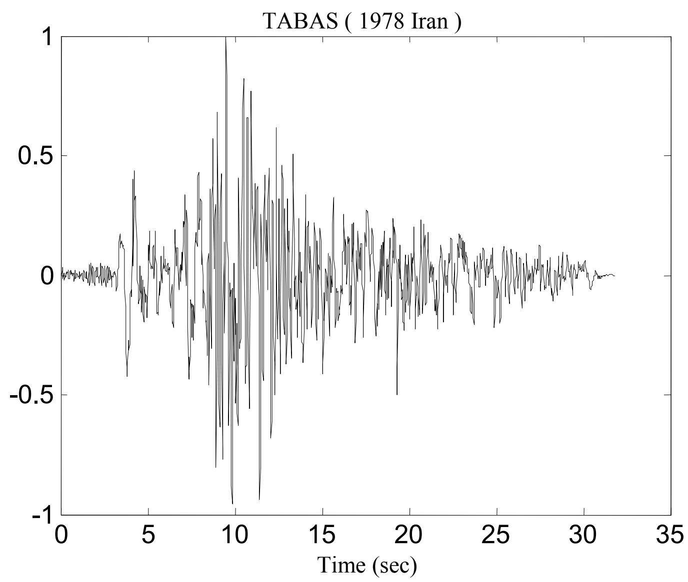

Fig. 6. Normalized Tabas record with respect to its peak ground acceleration (PGA)

As can be seen in Fig.7 changes in the difference of two nodes is similar to the rotational response history of the plastic hinge formed between them.

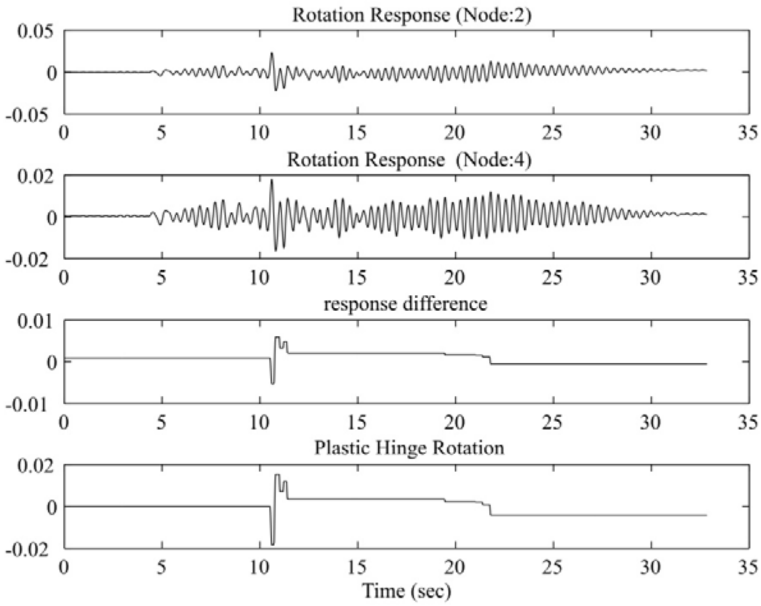

Fig. 7. Response difference and hinge rotation history

Hence having behavioral curve and rotational response history of the plastic hinge the current place on the behavior curve can be determined. Where the intensity of damage does not reach the point B, in other words if it lies between points A and B, there will also be a shift in the base line which demonstrates plastic deformation and can be captured by “approximate signal”, Fig.8.

In the case of intense damage, point B on the behavioral curve in Fig. 9, a total shift will occur in the base line which is visible in the wavelet approximation as well as the response itself. Also there will be an increase in the period of the structure which can be a criterion for determining intensity of damage.

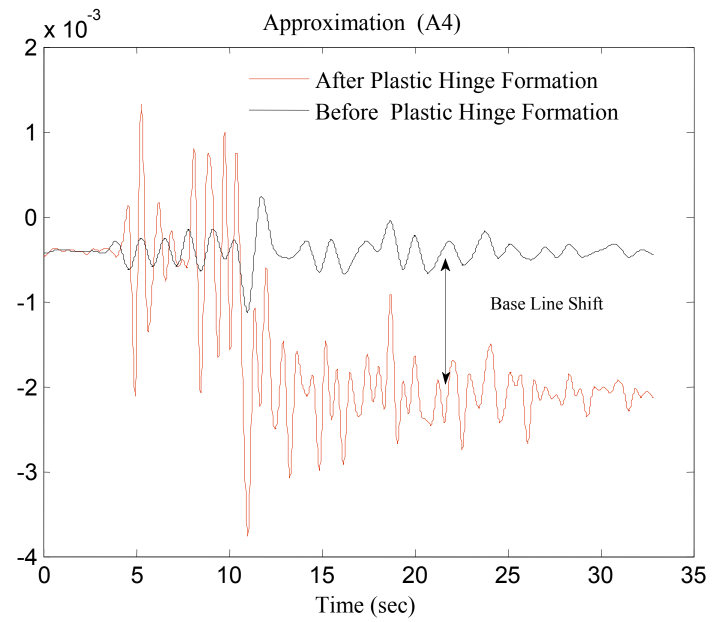

Fig. 8. 4th approximation obtained from wavelet transformation of point 2 rotational response (intensity corresponding to points A to B)

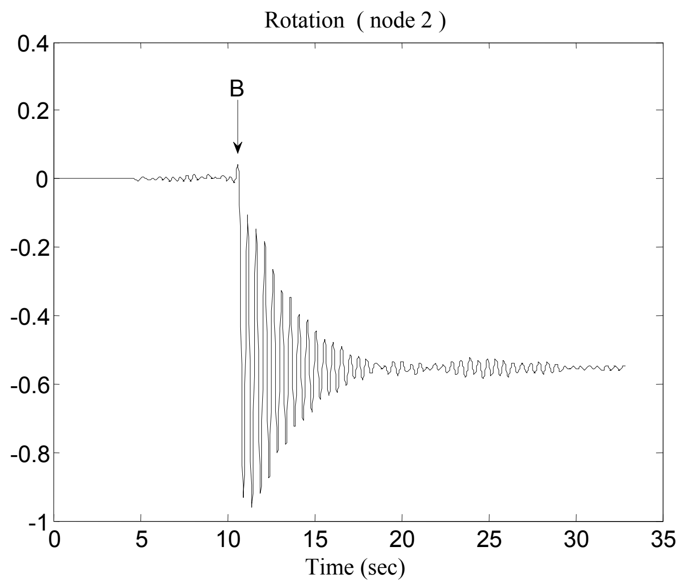

Fig. 9. Base line shift corresponding to point B

5 CONCLUSION

Plastic deformation causes permanent shift in response time history. In moment frames this shift is well represented in the rotational response time histories of nodes which mean plastic rotation in adjacent hinges. Recognizing any change in differences of the rotational response histories of the two adjacent nodes has a similar pattern to the rotational response history of the plastic hinge forming between them.

Shift in the base line is apparent in the "approximate" obtained from wavelet transform of the response. "Details" obtained from wavelet transform of the response could be used to determine damage onset while information on the severity of the damage can be estimated from "approximate"

REFERENCES

[1] Campbell, S.D., Richard, R.M., Partridge, J.E. Steel Moment Frame Damage Predictions Using Low-Cycle Fatigue. *14th World Conference on Earthquake Engineering, China* (2008).

[2] Misisti, M., Misiti, Y.,Oppenheim, G., Poggi, J. *Wavelets and Their Application*, ISTE Ltd, UK (2007).

[3] Ovanesova, A.V., Sua´rez, L.E. Applications of Wavelet Transforms to Damage Detection in Frame Structures. *Engineering Structures* (2004) **26**:39–49.

[4] *FEMA-356 Prestandard and commentary for the seismic rehabilitation of buildings*, Federal Emergency Management Agency, Washington, DC (2000).

[5] Raufi, F. and Bahar, O. Damage Detection in 3-Story Moment Frame Building by Wavelet Analysis , *14th ECEE* (2010).