Experimental Study of the Variation of the Damping and Natural Period of a Full Scale Steel Frame

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SUMMARY
Authors present the results of the analysis of the free vibration records of a single bay, two stories steel frame. The studied frame has 4.1m total height and 2.85m bay width. Damping and fundamental period were determined when the frame was excited by free vibration along the main axis. Some joints of the frame can be fixed or released to simulate different states of damage. In addition to the simulation of damage, three different level of mass were applied to the structure.

Keywords: Damping, Natural period, Free vibration, damage.

1. INTRODUCTION

Structural instrumentation has allowed determining some structural properties of constructions, particularly the natural periods and in some cases modal shapes. Some structures have permanent instrumentation, so it has been possible to determine their dynamical response due to seismic events. Nevertheless, the majority of the structures, even some quite important, do not have permanent instrumentation that permit to study their behaviour during an earthquake.

For several years, many authors have been studying the possibility to obtain that kind of dynamic characteristics by using of non-permanent seismic instrumentation and most of these studies have been focused to the analysis of ambient vibration with reasonable results. A quite specific interest of those studies is the possibility to identify structural changes due to small or moderate earthquakes by the analysis of ambient vibration. There is a lot of work to do in this matter, so, authors of this article considered quite interesting to study the free vibration response of a steel structure in the laboratory with different mass patterns as well as different simulated structural stages of damage in order to experimentally measure the change of the structural damping as well as fundamental period of the structure studied.

2. STRUCTURAL MODEL

The structural steel model if formed by two parallel frames separated 0.8m. Each frame has two levels, 2.0m high, and one 2.85m bay (Figs. 2.1., 2.2., and 2.3.). Al steel bars in the structure are type OR 102mm x 51mm x 6.4mm. The joints between beams and columns were designed using steel plates, roller bearings and screws in a way that permitted even a rigid or a rotation-free joint in selected points. The model was built and tested in the Large Models Laboratory of the Materials Department in the Metropolitan Autonomous University campus Azcapozalco, in México City.

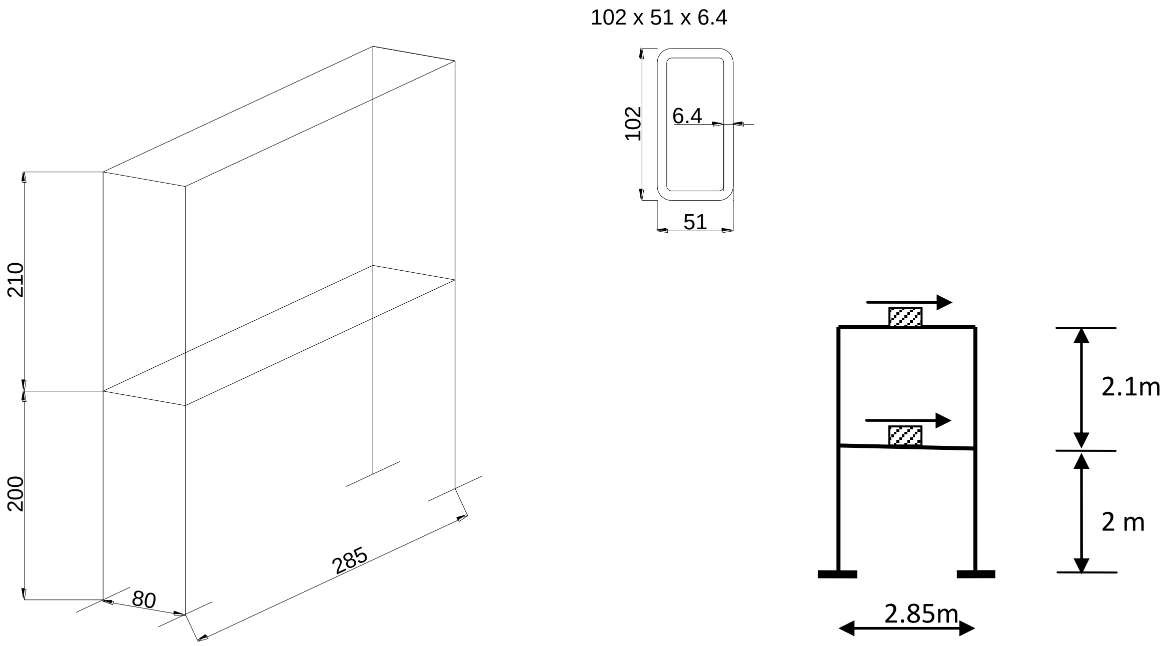

Figure 2.1. Geometry and location of sensors of the model studied

Figure 2.2. View of the steel frame studied

Figure 2.3. View of the special joints designed for the frame

3. METODOLOGY

3.1. Description of Equipment

In order to register the free vibration of the model, five FBA-11 Kinemetrics uniaxial accelerometers were located in the structure. Accelerometers were connected to a Kinemetrics K2 digital recorder. The system was controlled by a computer. The accelerometers were oriented along the longitudinal axis of the structure (Fig. 3.1.)

Figure 3.1. Equipment used for the study

3.2. Combinations of load and states of damage

Several combinations of load and states of damage were considered. Load combinations were three:

Load 1: 300 Kg in each level, 600 Kg total
Load 2: 200 Kg in each level, 400 Kg total
Load 3: 100 Kg in each level, 200 Kg total

Regarding states of damage, they were obtained by removing the screws of a particular joint, so, it was rigid before and free to rotate after the screws were removed, converting the joint from rigid to articulated. In all cases, the articulated joints were generated in the longitudinal axis only, in other words, the loss of rigidity was generated in the longitudinal axis only, not in the transversal axis.

Joints with these conditions were located in the first level beams, as well as in the inferior and superior extremes of the first level columns. Table 3.2.1. describes the combinations of load-state of damage studied.

Table 3.2.1. Combinations Of Load And State Of Damage

Load	Code	State of damage
Load 1: 600 Kgs	A1	Original condition (No damage)
	A2	Two beams with one articulation each
	A3	Two beams bi-articulated
	A4	Two beams bi-articulated plus two beams with one articulation
	A5	Four beams bi-articulated
	A6	Four beams bi-articulated plus one inferior articulation in a column
	A7	Four beams bi-articulated plus two inferior articulations in two columns
	A8	Four beams bi-articulated plus three inferior articulations in three columns
	A9	Four beams bi-articulated plus six inferior articulations in six columns

	A10	Four beams bi-articulated plus six inferior articulations in six columns plus one superior articulation in one column
	A11	Four beams bi-articulated plus six inferior articulations in six columns plus two superior articulations in two columns
Load 2: 400 Kgs	B1	Original condition (No damage)
	B2	Two beams with one articulation each
	B3	Two beams bi-articulated
	B4	Two beams bi-articulated plus two beams with one articulation
	B5	Four beams bi-articulated
	B6	Four beams bi-articulated plus one inferior articulation in a column
	B7	Four beams bi-articulated plus two inferior articulations in two columns
	B8	Four beams bi-articulated plus three inferior articulations in three columns
	B9	Four beams bi-articulated plus six inferior articulations in six columns
	B10	Four beams bi-articulated plus six inferior articulations in six columns plus one superior articulation in one column
	B11	Four beams bi-articulated plus six inferior articulations in six columns plus two superior articulations in two columns
Load 3: 200 Kgs	C1	Original condition (No damage)
	C2	Two beams with one articulation each
	C3	Two beams bi-articulated
	C4	Two beams bi-articulated plus two beams with one articulation
	C5	Four beams bi-articulated
	C6	Four beams bi-articulated plus one inferior articulation in a column
	C7	Four beams bi-articulated plus two inferior articulations in two columns
	C8	Four beams bi-articulated plus three inferior articulations in three columns
	C9	Four beams bi-articulated plus six inferior articulations in six columns
	C10	Four beams bi-articulated plus six inferior articulations in six columns plus one superior articulation in one column
	C11	Four beams bi-articulated plus six inferior articulations in six columns plus two superior articulations in two columns

3.2. Free Vibration Registration

Five events of free vibration of the structure were registered for each combination of load-state of damage established. Free vibration was produced by applying a displacement to the structure along its longitudinal axis. After that, the structure was liberated and it vibrated freely while the instrumentation recorded their movement. Each event last 60 seconds and the digital recorder saved it at 200 samples of acceleration per second.

4. RESULTS

For each combination of load-state of damage studied, uncorrected and unfiltered accelerograms were obtained for the five events recorded (Fig. 4.1.) Then, filtered and corrected accelerograms were obtained. From corrected and filtered accelerograms, Fourier spectra were obtained using Seismic Workstation Software by Kinemetrics. For each combination, mean Fourier spectra were calculated. In addition, damping was obtained from accelerograms by means of measure the amplitude of the peak acceleration as well as the time between them. Damping presented is the average of five cases for each combination. Results are presented in table 4.1 and also in Figs. 4.2. to 4.9.

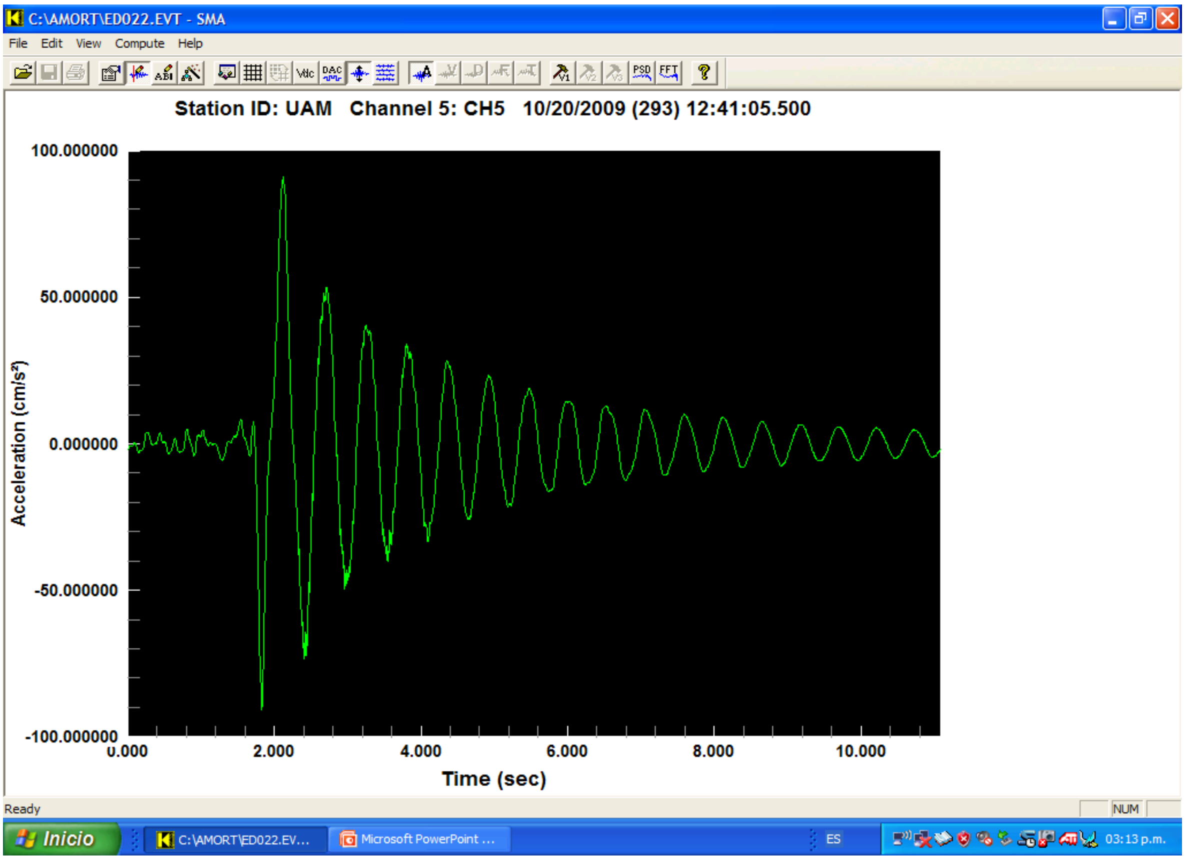

Figure 4.1. Example of free vibration accelerogram registered

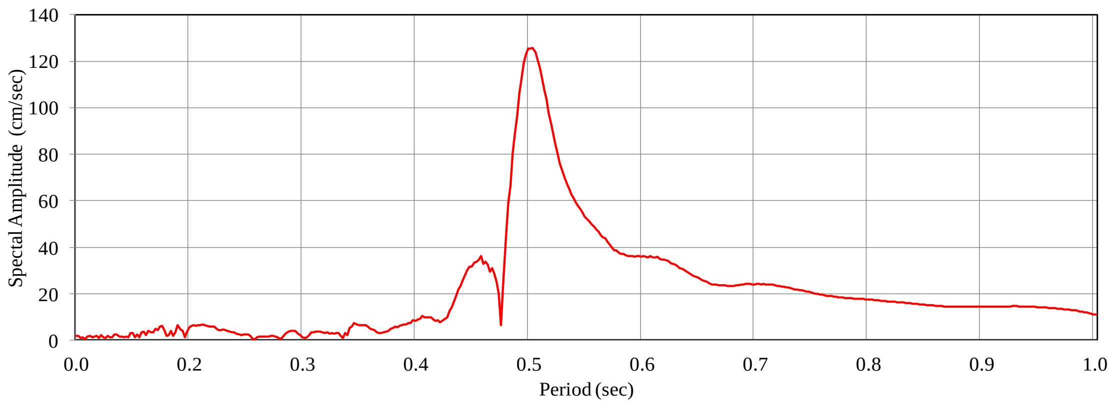

Figure 4.2. Fourier Spectrum for combination A1

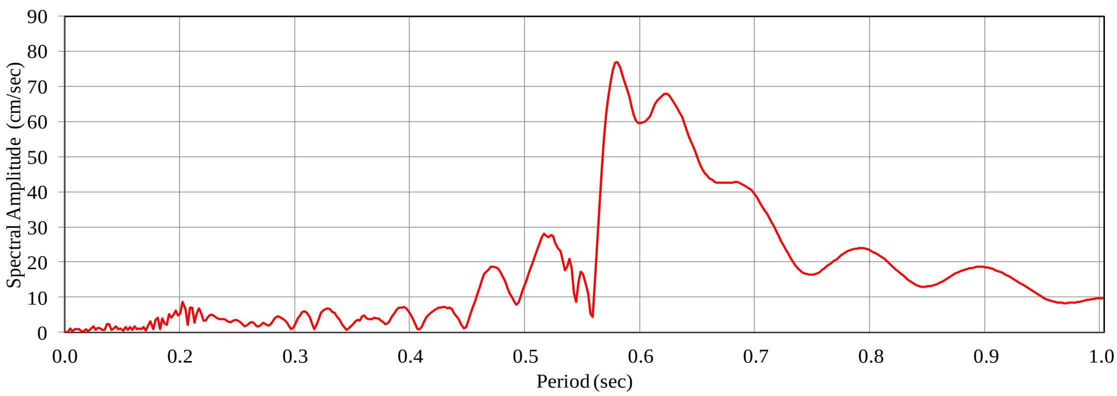

Figure 4.3. Fourier Spectrum for combination A11

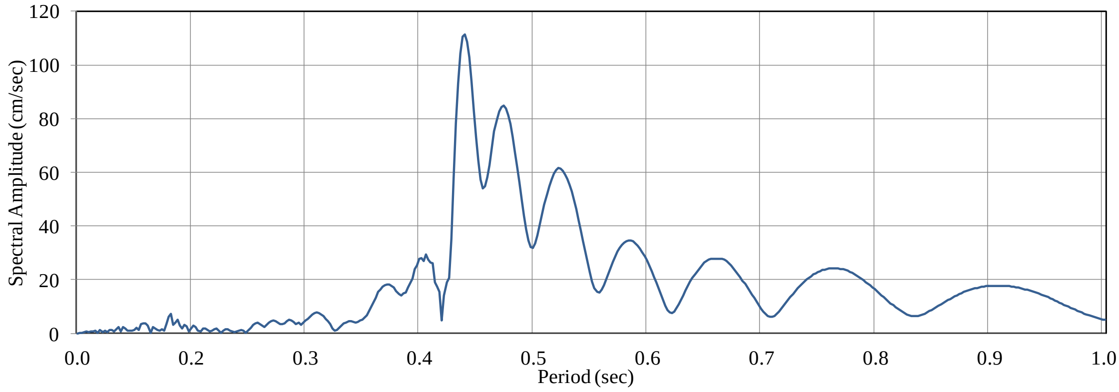

Figure 4.4. Fourier Spectrum for combination B1

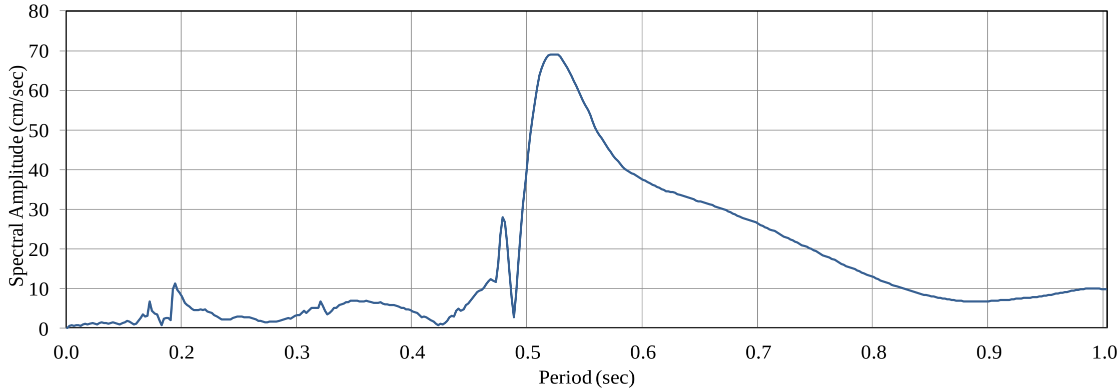

Figure 4.5. Fourier Spectrum for combination B11

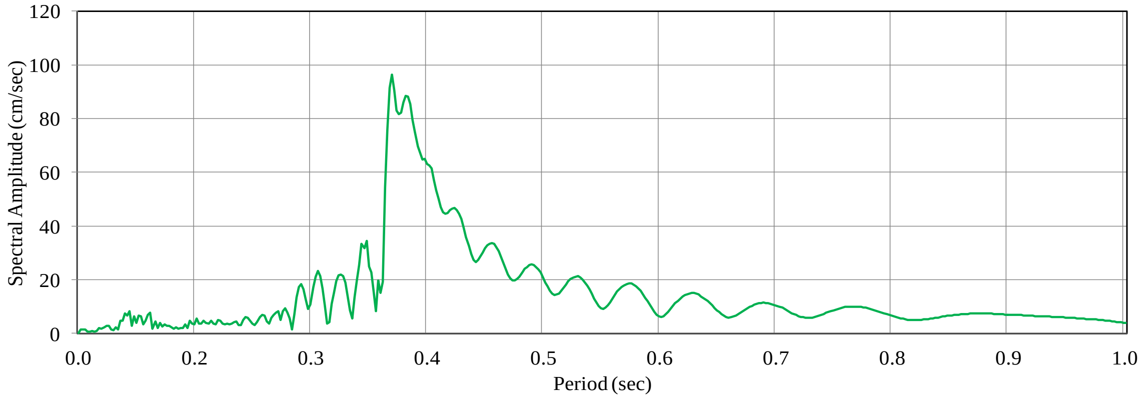

Figure 4.6. Fourier Spectrum for combination C1

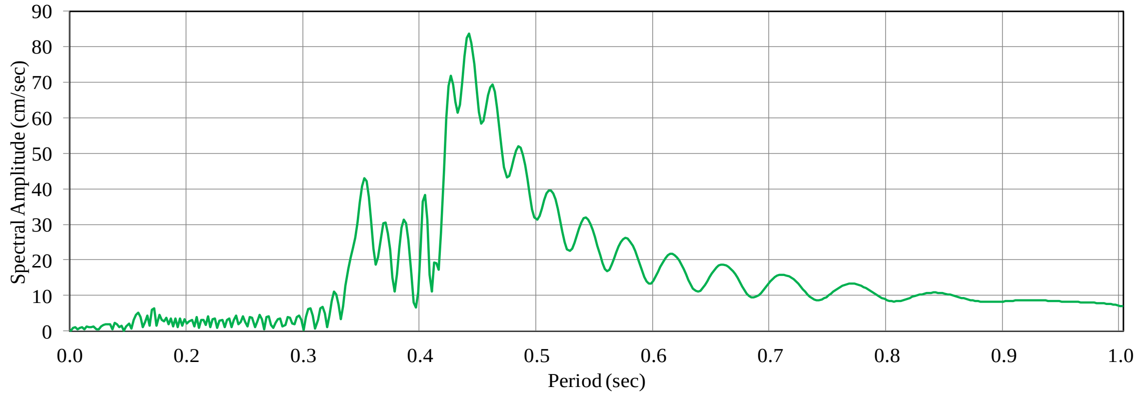

Figure 4.7. Fourier Spectrum for combination C11

Table 4.1. Period And Damping Obtained For The Combinations Of Load - State Of Damage

Load	Code	State of damage	Period (sec)	Damping (%)
Load 1: 600 Kg	A1	Original condition (No damage)	0.50	1.9
	A2	Two beams with one articulation each	0.51	2.0
	A3	Two beams bi-articulated	0.52	2.1
	A4	Two beams bi-articulated plus two beams with one articulation	0.50	2.1
	A5	Four beams bi-articulated	0.50	2.0
	A6	Four beams bi-articulated plus one inferior articulation in a column	0.50	2.4
	A7	Four beams bi-articulated plus two inferior articulations in two columns	0.52	2.0
	A8	Four beams bi-articulated plus three inferior articulations in three columns	0.55	--
	A9	Four beams bi-articulated plus six inferior articulations in six columns	0.55	2.4
	A10	Four beams bi-articulated plus six inferior articulations in six columns plus one superior articulation in one column	0.58	2.6
	A11	Four beams bi-articulated plus six inferior articulations in six columns plus two superior articulations in two columns	0.58	2.6
Load 2: 400 Kg	B1	Original condition (No damage)	0.43	2.0
	B2	Two beams with one articulation each	0.45	2.0
	B3	Two beams bi-articulated	0.45	1.9
	B4	Two beams bi-articulated plus two beams with one articulation	0.46	1.8
	B5	Four beams bi-articulated	0.46	1.7
	B6	Four beams bi-articulated plus one inferior articulation in a column	0.46	1.8
	B7	Four beams bi-articulated plus two inferior articulations in two columns	0.50	2.3
	B8	Four beams bi-articulated plus three inferior articulations in three columns	0.50	2.0
	B9	Four beams bi-articulated plus six inferior articulations in six columns	0.50	2.0
	B10	Four beams bi-articulated plus six inferior articulations in six columns plus one superior articulation in one column	0.50	2.4
	B11	Four beams bi-articulated plus six inferior articulations in six columns plus two superior articulations in two columns	0.52	2.7
Load 3: 200 Kg	C1	Original condition (No damage)	0.37	1.9
	C2	Two beams with one articulation each	0.37	1.7
	C3	Two beams bi-articulated	0.38	1.8
	C4	Two beams bi-articulated plus two beams with one articulation	0.38	2.0
	C5	Four beams bi-articulated	0.38	1.8
	C6	Four beams bi-articulated plus one inferior articulation in a column	0.38	1.8
	C7	Four beams bi-articulated plus two inferior articulations in two columns	0.39	2.0
	C8	Four beams bi-articulated plus three inferior articulations in three columns	0.40	2.2
	C9	Four beams bi-articulated plus six inferior articulations in six columns	0.40	1.9
	C10	Four beams bi-articulated plus six inferior articulations in six columns plus one superior articulation in one column	0.42	2.3
	C11	Four beams bi-articulated plus six inferior articulations in six columns plus two superior articulations in two columns	0.44	3.0

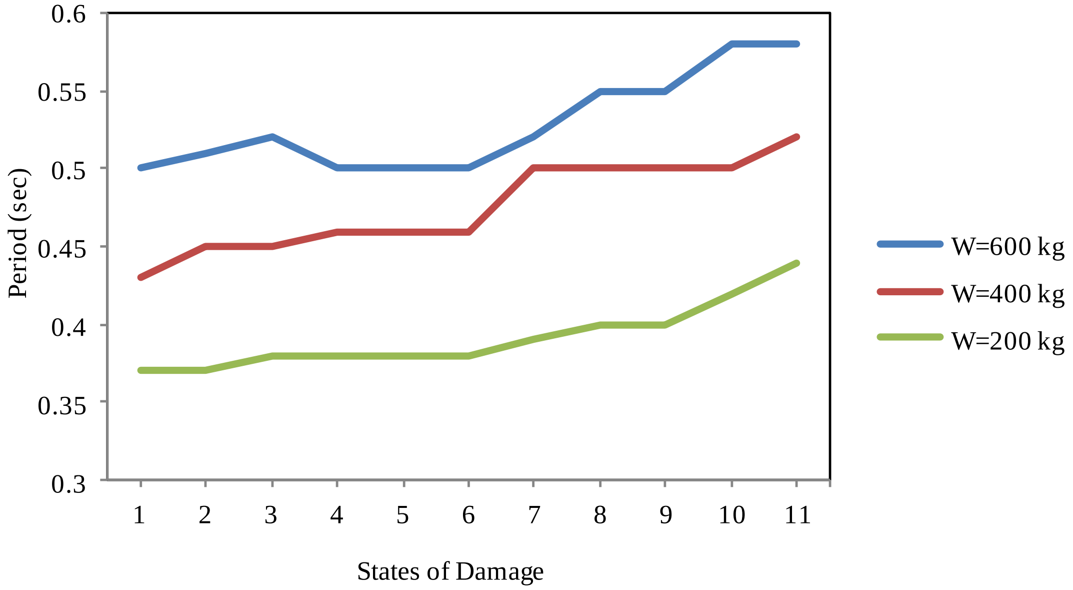

Figure 4.8. Variation of the period due to the change of the load and the loss of rigidity of the model

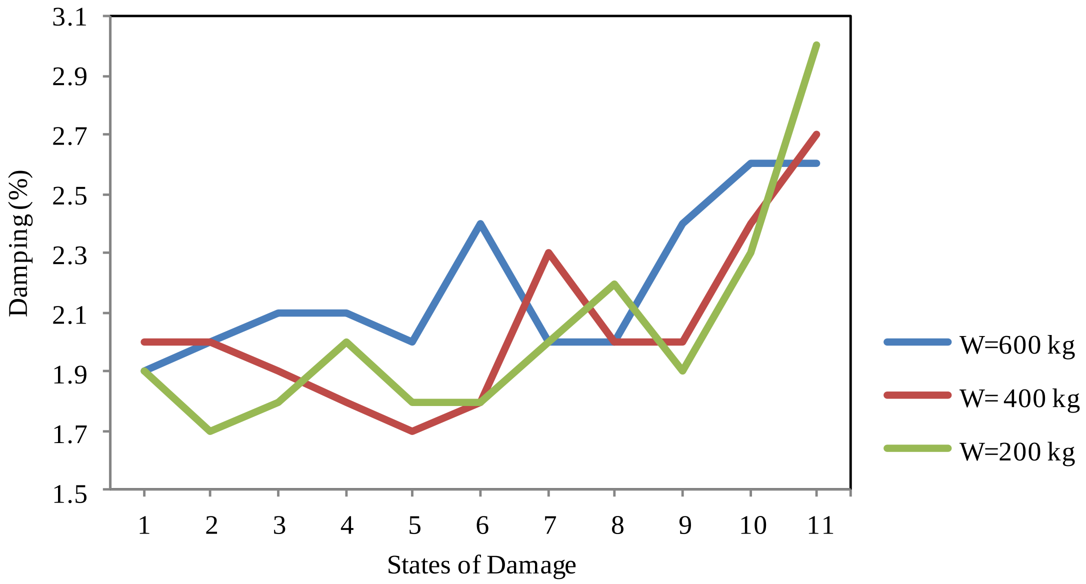

Figure 4.9. Variation of the damping due to the change of the load and the loss of rigidity of the model

In general, from the results presented, it can be observed that for each load, period and damping increased their value when restrictions disappeared consecutively.

Load I: 600 kg. Period of structure without damage was 0.50s. It increased its value in 4% in the first two stages. Period returned to 0.50s in stages A4, A5 and A6. Then, period increased slowly until 16%, it was the total increment for this load. Rigidity decreased in 26%. Damping started in 1.9% and finished in 2.6%, an increment of 37%.

Load II: 400 kg. Initial period was 0.43s. When rigidity decreased, period slowly increased until 0.52s, that represent 21% more than original one. For this case rigidity decreased 32%. Damping went from 2.0% to 2.7%, it means 35% of total increment.

Load III: 200 kg. Original period was 0.37s and increased to 0.44s, which means an increment of 19%.

Rigidity decreased 32%. Damping started in 1.9% and finished in 3%. Total increment was 56%

In conclusion, significant increments were observed in fundamental period as well as in damping when rigidity was deteriorated. It can be observed for the three types of load considered. Nevertheless, these significant increments only can be observed for advanced stages of damage. For low and medium loss of rigidity the increment of the period or the damping were small.

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