System Identification procedures for nonlinear response of Buckling Restrained Braces

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ABSTRACT:

Buckling Restrained Braces are a type of hysteretic steel dampers in which it is not possible to visually inspect the level of damaged of the element after large earthquakes. This article is part of an investigation to evaluate different procedures to identify nonlinear behavior and possible damage of systems that present this type of elements. In this article three typical linear identification methods are used to evaluate their performance under possible nonlinear response of the element. The conclusion of this paper is that the results from this identification techniques do not generally provide a good identification or an equivalent linear system. All the methods evaluated give similar results indicating that the predominant system period is close to the initial linear conditions and not to the secant one, measured at the maximum deformation point of the hysteresis. On the contrary the identified damping ratio, increases when the nonlinearity does.

Keywords: Buckling Restrained Braces, Identification, Damage

1. INTRODUCTION

Buckling Restrained Braces (BRB) are starting to be used as an efficient hysteretic damper in seismic areas. They consist of a steel core brace that resist axial loads and an outer casing filled with concrete that restrains the buckling of the brace. The final response of the elements is a stable hysteresis loop with high energy dissipating capacity. Because the buckling restraining mechanism hides the core brace component, it is not possible to visually inspect the level of damaged that has occurred in the component after a large earthquake. In this article an analysis is performed on a single degree of freedom system to try to do identify the effect of different system identification techniques on the nonlinear response of a representative model of a buckling restrained structure.

This article is part of a research on system identification techniques applicable to detect the nonlinear response of structures with buckling restrain braces.

As an initial evaluation two typical system identification techniques are used on the nonlinear response of a single degree of system that exhibits the hysteresis of a buckling restrained braced system.

2. THE MODEL

The nonlinear response is modelled using the Bouc Wen model (Wen, 1976) adjusted to represent a smooth bilinear response (Black, Markis and Aiken, 2004). The hysteresis is modified for different elastic vibration periods (0.5 and 1.5 seconds, defined as T), post stiffness values (0, 0.2 and 0.5 of the elastic stiffness, Kpost) and yield level (Reduction values, R, of 2, 5 and 10 of the elastic response). Damping values in all cases is 2% critical damping ratio considering the initial stiffness. Fig. 1 presents the typical hysteresis obtained.

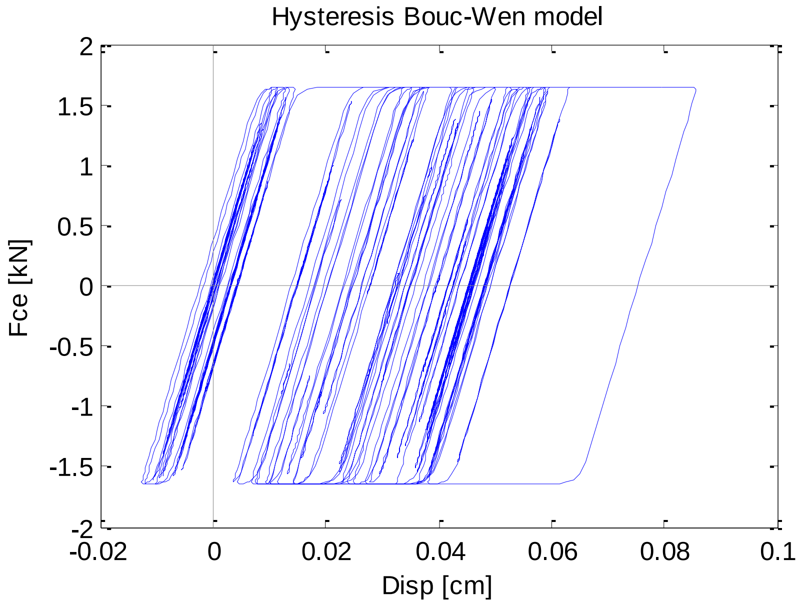


Figure 1: Typical hysteresis modeled by Bouc-Wen

3. THE IDENTIFICATION PROCEDURES

In this article only linear based system identification techniques are used. This is a standard procedure in analysis where the nonlinear response of the system is windowed and inside the window a linear response is assume. The objective of the article is to present the results obtained from this procedure.

Two type of excitation are applied at the base of the model, White Gaussian Noise (wgn), and the data of Llolleo Earthquake in 1985, Chile, recorded at Melipilla City (Melipilla85). Displacement (*d*), acceleration (*a*) and restorative force (*Q*), are captured from the response of each system. The identification is made over the acceleration data. Several other earthquake records have been evaluated with similar conclusions so they not presented here.

For the Gaussian noise excitation the identification is done using the non-parametric peak picking technique (Bendat and Piersol, 1986) and the parametric technics Stochastics Subspace Identification (Van Overschee, 1994). For the seismic excitation Multivariable Output-Error State Space technique (Moesp) (Verhaegen, 1994) with the Fast Multi Order implementation is used over the entire record.

3.1 Peak Peaking Technique

Peak Picking from Power Spectral Density (PSD) identification is performed on a nonlinear single degree of freedom system. The PSD is estimated using the Welch Method. Window length (Vh) of 30, 45, 60 and 90 second are used. The selected peak is associated with the predominant frequency and the equivalent stiffness of the system.

3.2 SSI-COV Technique

SSI-COV identification is performed on a nonlinear single degree of freedom system. A stabilization diagram is performed for order 2 to 100, and the automatic technique (Boroschek and Bilbao, 2015), which choose the stable modes of the system, is carried out. The modes are chosen and their respective identified stiffness (Kid) is plotted over hysteresis and compared with the initial stiffness (Kel).

3.3 Multivariable Output-Error State Space Technique

The Moesp technique is performed using 2 to 150 orders in Fast Multi Order implementation. A stabilization diagram is performed for order 2 to 100, and the same automatic technique, which choose the stable modes of the system, is carried out.

The transference function of the system, which is obtained dividing the Fast Fourier Transform (FFT) of the relative acceleration response to the ground acceleration is plotted together on the Stabilization Diagram. The modes are chosen and their respective identified stiffness (Kid) is plotted over hysteresis and compared with the initial stiffness (Kel).

4. RESPONSES CASES

The identified variables from both methods, for changing yield level, post yielding stiffness, period and stiffness nonlinear transition, are evaluated. Fig. 2 to Fig. 8 presents some of the responses obtained.

4.1 Variation of Yield Level

The first variation is the modification of the yield force. For this the reduction factor, R, is modified with, R = 0.5, 5 and 10. The linear and R=10 response and identification are presented in Fig. 2 and Fig. 3. This figures present the relative displacement and total acceleration response, the force displacement plot and the PSD. The identified stiffness with both methods and in all the cases is similar to the initial one. The form of the PSD spectrum shape exhibits changes as the system goes into nonlinear range, showing more local maxima and a wider bandwidth.

From SSI-COV results it is observed that the increase in the incursion in the nonlinear range reduces the equivalent stiffness (85% of initial one) and increases the equivalent damping ratio reaching 20% ratio above the original 2% when R is 10. This result is presented in Fig. 4.

Moesp results are similar to SSI-COV ones. Equivalent stiffness decreases and equivalent damping ratio increases while the system goes into nonlinear range. The equivalent damping, although, doesn't increase as much as in the precedent identification technique, and shows more dispersion as the order changes.

All frequency identify are quite close to the elastic, initial stiffness, values, The largest deviation observed in stiffness was larger than 80% of the initial, quite far from a secant stiffness.

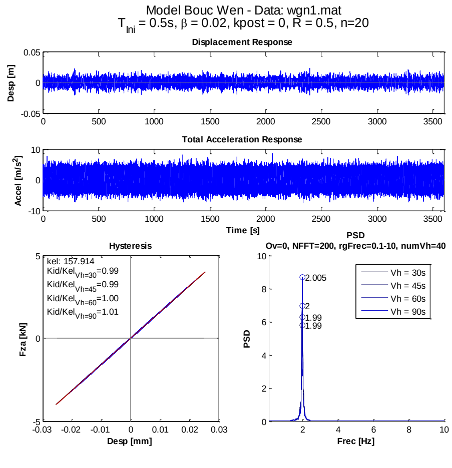


Figure 2. Linear system response to wgn. Hysteresis and Identified stiffness. Psd spectrum.

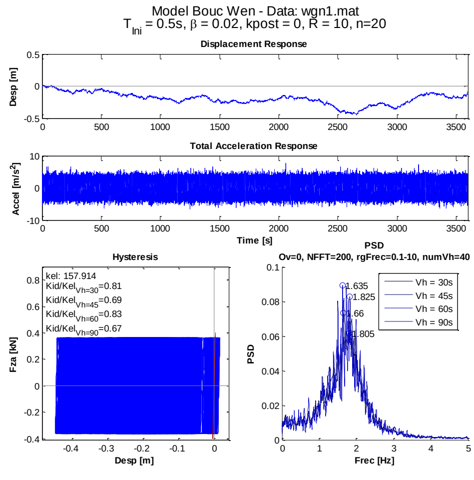
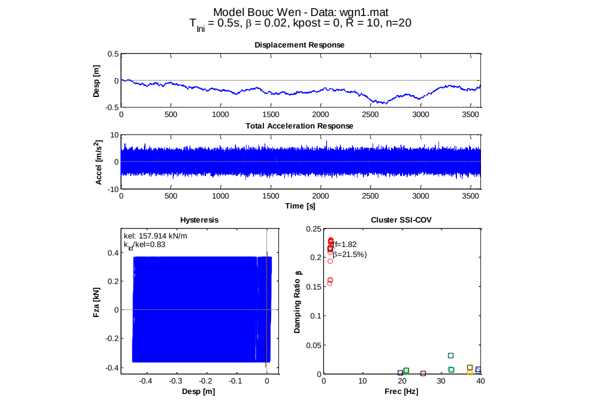


Figure 3. R=10 system response to wgn. Hysteresis and Identified stiffness. Psd spectrum.



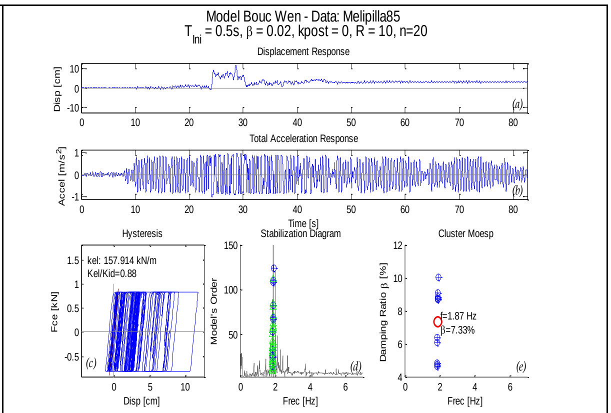


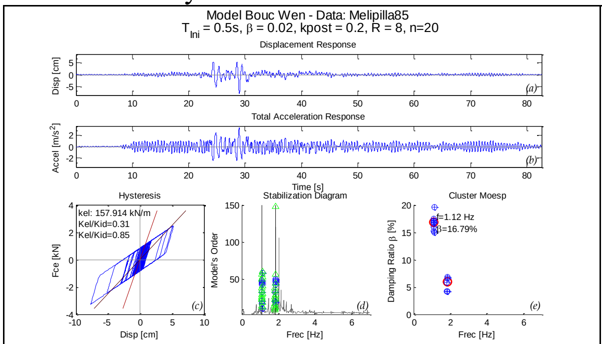
Figure 4. R=10 system response to wgn. hysteresis and identified stiffness. SSI-COV.

Figure 5. R=10 system response of earthquake. hysteresis and identified stiffness. Moesp.

4.2 Variation of Post Yield Stiffness

The increases in Kpost and small incursion in nonlinear range (R=2) does not modify significantly the linear PSD showing a stable peak around the elastic frequency. However, when this incursion is larger (R=8), the obtained stiffness is lower than the initial one, Fig. 6. When the incursion in the nonlinear range is large, R = 8, a decrease in the equivalent stiffness is visible reaching approximately 90% of its initial value, however, this is due to R, and Kpost has only a small impact. On the other hand, a light decrease in the identified damping ratio is observed, changing from ~15% when no Kpost is zero to ~11% when Kpost is 0.5.

The Moesp technique shows a similar trend in the estimation of equivalent stiffness, however in some response data this technique can capture a second mode that can be related to a secant stiffness associated with the maximum deformation, Fig. 7 and Fig. 8. Noteworthy that in some cases Moesp doesn't see any stable mode.



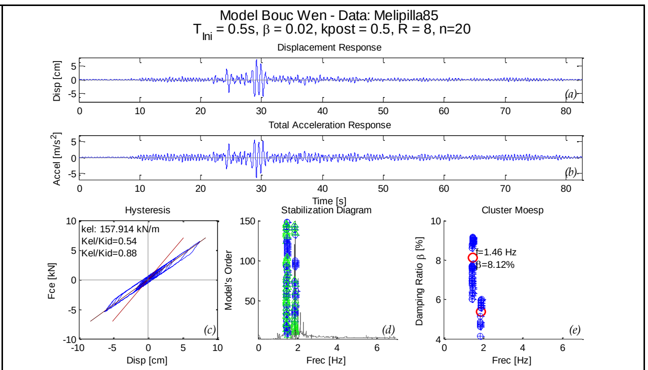


Figure 7. Variation of Post Yielding Stiffness and identified second mode.

Figure 8. Variation of Post Yielding Stiffness and identified second mode.

4.3 Transition between Elastic and Inelastic Response

When the transitions to the yielding phase is smooth, *n* values decrease for the Bouc-Wen model, the identify stiffness tends to decrease, starting from the initial stiffness associated with systems with *n* =

20, to approximately an equivalent stiffness that is 85% of the initial one, when n = 0.8, Fig. 9 to Fig. 11.

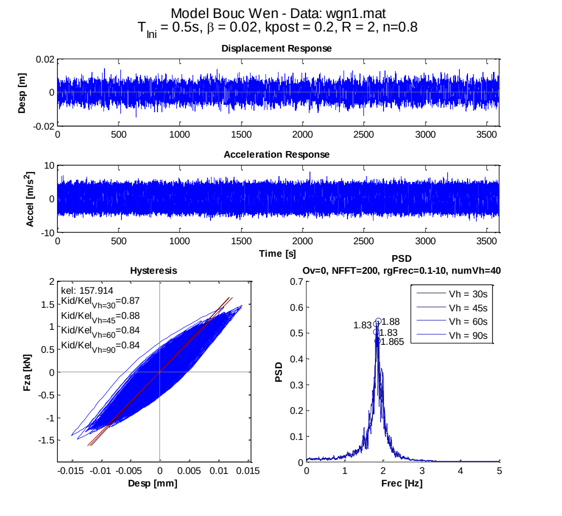


Figure 9. Response to varying transitions, n=0.8. PSD Method

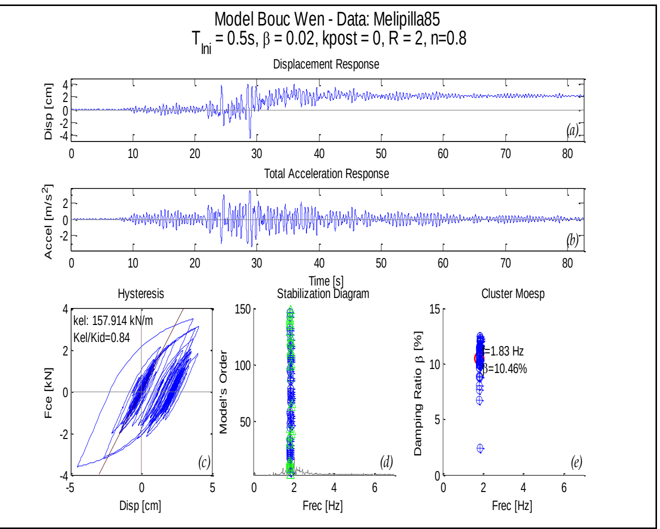


Figure 11. Response to varying transitions, n=0.8. Moesp.

For systems with high Reduction Factor, (R=8) the equivalent stiffness can go from 88% of the elastic stiffness, in systems with sharpness transition (n=20), up to approximately 70% in systems with very smooth transitions (n=0.8), and; the equivalent damping varies from approx. 15% to approx. 22%. Fig. 12 and Fig. 13 shows a system with large nonlinear excursions and smooth transition. Again, post yielding stiffness ratio contributes to a little decrease in the identified damping ratio under this conditions.

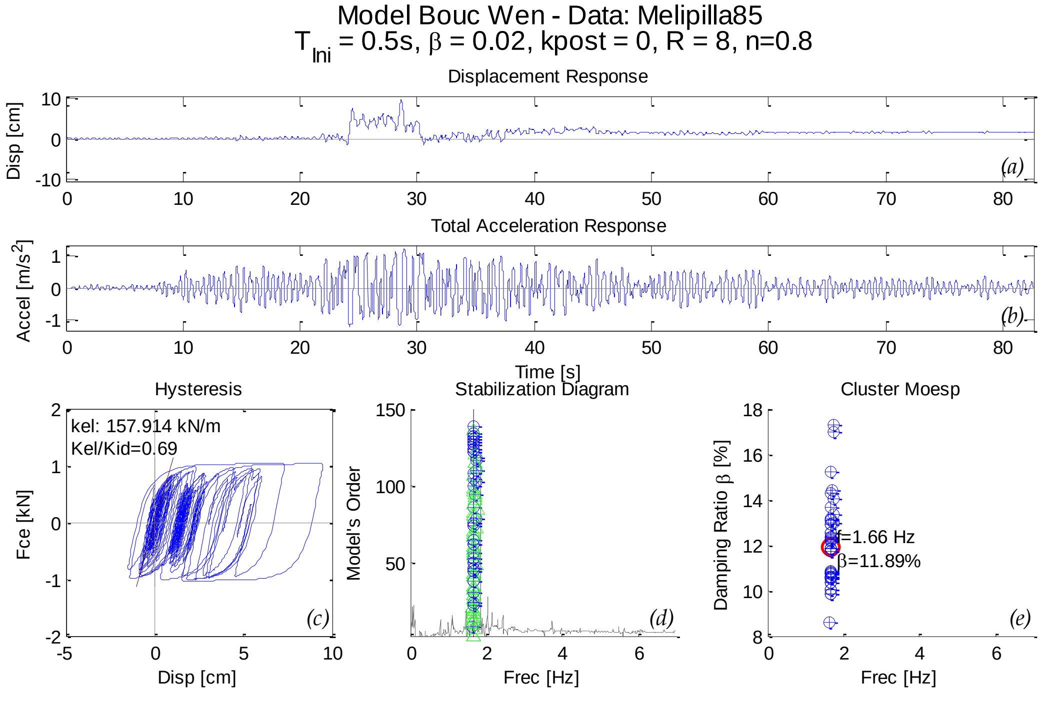


Figure 13. Response to varying transitions at large R values, n=0.8. Moesp

Also under more rounded hysteresis, Moesp shows also an identify frequency that corresponds to an equivalent stiffness close to the secant one associated at the maximum deformation. Fig. 14.

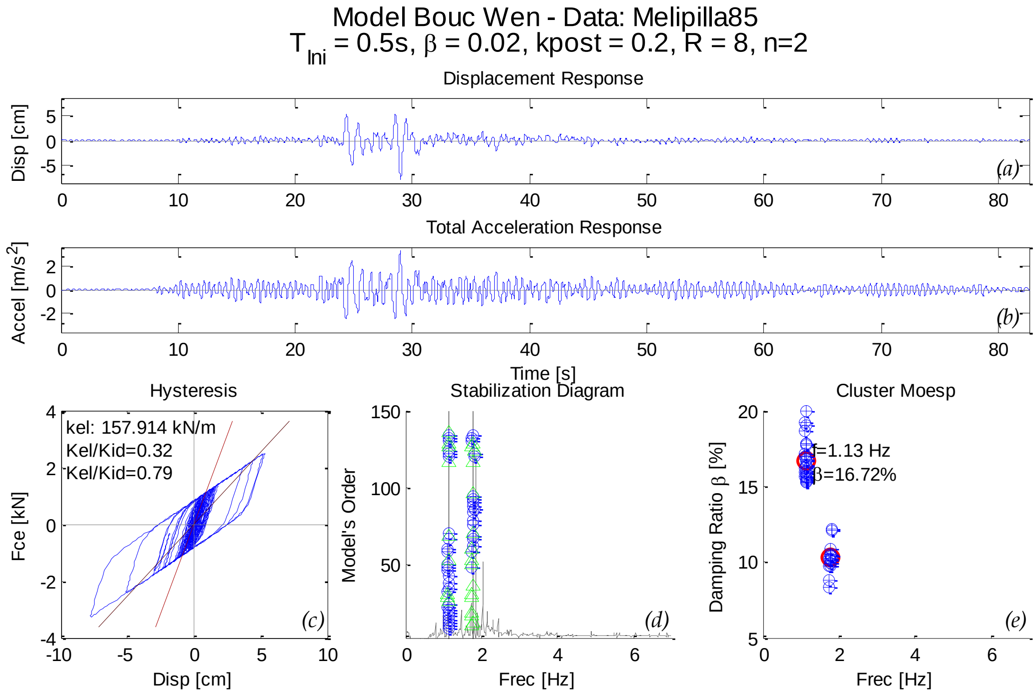


Figure 14. Two significant Equivalent Stiffness, n= 2. Moesp

4.4 Single Pulse and Gaussian Noise Excitation

In this case a pulse is applied over the acceleration Gaussian noise, in order to produce one large yield displacement in the middle of linear and elastic oscillation. Three pulses were uses, applied at the 10%, 50%, and 90% of the total time of data. Fig. 15 show them.

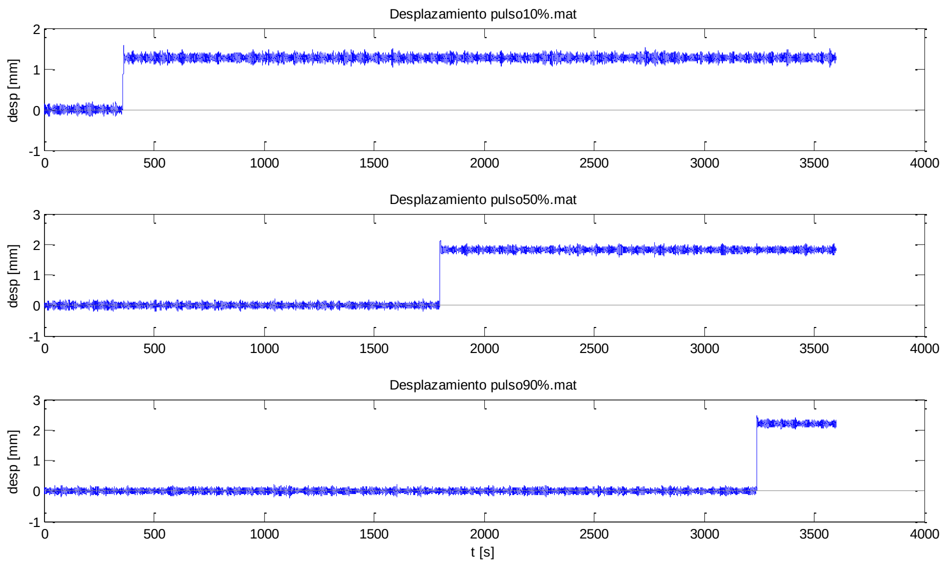


Figure 15. Displacement response record including a pulse

PSD spectrum of is plotted in Fig. 16. All of them show the same behavior resulting in the initial period. This result implies that a single incursion in nonlinear range does not changes the identified equivalent stiffness of the system, and a limited number of incursion would not change this result significantly either. On the other hand, when the degradation of stiffness starts before the system reach the yield force, as happened when n = 1, and many cycles of the hysteresis are wider and rounded, the equivalent stiffness decrease, as is visible in Figure 17.

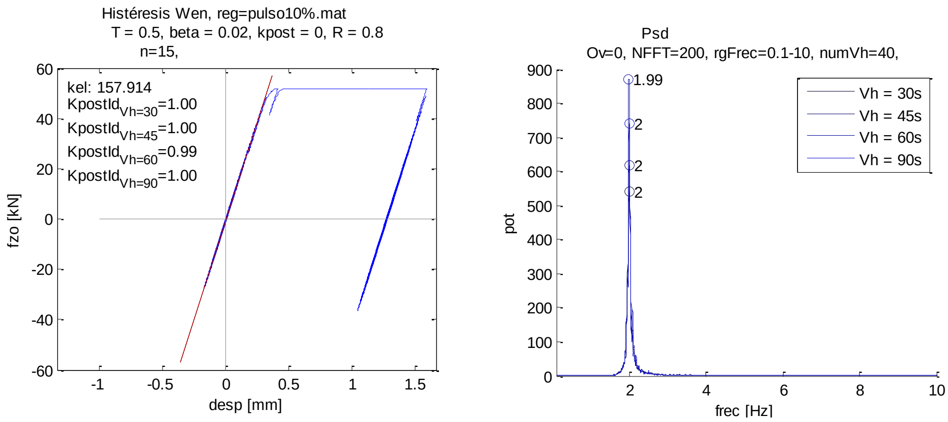


Figure 16. Nonlinear response two Gaussian noise with an added single pulse. High elastic to inelastic transition value (n=15).

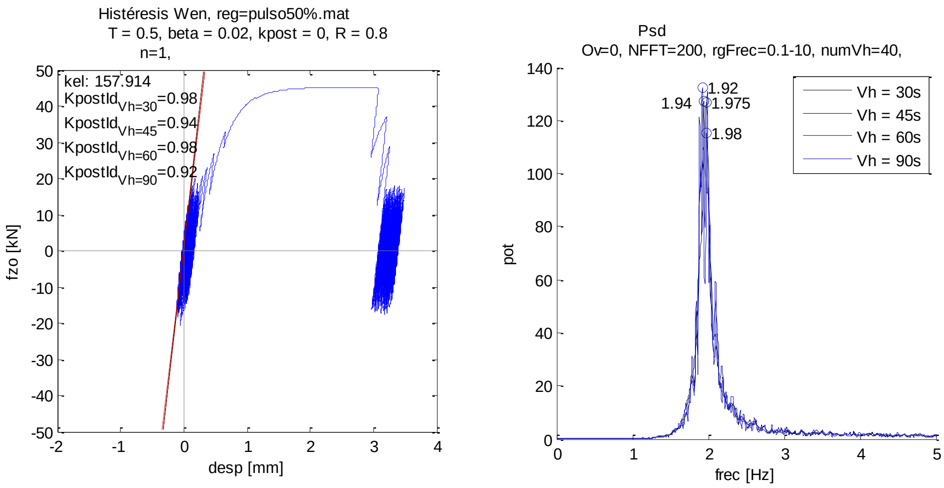


Figure 17 Nonlinear response two Gaussian noise with an added single pulse. Low elastic to inelastic transition value (n=1).

5. CONCLUSION

Linear identification technique was applied to a nonlinear system subject to white Gaussian noise and seismic ground motion. The equivalent stiffness derived from the identify frequency is similar to the initial stiffness and no close to an equivalent linear secant. On the contrary the identified damping ratio, increases when the nonlinearity does.

Large nonlinearities in these systems produce PSD spectrum with a clear maxima amplitude and large bandwidth. The predominant frequency corresponds to the natural frequency of the elastic system. SSI-COV identified periods close to the elastic one, nevertheless damping ratios increase with the level of nonlinear response.

Moesp identifies mainly the initial elastic periods, although in some cases it shows also the equivalent linear model secant values at maximum deformation point. Equivalent damping values increases when nonlinearity does, but it shows a lot of dispersion in the determination of its value.

It is confirmed that applying linear techniques on nonlinear response of systems do not necessarily indicate the severity of the change in structure properties rather the most present frequency on the system. The use of linear identification methods in nonlinear systems has to be used with care in order to properly evaluate the response of structures with the model used in this part of the research.

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