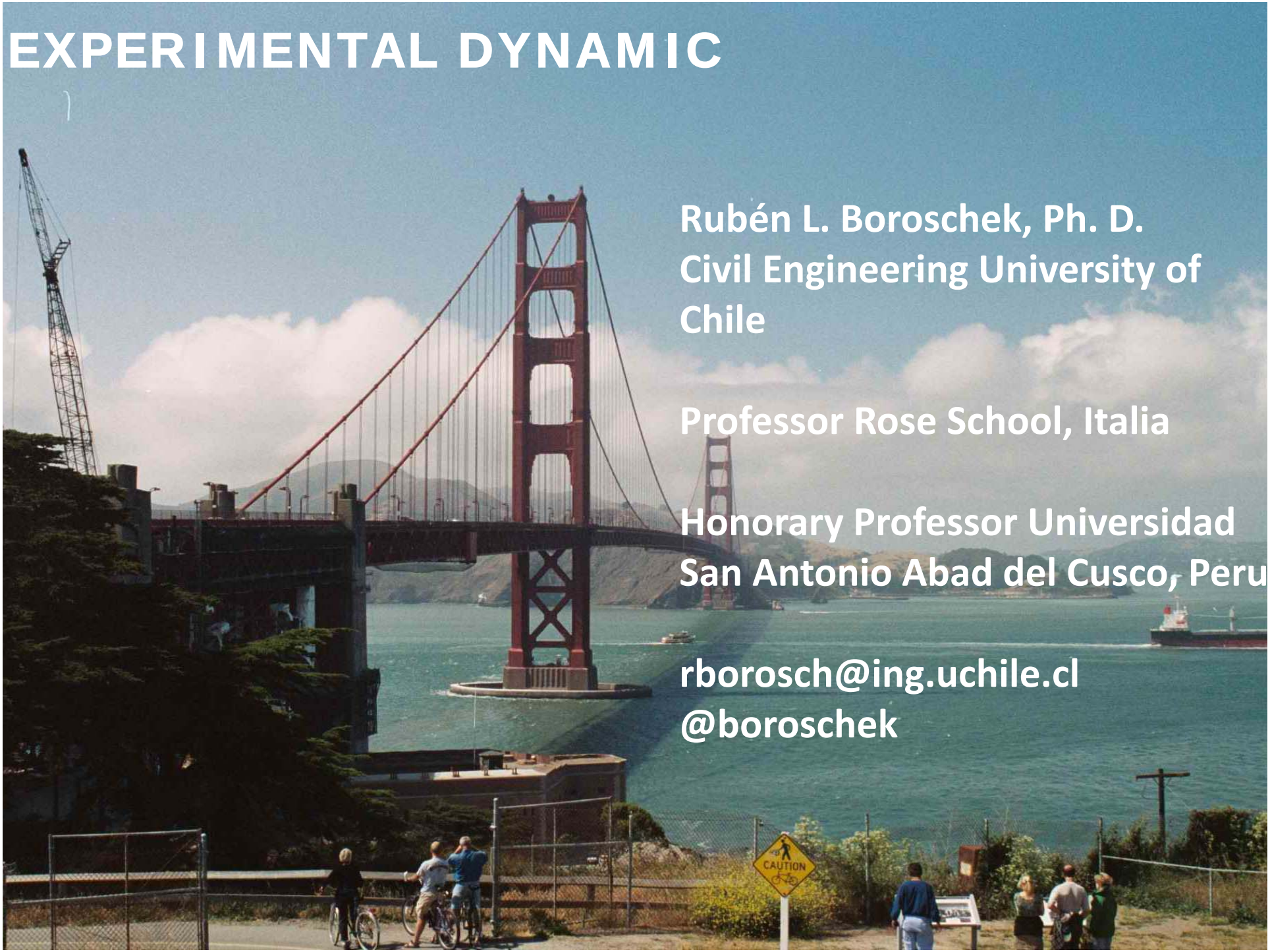
EXPERIMENTAL DYNAMIC



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OBJECTIVES

- Evaluate
  - Dynamic Properties
  - Response
- Model Verification and Updating
- Analysis and Design Recommendations
- Others

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LABORATORY TEST

Limitations

- Not full structure or full size.
- Representatives construction, environmental or boundary conditions.
- Limited excitations conditions

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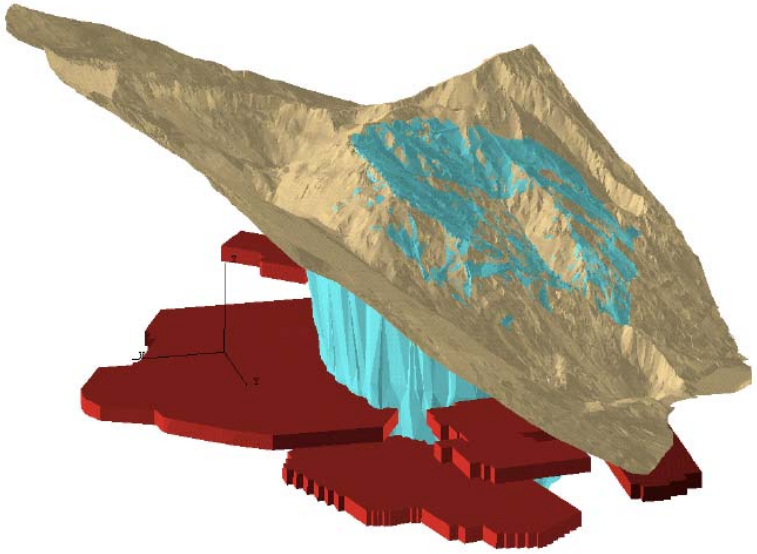
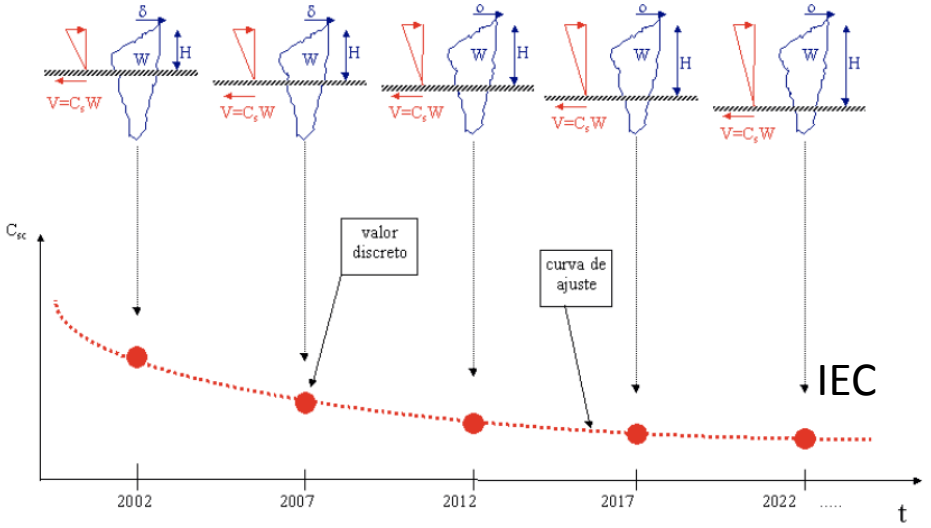
LABORATORY TEST (UCB S. MAHIN)

FIELD TEST





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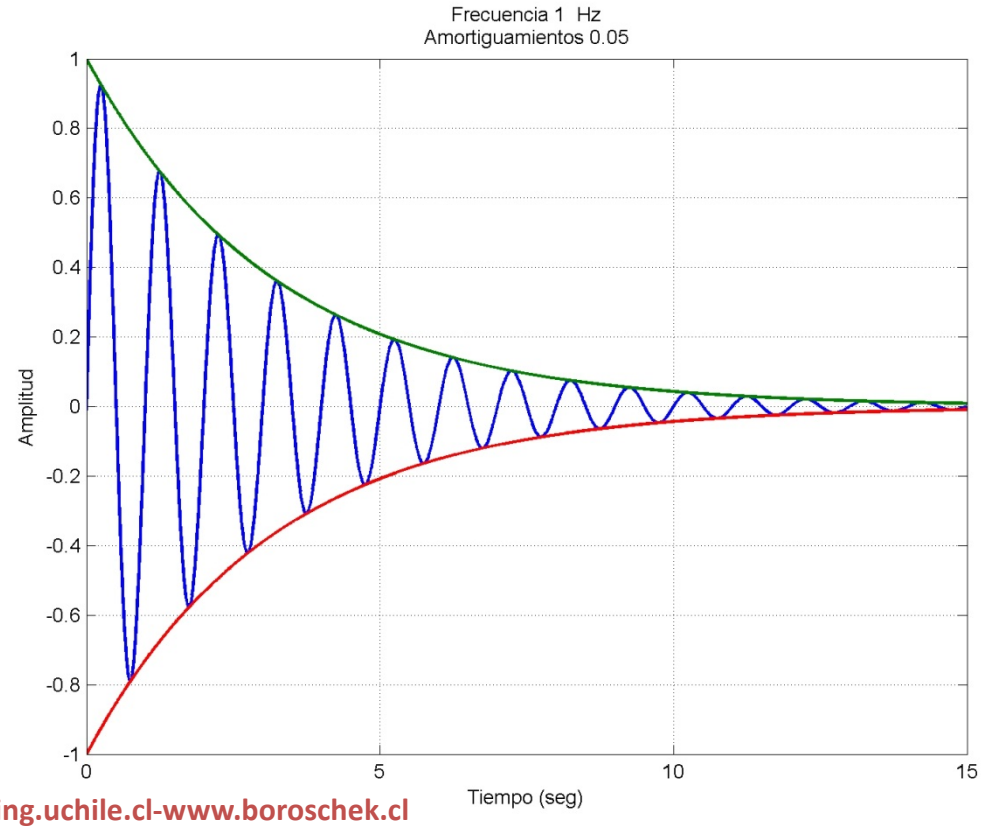
TYPICAL METHODS IN CIVIL ENG

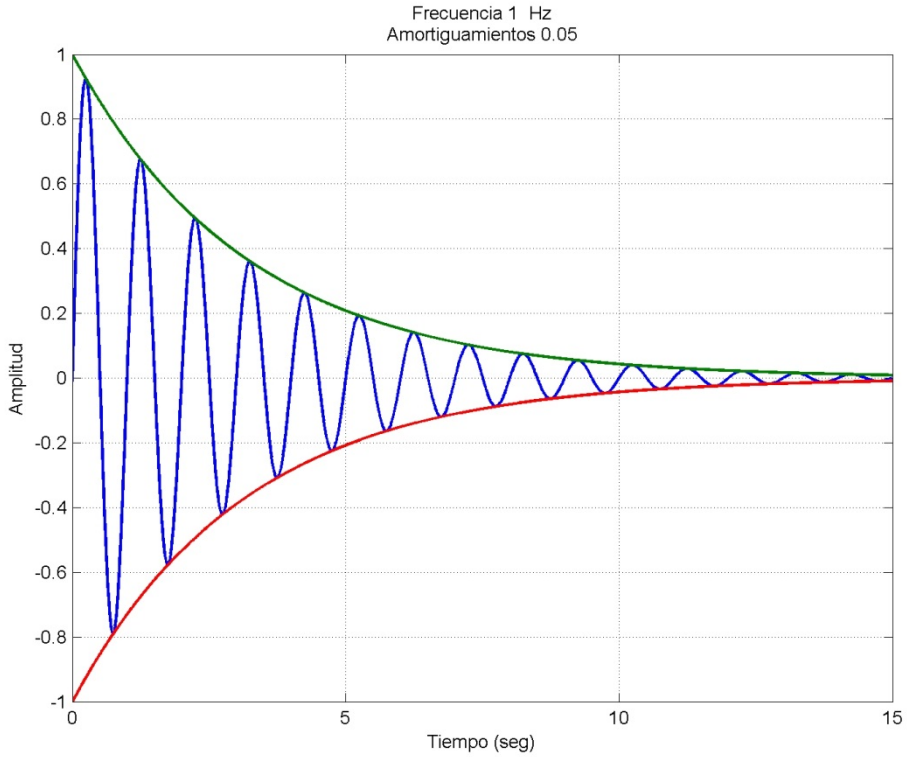
- Initial Conditions (Impact- Pull Back Displacement Velocity)
- Controlled Forced Vibration:
  - Monofrequency
  - Random
  - Hybrid
- Ambient Vibration (microtremors)
- Operational Conditions.
- Earthquakes.

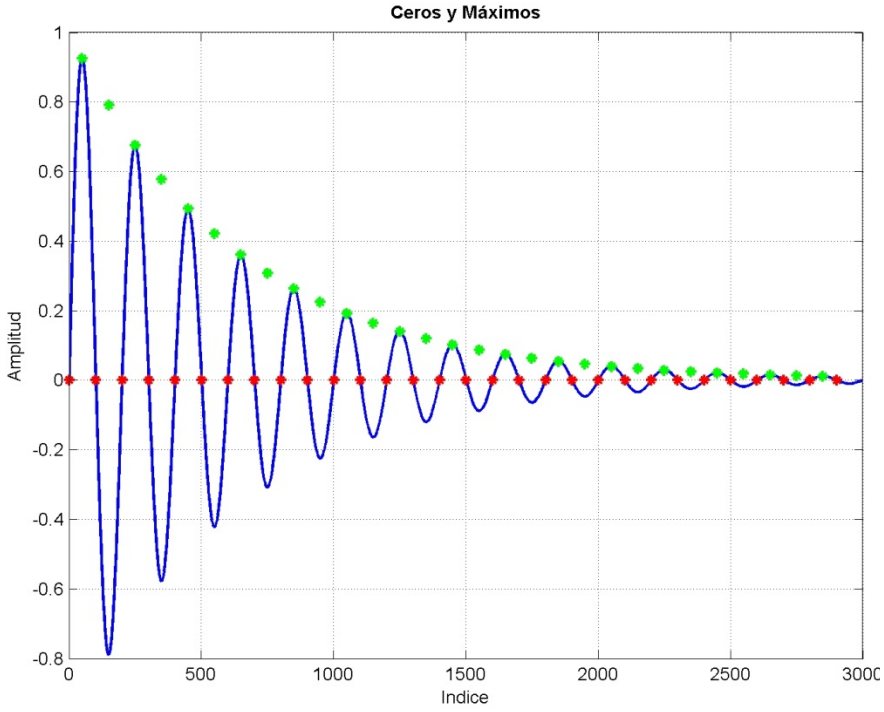
INITIAL CONDITIONS

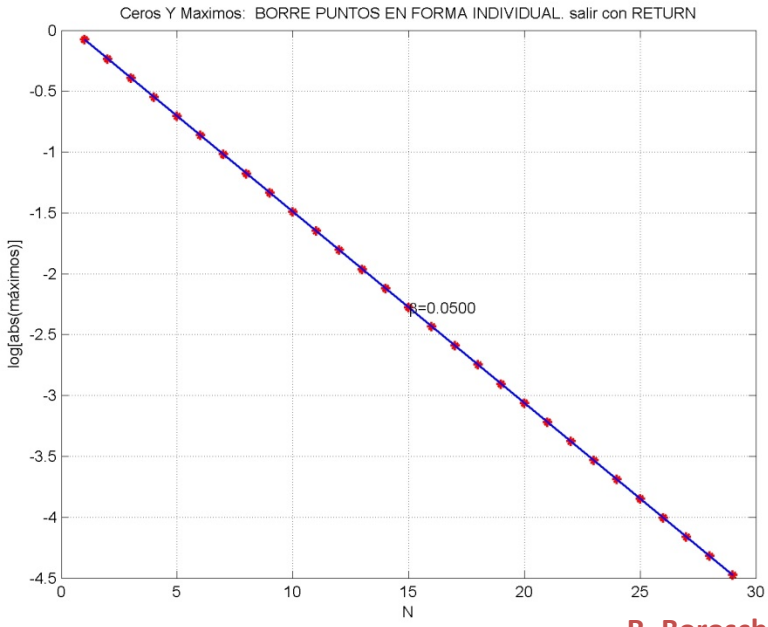
$$v(t) = e^{-w\beta t}\left(A\cos(w_d t) + Bsen(w_d t)\right)$$

$$\ln\left(\frac{v_i}{v_{i+mT}}\right) = \frac{2\pi\beta m}{\sqrt{1-\beta^2}}$$









$$\beta = \frac{pendiente}{\pi}$$

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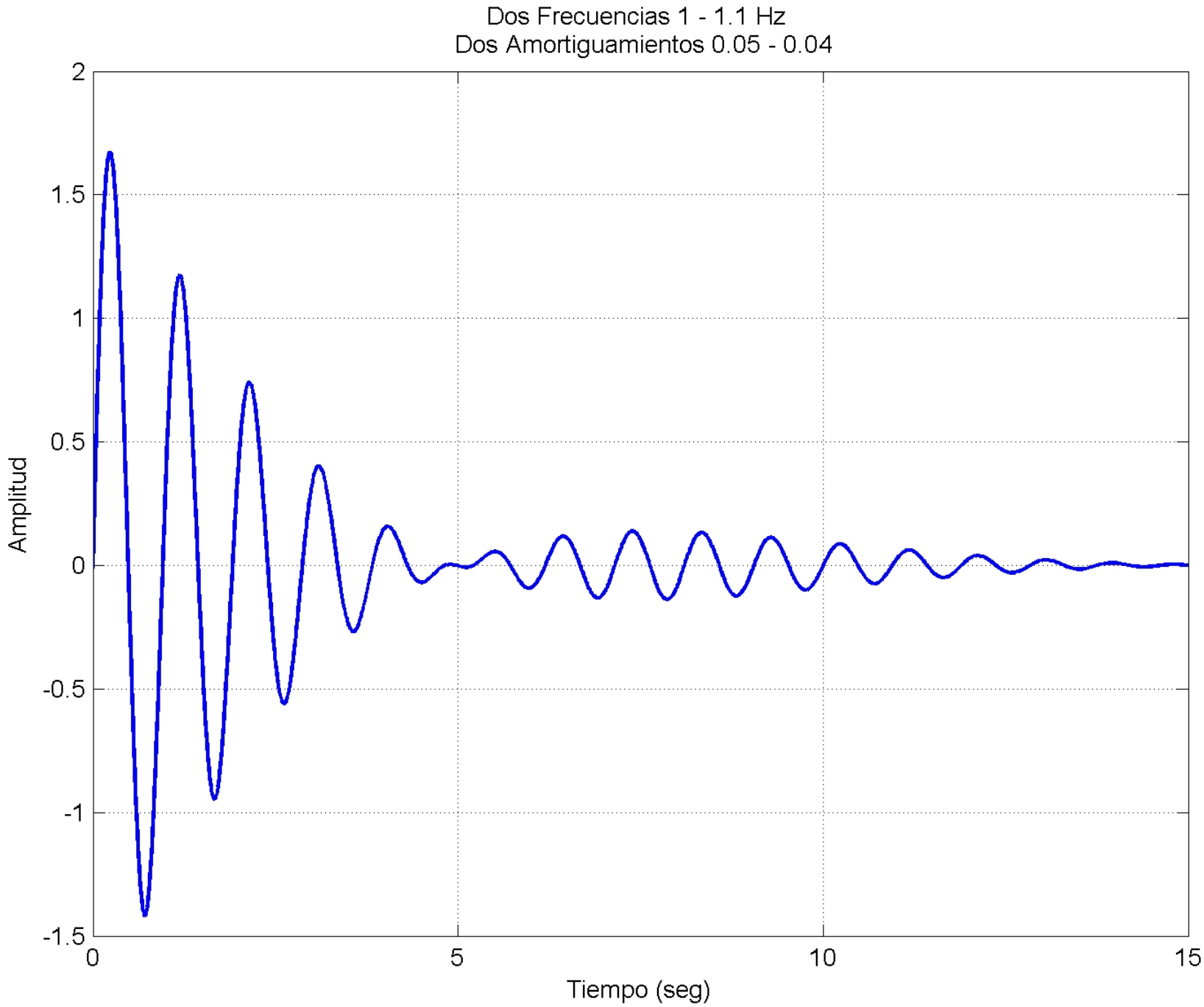

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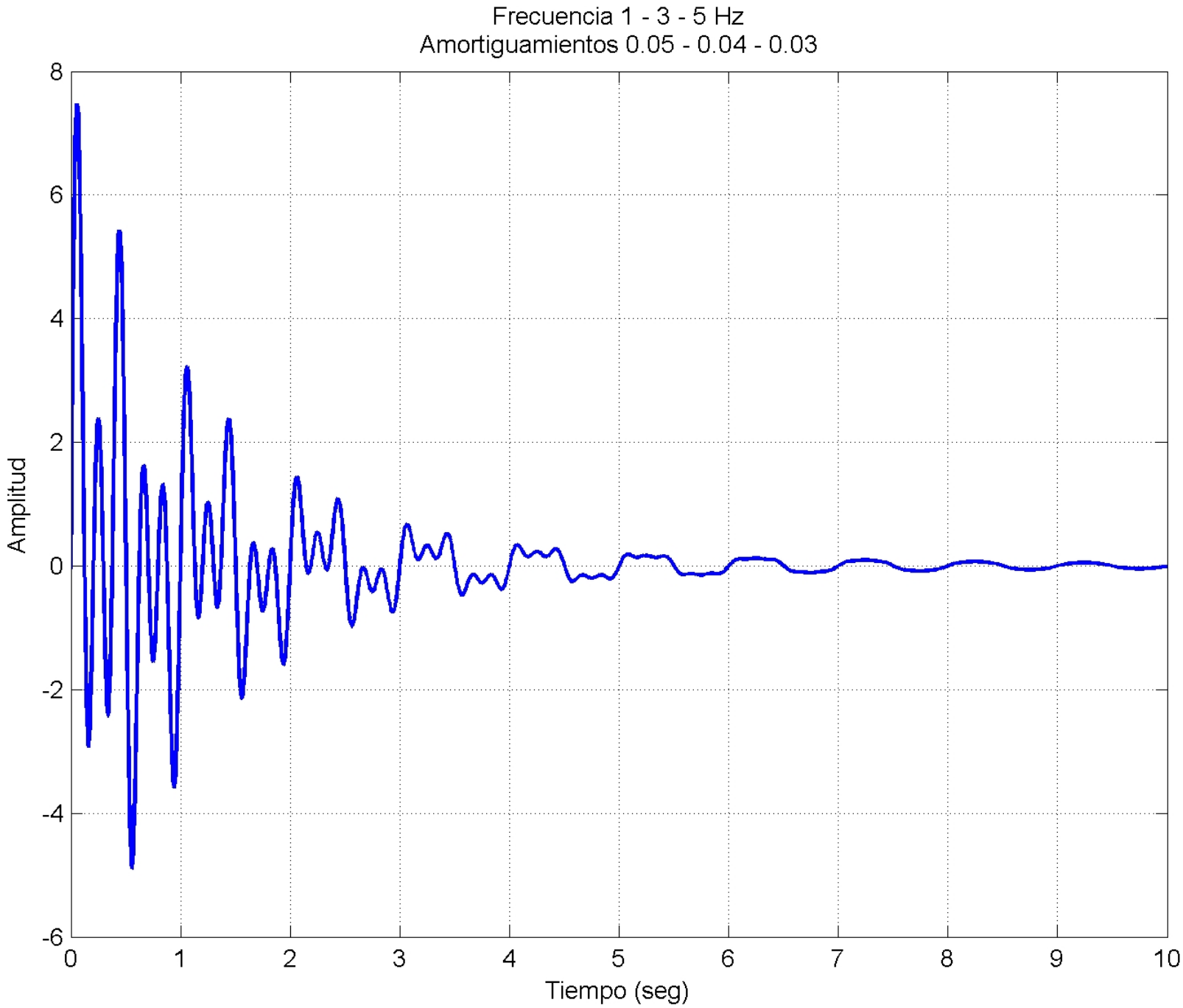

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NO LINEAR FIT (?)

$$v(t) = \sum_{i=1}^{Modos} e^{-w_i \beta_i t} \left(A_i \cos(w_{di} t - \theta_i) \right)$$

Slow and difficult to converge

IBRAHIM TIME DOMAIN

$$[M][\ddot{v}(t)]+[C][\dot{v}(t)]+[K][v(t)]=[0]$$

$$[v(t)]=\sum_{r=1}^{2N}\left[\hat{\phi}_r\right]Y_r(t)=\sum_{r=1}^{2N}\left[\hat{\phi}_r\right]G_r e^{s_r t}$$

$$\begin{bmatrix} v_1(t_1) & v_1(t_2) & \dots & v_1(t_L) \\ \vdots & \vdots & & \\ \vdots & \vdots & & \\ v_q(t_1) & v_q(t_2) & \dots & v_q(t_L) \end{bmatrix} = \begin{bmatrix} \varphi_{11} & \dots & \varphi_{1-2N} \\ \vdots & & \\ \varphi_{q1} & & \varphi_{q-2N} \end{bmatrix} \begin{bmatrix} e^{s_1 t_1} & \dots & e^{s_1 t_L} \\ \vdots & & \\ e^{s_{2N} t_1} & & e^{s_{2N} t_L} \end{bmatrix}$$

$$v_i(t_j)=\sum_{r=1}^{2N} G_r \hat{\phi}_{ir} e^{s_r t_j} \qquad [V]=[\Psi][\Delta]$$

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ITD CONT 2

$$v_i(t_j + \Delta t) = \sum_{r=1}^{2N} G_r \hat{\phi}_{ir} e^{s_r (t_j + \Delta t)}$$

$$\left[\hat{V}\right] = \left[\hat{\Psi}\right][\Delta]$$

$$[A_s] = \tfrac{1}{2}\left\{\left(\left[\hat{V}\right]\left[\hat{V}\right]^T\right)\left([V]\left[\hat{V}\right]^T\right)^{-1} + \left(\left[\hat{V}\right][V]^T\right)\left([V][V]^T\right)^{-1}\right\}$$

$$\left\{[A_s] - e^{s_r \Delta t}[I]\right\}\{\psi_r\} = \{0\}$$

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INITIAL CONDITIONS

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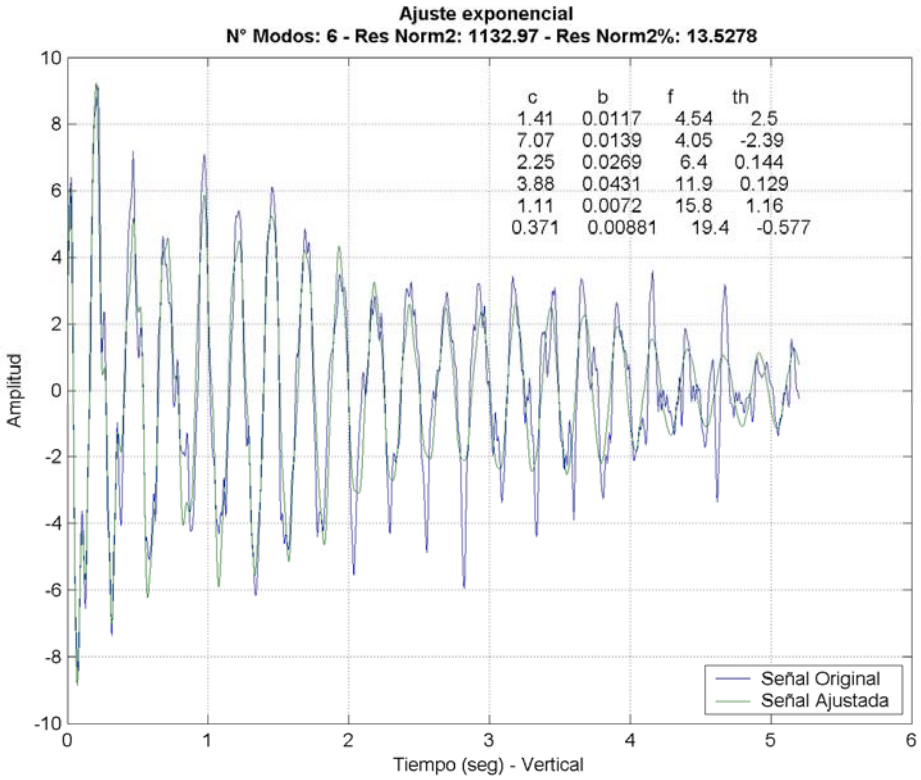

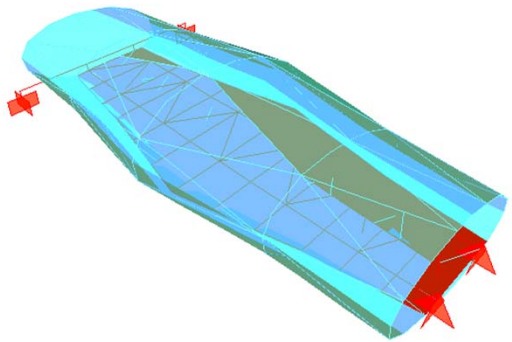

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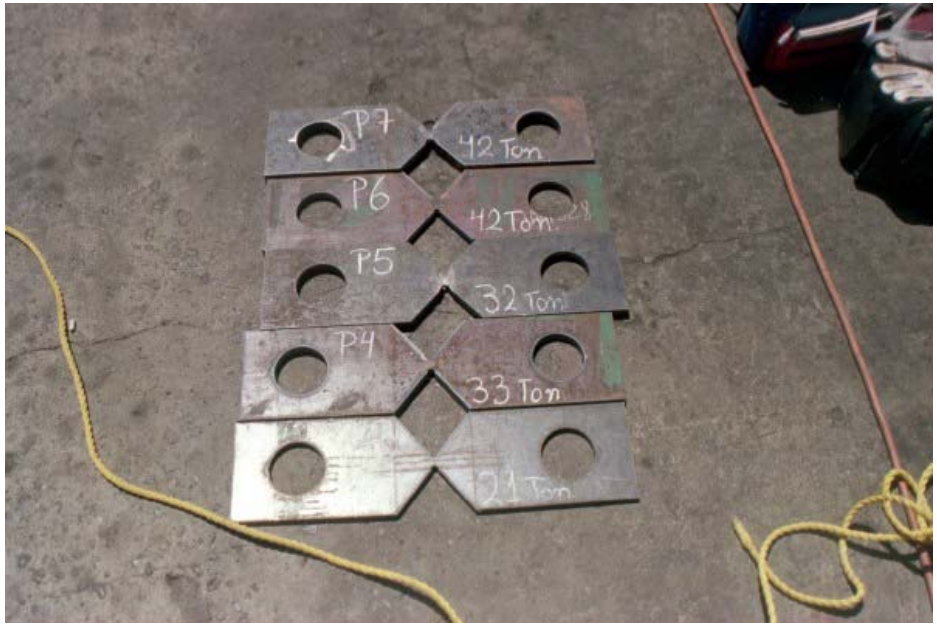

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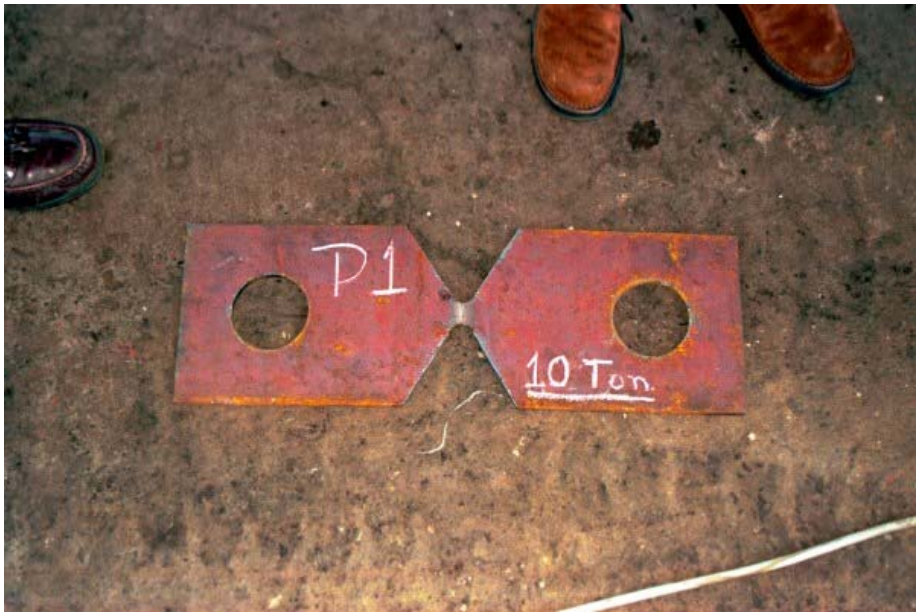
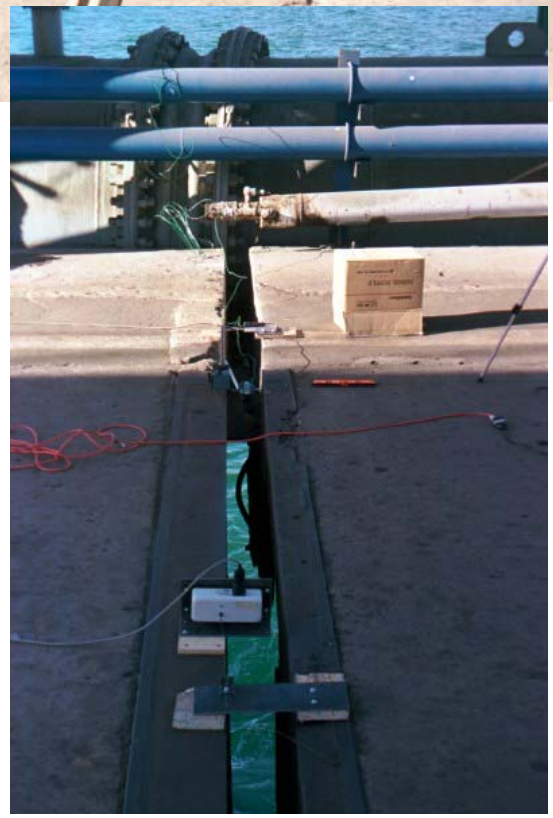

P1
10 Ton.




P1
10 Ton.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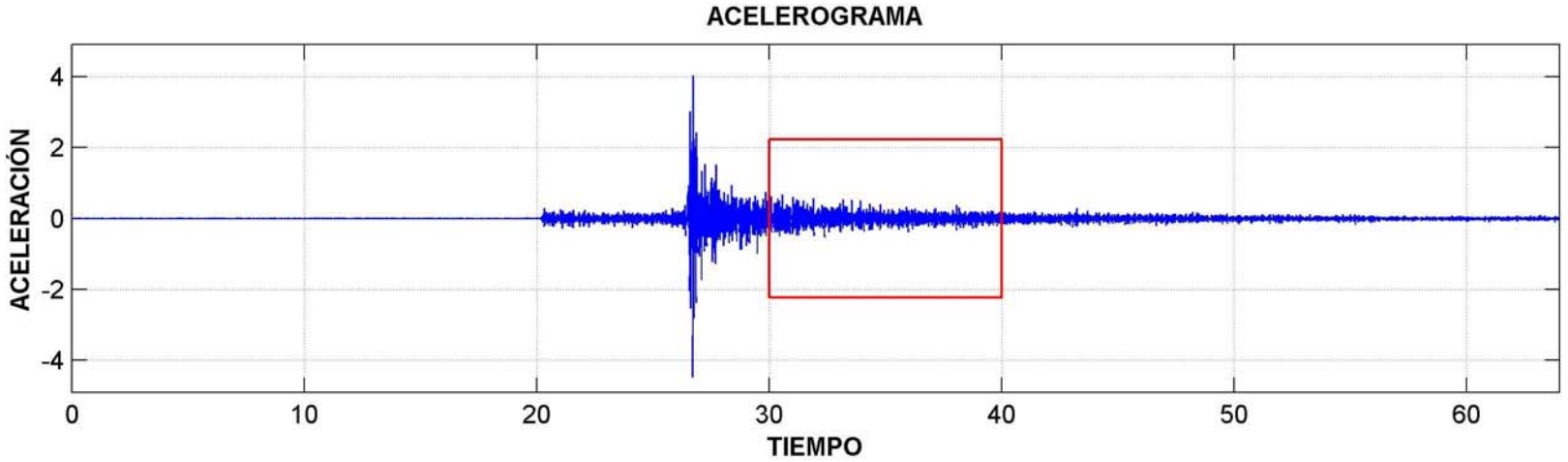
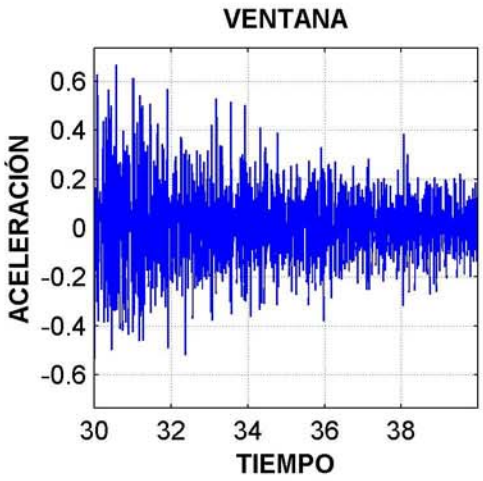
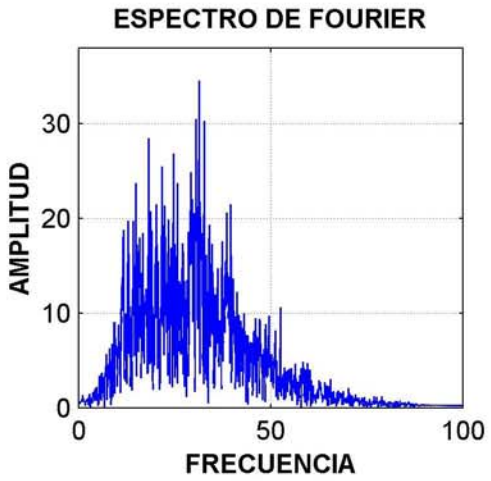
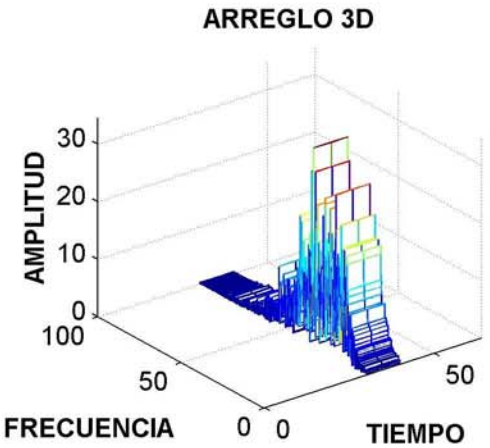
TRANSFORMADA DE FOURIER POR VENTANAS

SPECTROGRAM









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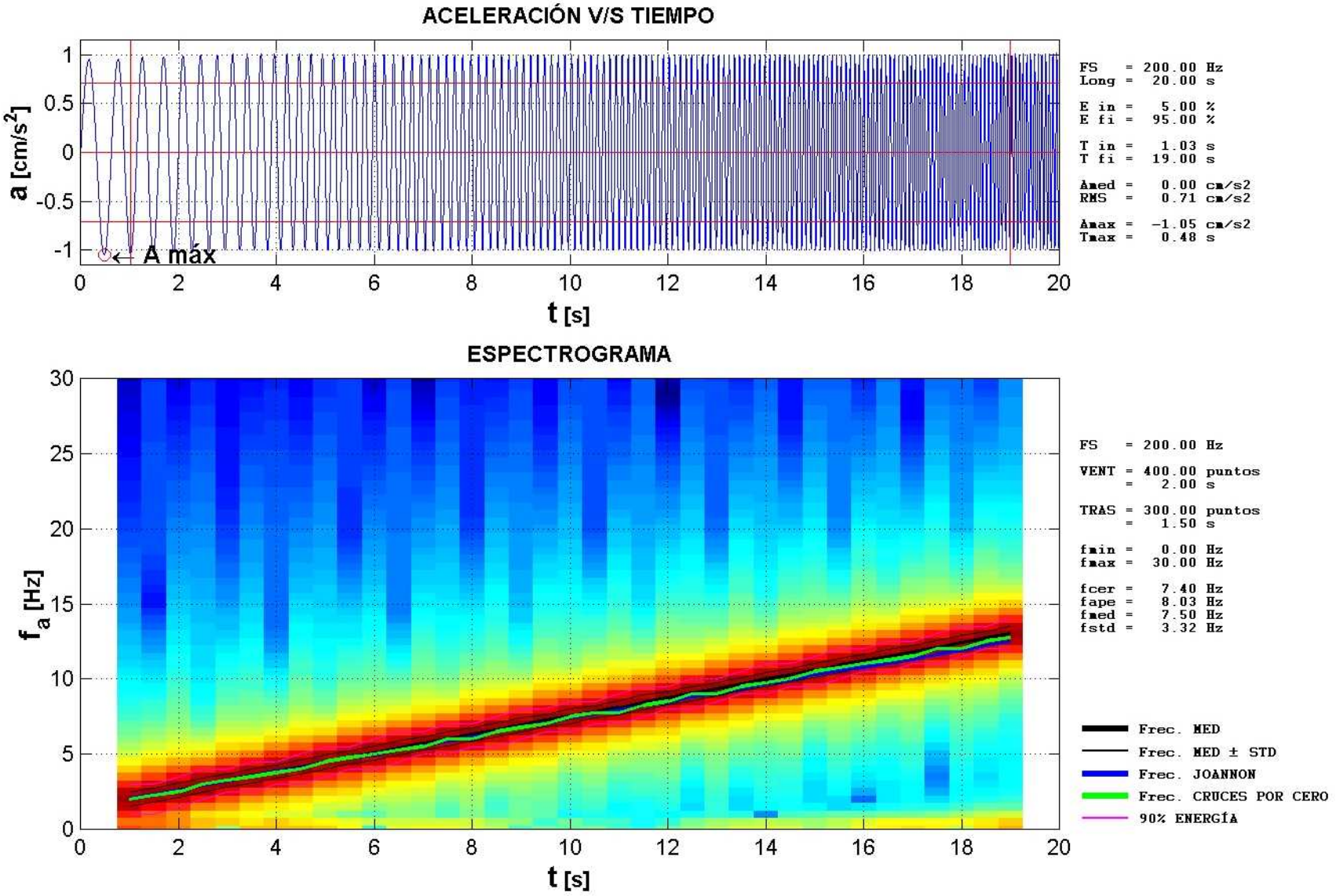
ACELEROGRAMA ARTIFICIAL

Frecuencia linealmente variable
(f_1 = 2.0 Hz y f_2 = 14.0 Hz)



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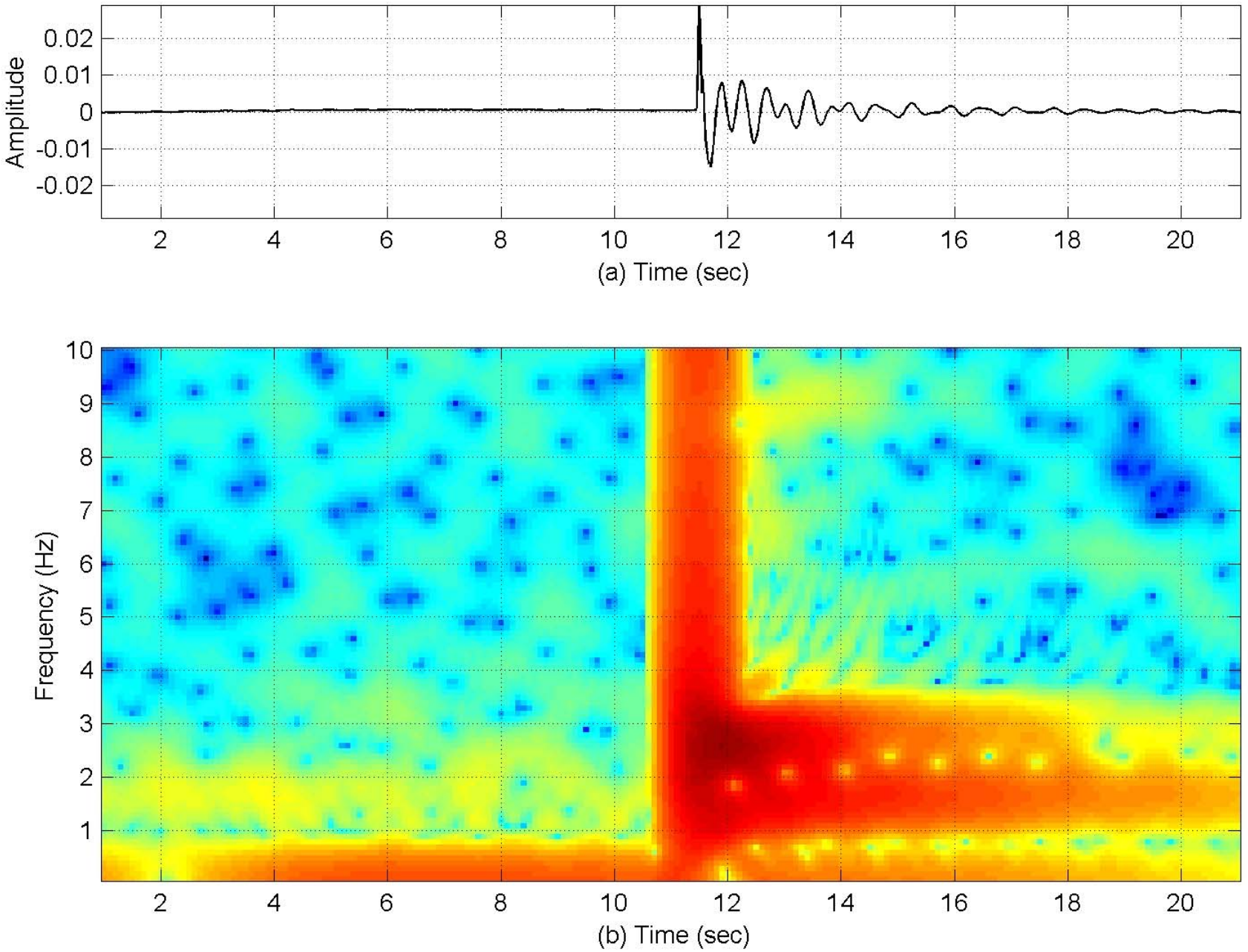

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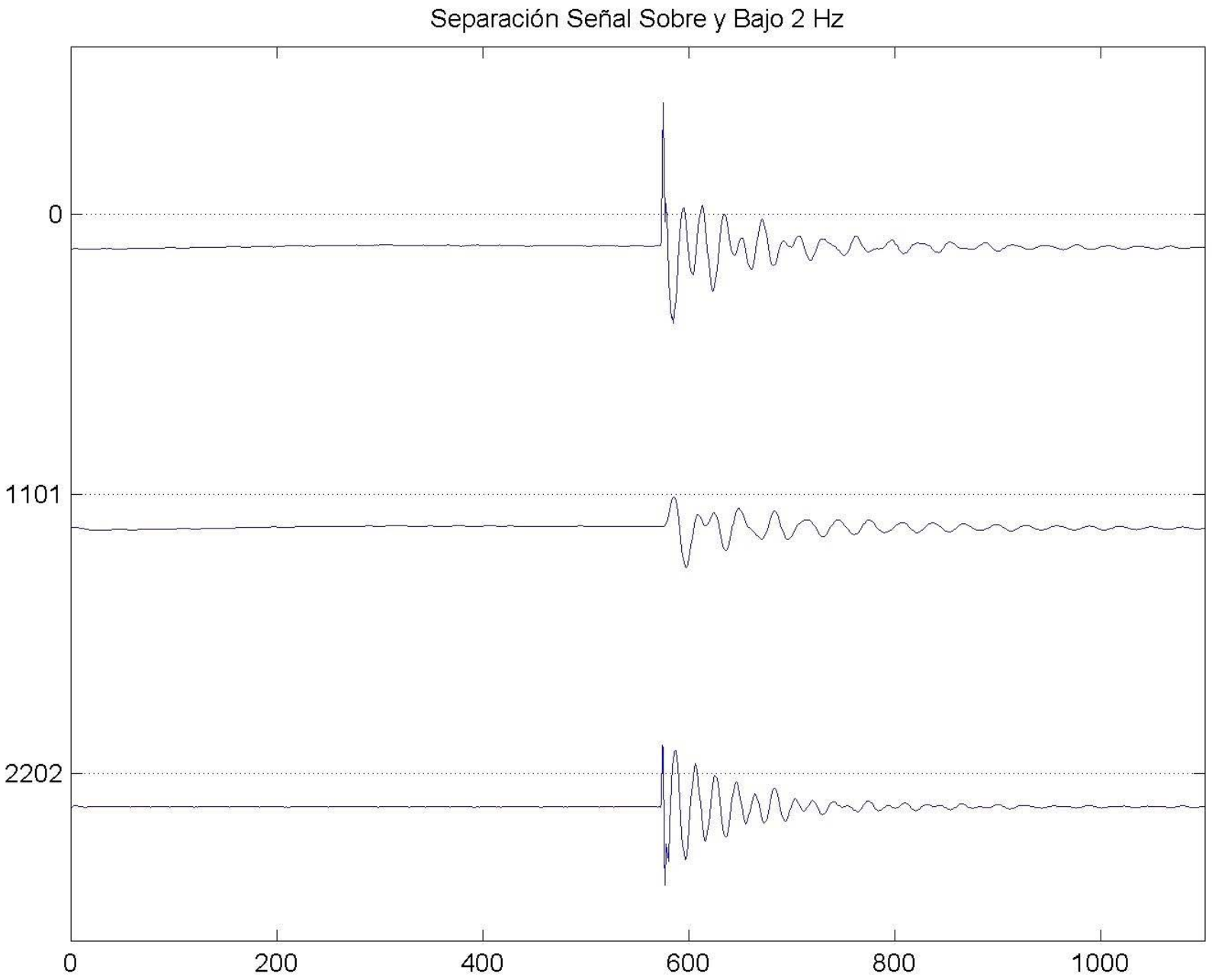

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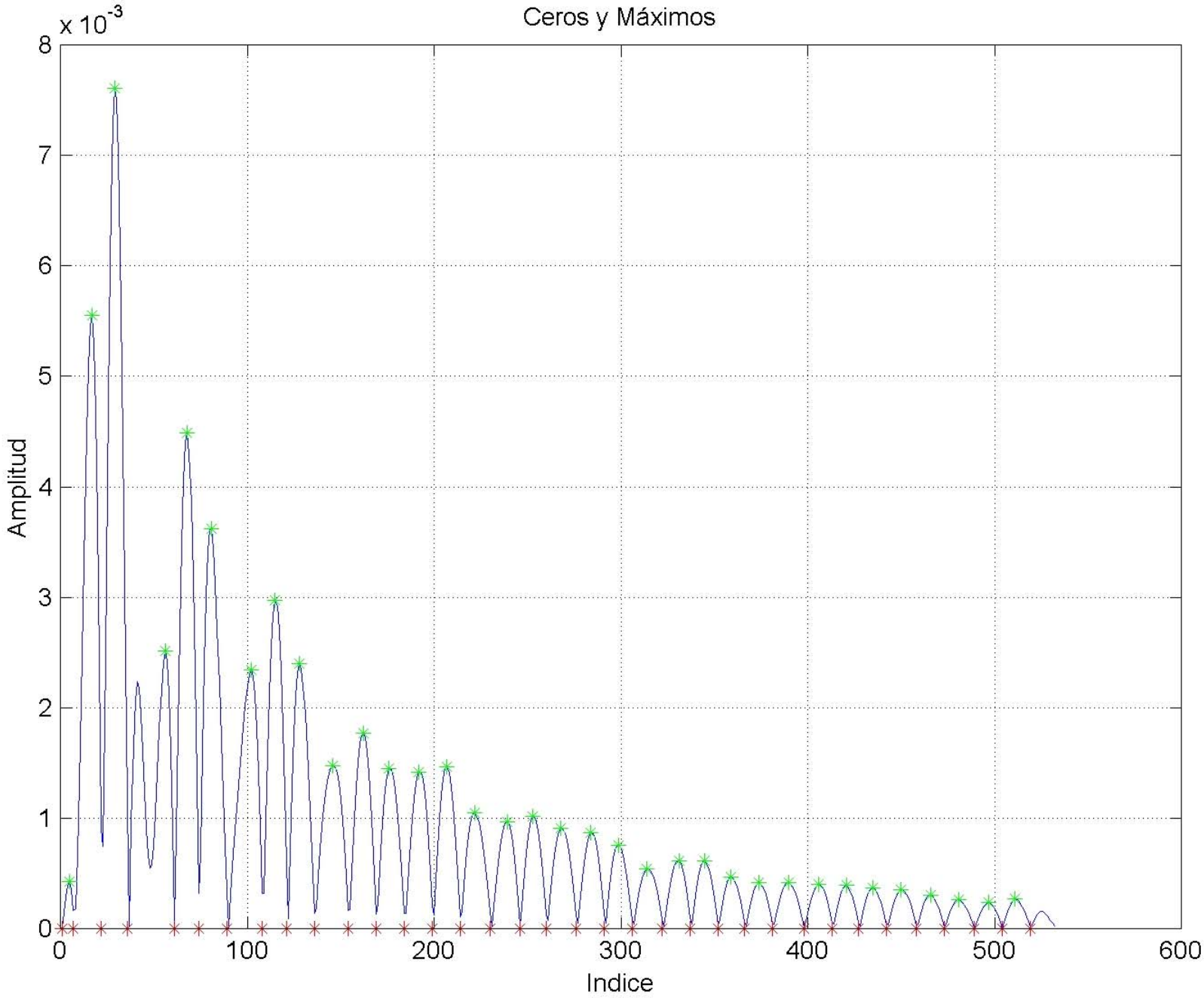

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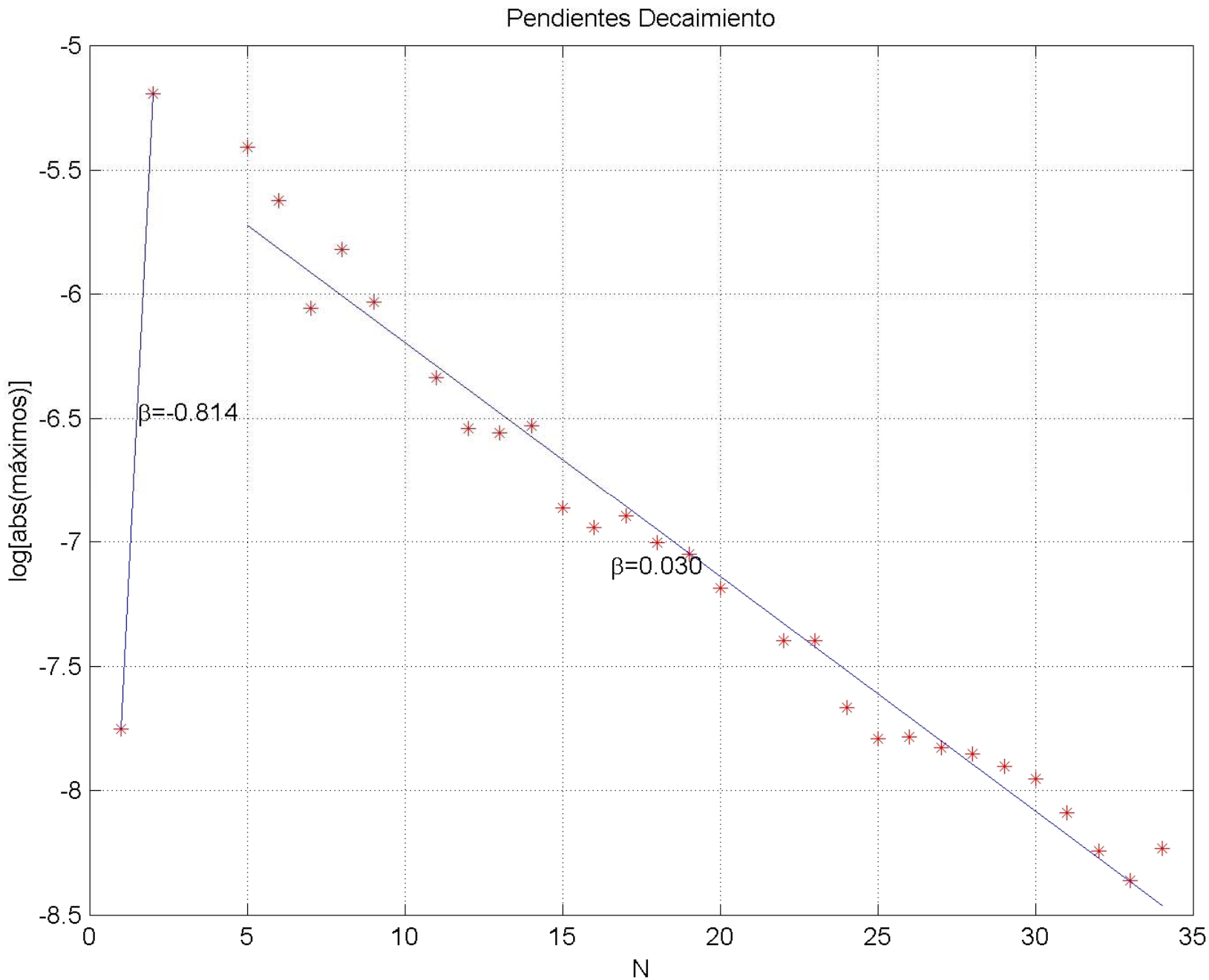

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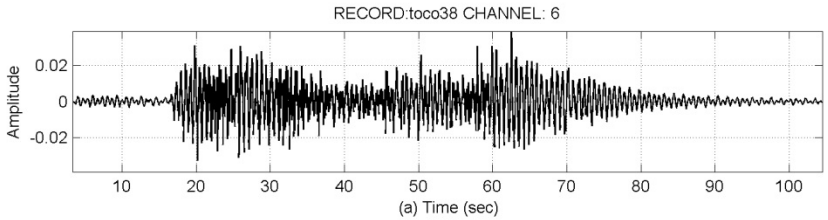

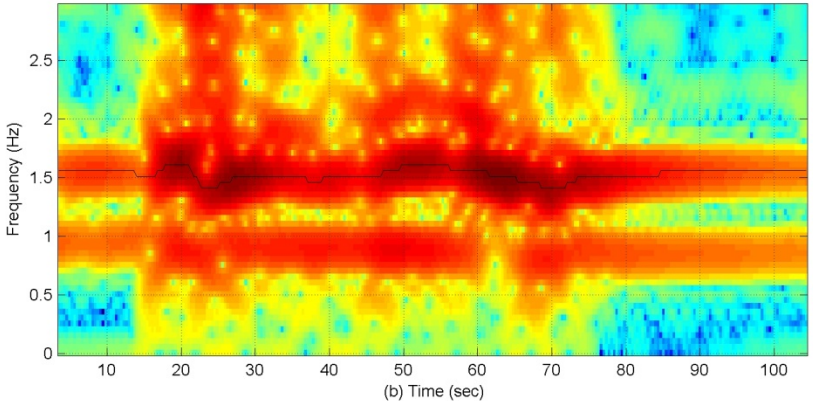

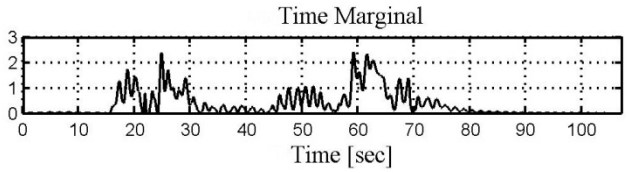

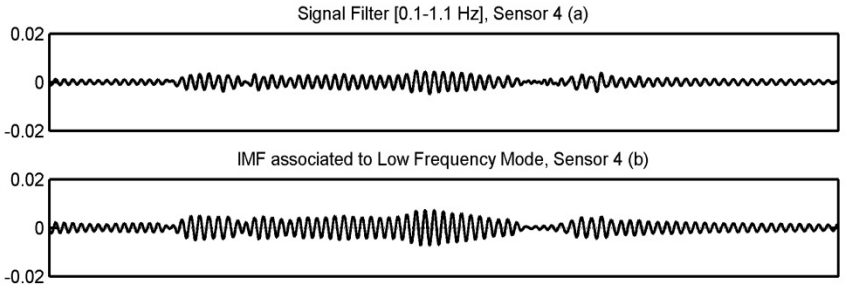

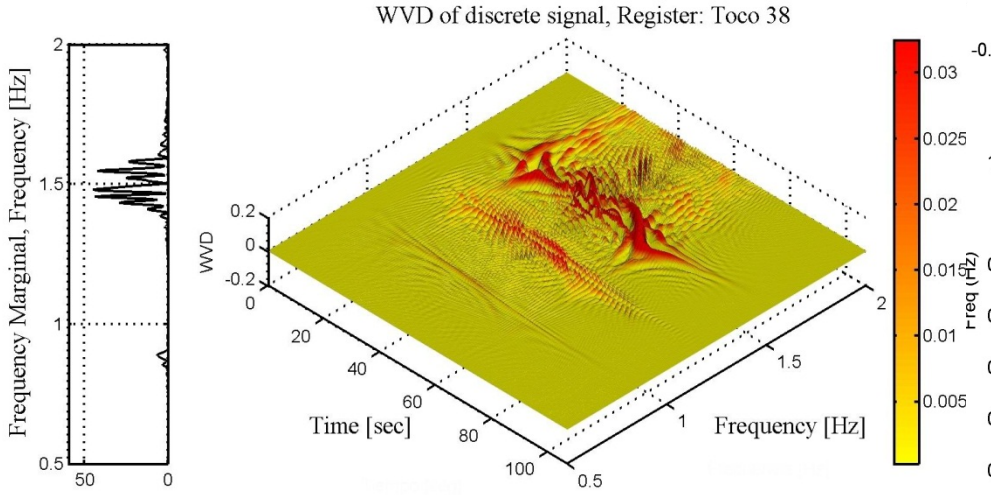

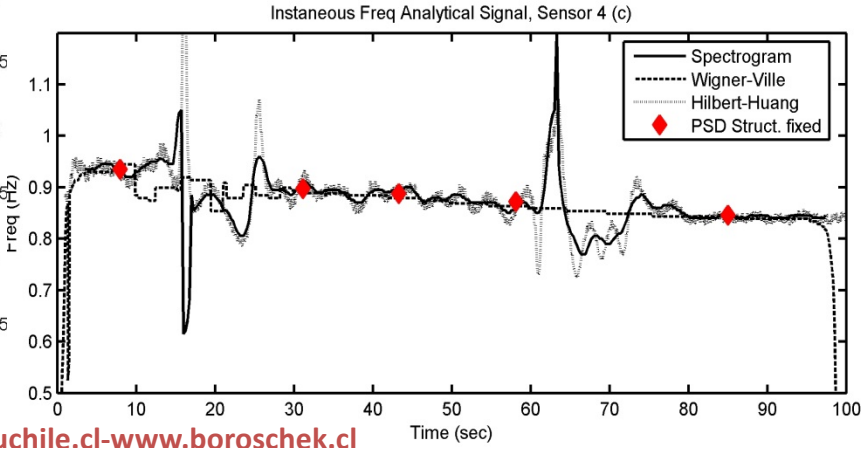

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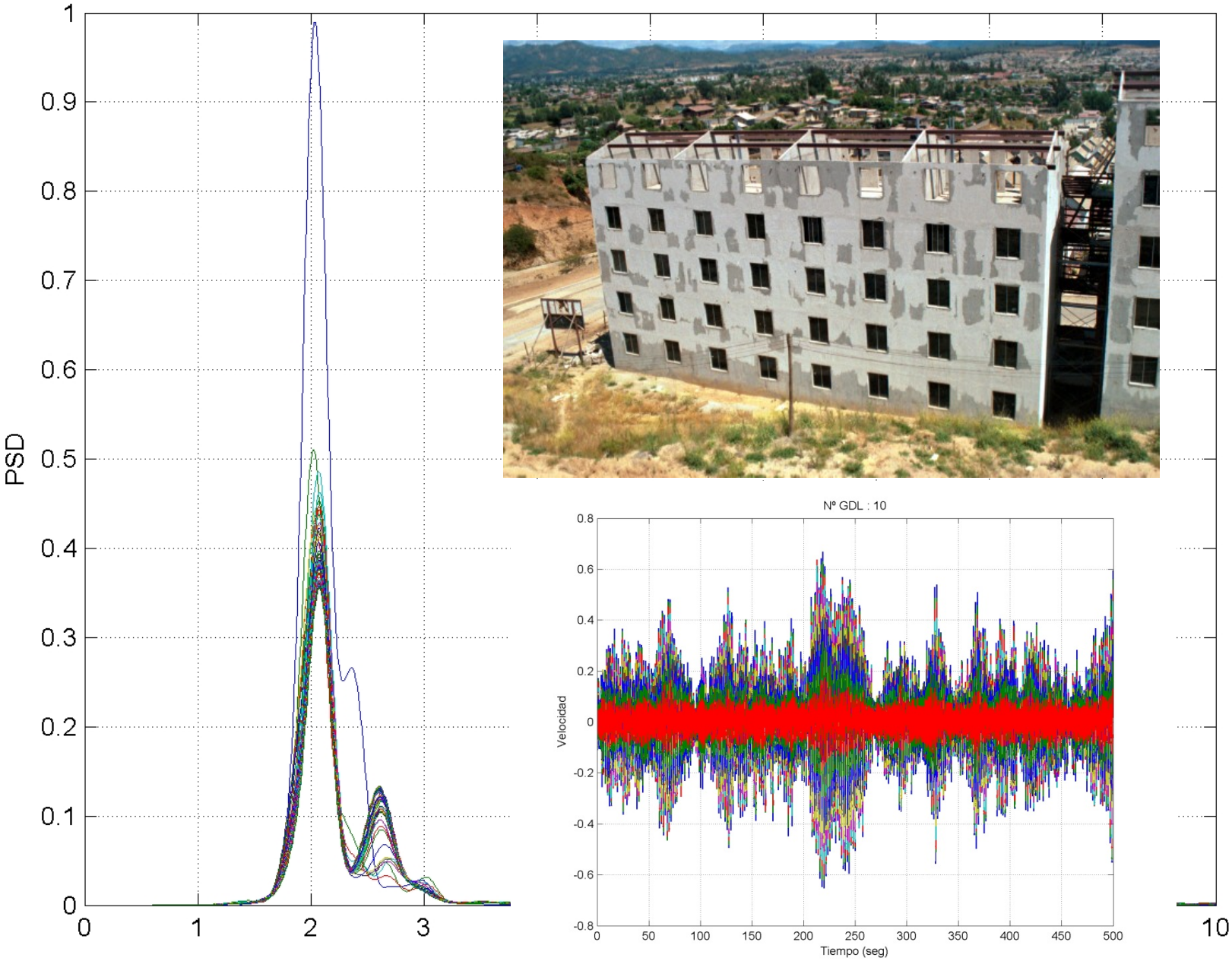
AMBIENTE VIBRATIONS



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WELCH METHOD

$$H(f) = \frac{P_X(f)}{P_F(f)}$$ FRF

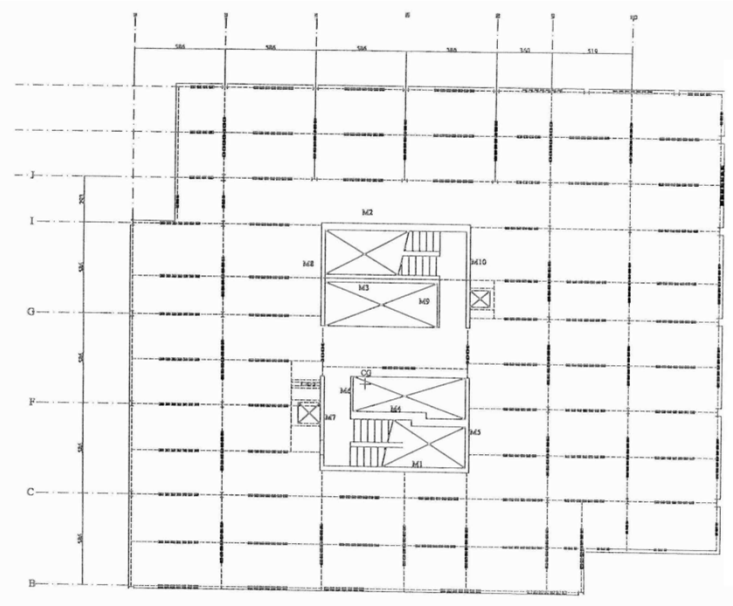
$$H_1(f) = \frac{P_X(f)P_F^*(f)}{P_F(f)P_F^*(f)} = \frac{G_{XF}}{G_{FF}}$$

$$H_2(f) = \frac{P_X(f)P_X^*(f)}{P_F(f)P_X^*(f)} = \frac{G_{XX}}{G_{FX}}$$

$$G_{xy}(f) = \frac{1}{N_a}\sum_{n=1}^{N_a}\left(\frac{G_x}{G_y}\right)_n$$

LAS CONDES AÑO 1990

- N =26 +3 (S)
- H = 91 m h =3.3 m
- Marco (A)- Muro (H)
- d= 0.6 - 1.9%/dirección
- T = 1.67 seg H/T =55m/s



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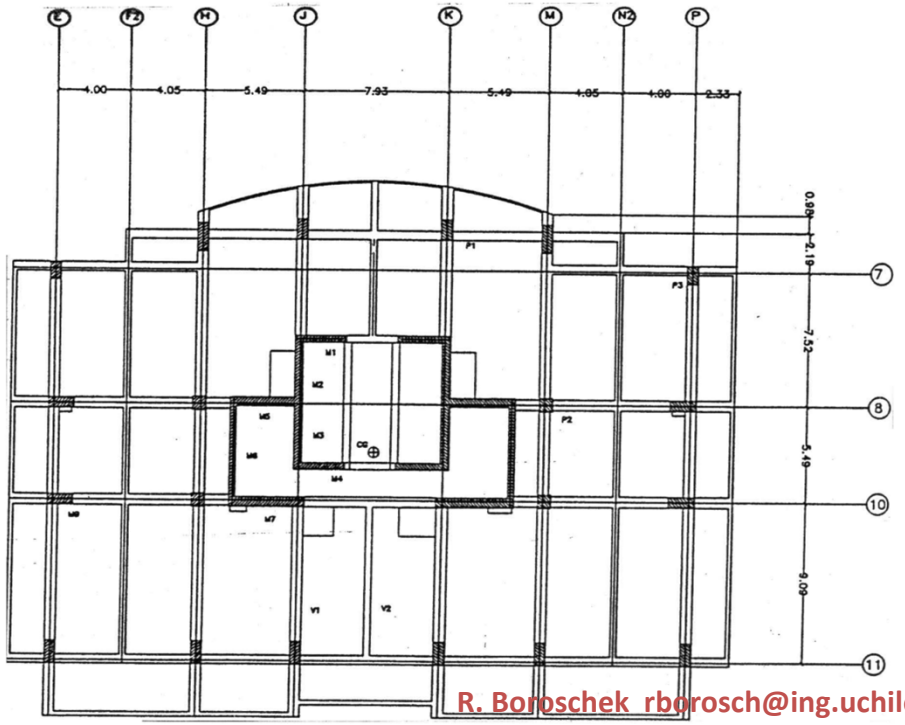
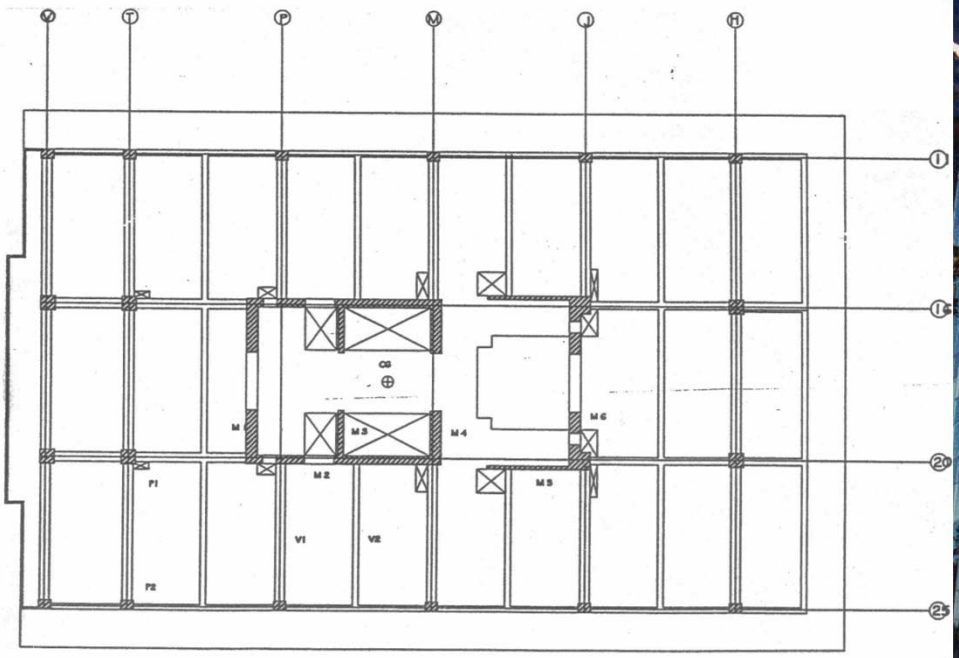
VITACURA AÑO 1996

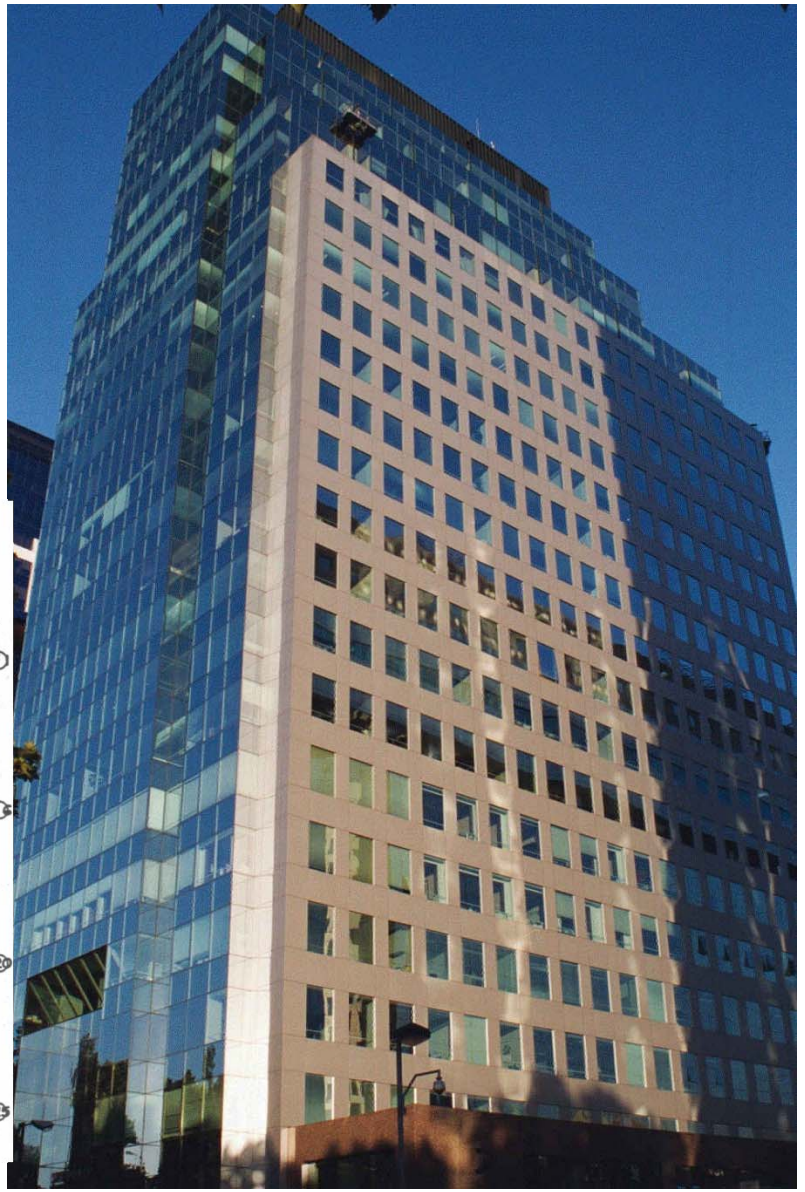
- N =23 +5 (S)
- H = 87 m h =3.15 m
- Marco (H)- Muro (H)
- d= 1.0 - 1.6%/dirección
- T = 1.1 seg H/T =79 m/s



PACÍFICO AÑO 1992

- N =27 +4(S)
- H = 97 m h =3.25 m
- Marco (H)- Muro (H)
- d= 0.9 - 1.4%/dirección
- T = 1.6 seg H/T =61 m/s





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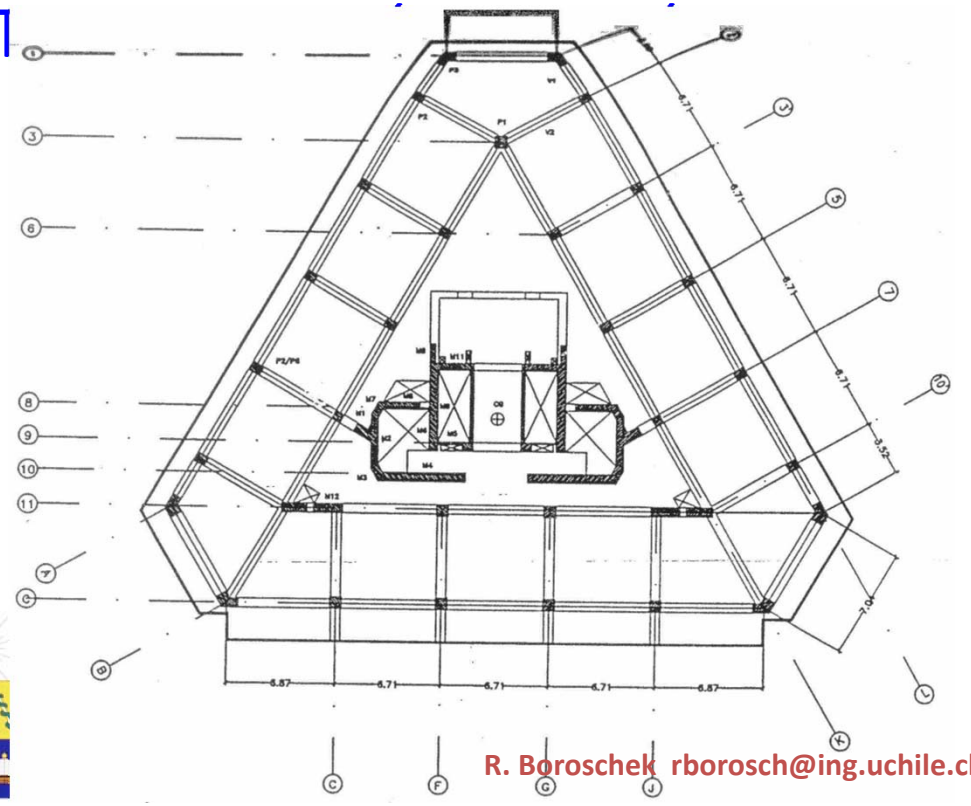
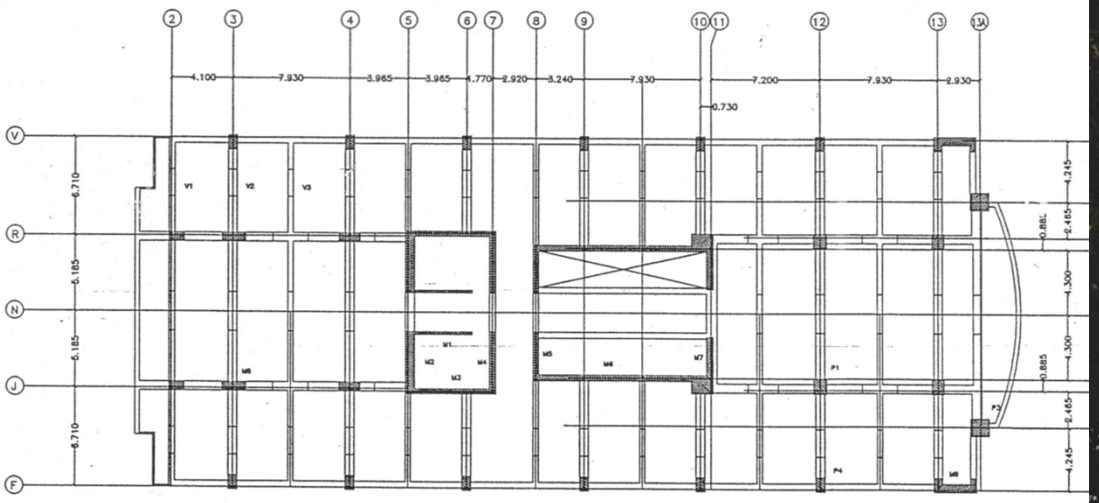
INDUSTRIAS AÑO 1991

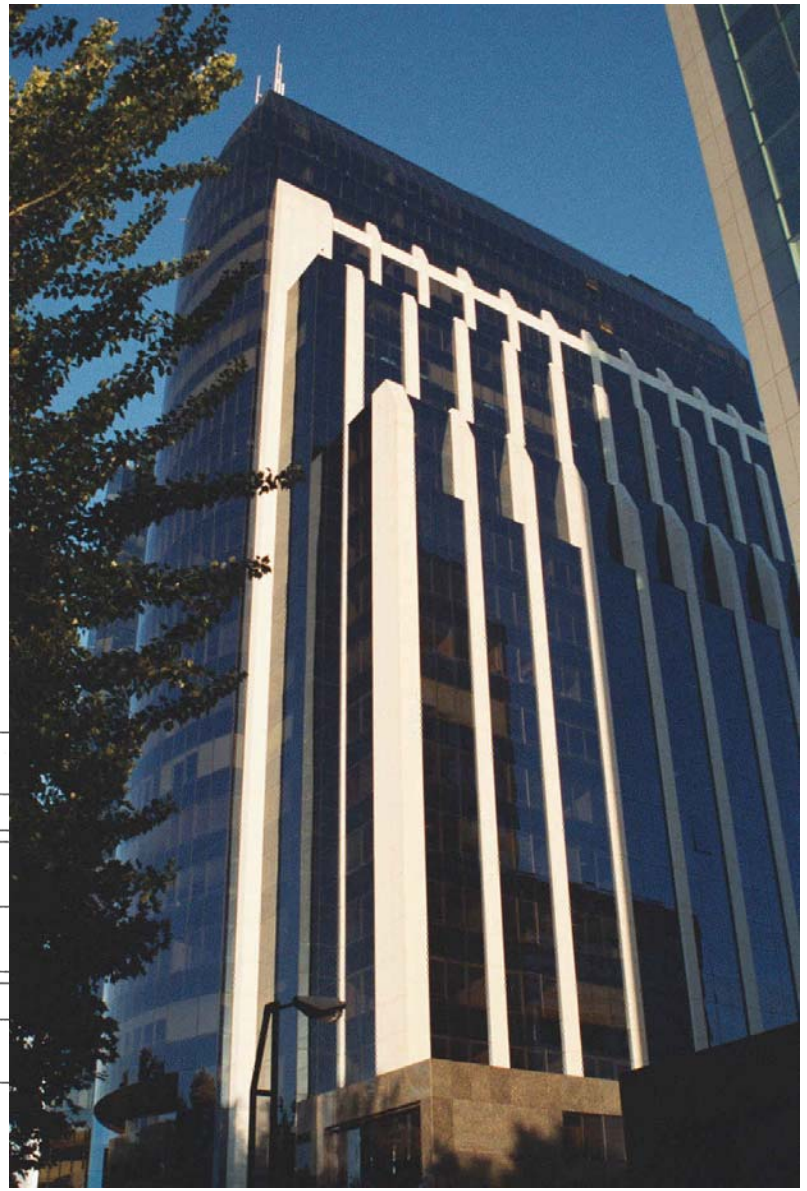
- N =33 +3(S)
- H = 102 m h =3.2 m
- Marco (H)- Muro (H)
- d= 1.8 - 2.6%/dirección
- T



ANDRÉS BELLO AÑO 1995

- N =27 +4(S)
- H = 96 m h =3.2 m
- Marco (H)- Muro (H)
- d= 1.2 - 1.9%/dirección
- T = 1.5 seg H/T =64 m/s





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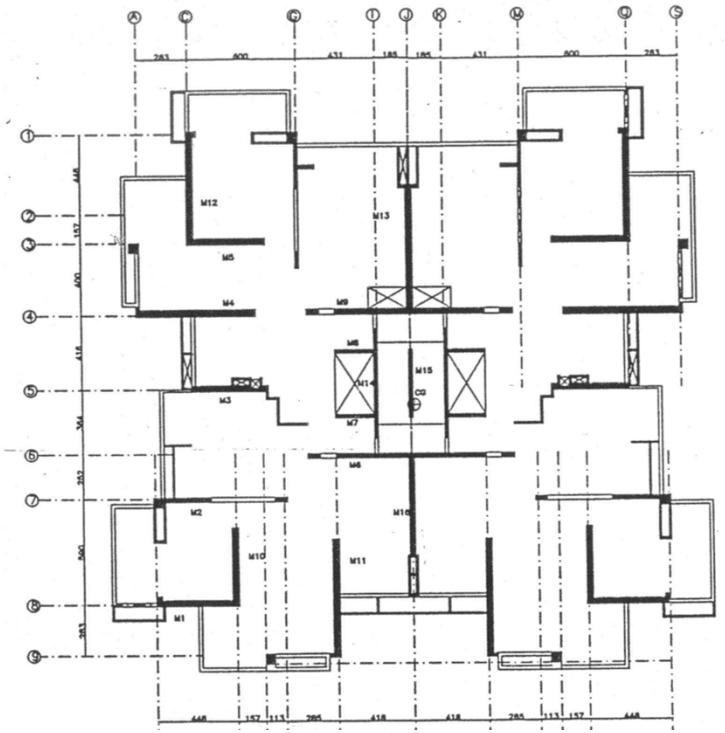
MARISCAL PETAIN AÑO 1996

- N =24 +3 (S)
- H = 73 m h =2.7 m
- Muro (H) d= 2% T y 1% L
- Tl = 1.0 seg H/T =73m/s
- Tr = 2.50 seg



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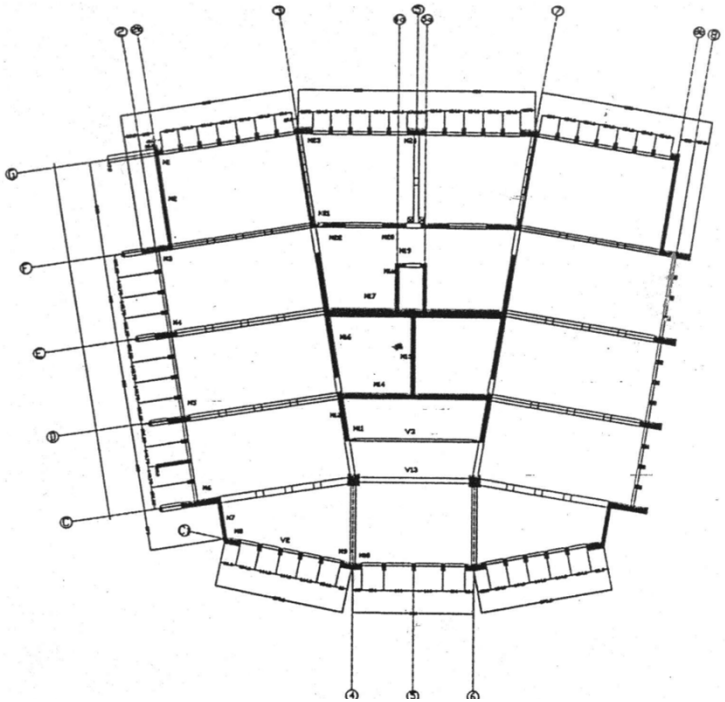
CÁMARA CHILENA 1987

- N =21 +3(S)
- H = 78 m h =3.3 m
- Marco (H)- Muro (H)
- d= 2.3 - 4.6%/dirección
- T = 0.95 seg H/T =82m/s



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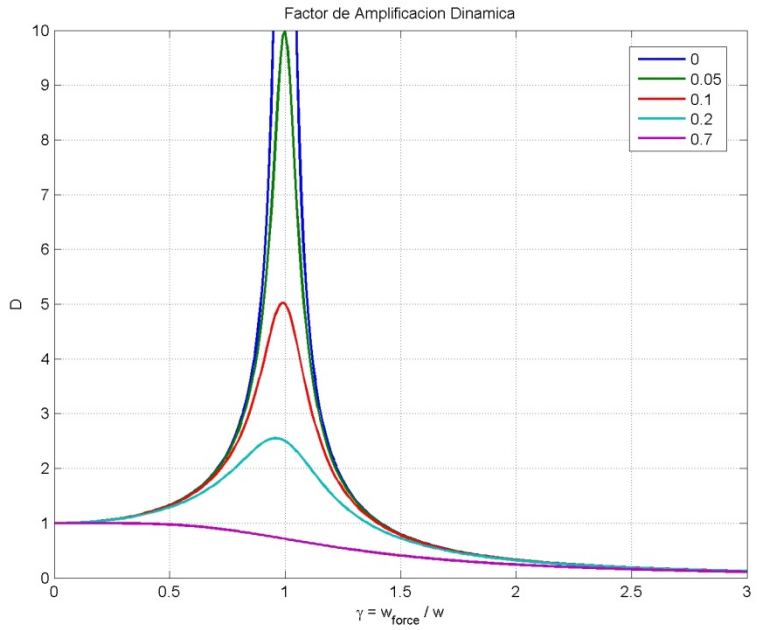
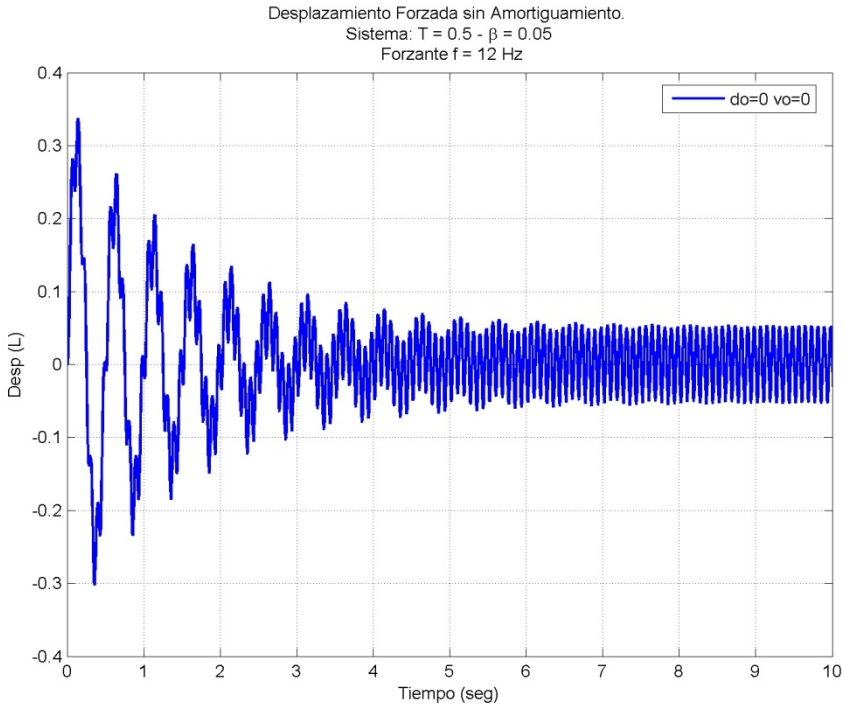
FORCED VIBRATION

$$m\ddot{v}(t)+c\dot{v}(t)+kv(t)=\begin{cases}P_0\sin(\bar{\omega}t)\\ P_0\cos(\bar{\omega}t)\\ P_0e^{i(\bar{\omega}t)}\end{cases}$$

$$v(t)=\underbrace{e^{-\omega\beta t}\left(A\sin\left(\omega_D t\right)+B\cos\left(\omega_D t\right)\right)}_{\textit{Transiente}}+\underbrace{\frac{P_0}{k}D\begin{cases}\sin(\bar{\omega}t-\theta)\\ \cos(\bar{\omega}t-\theta)\\ e^{i(\bar{\omega}t-\theta)}\end{cases}}_{\textit{Permanente}}$$





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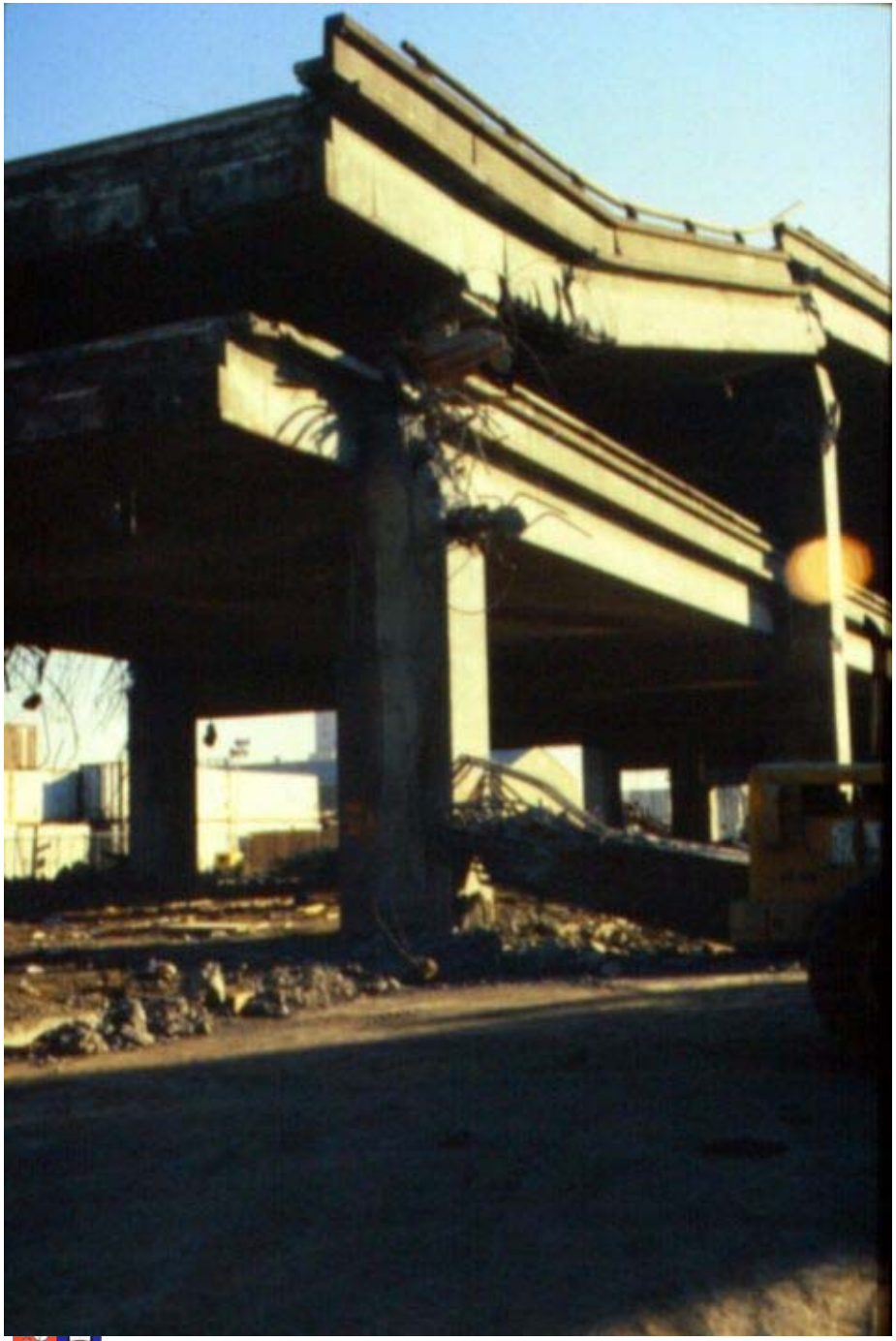

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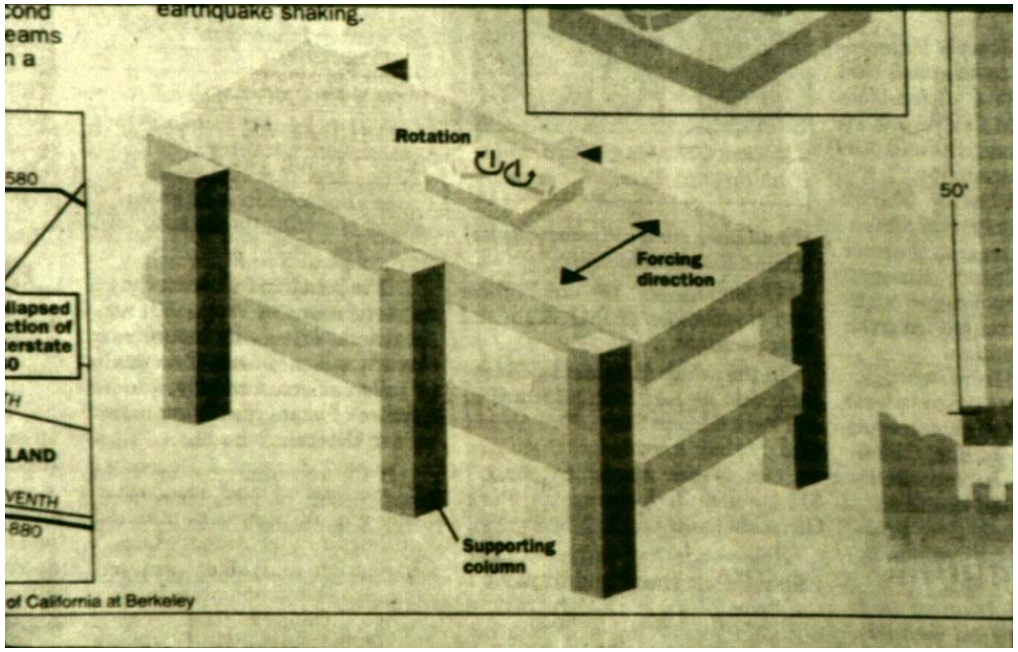
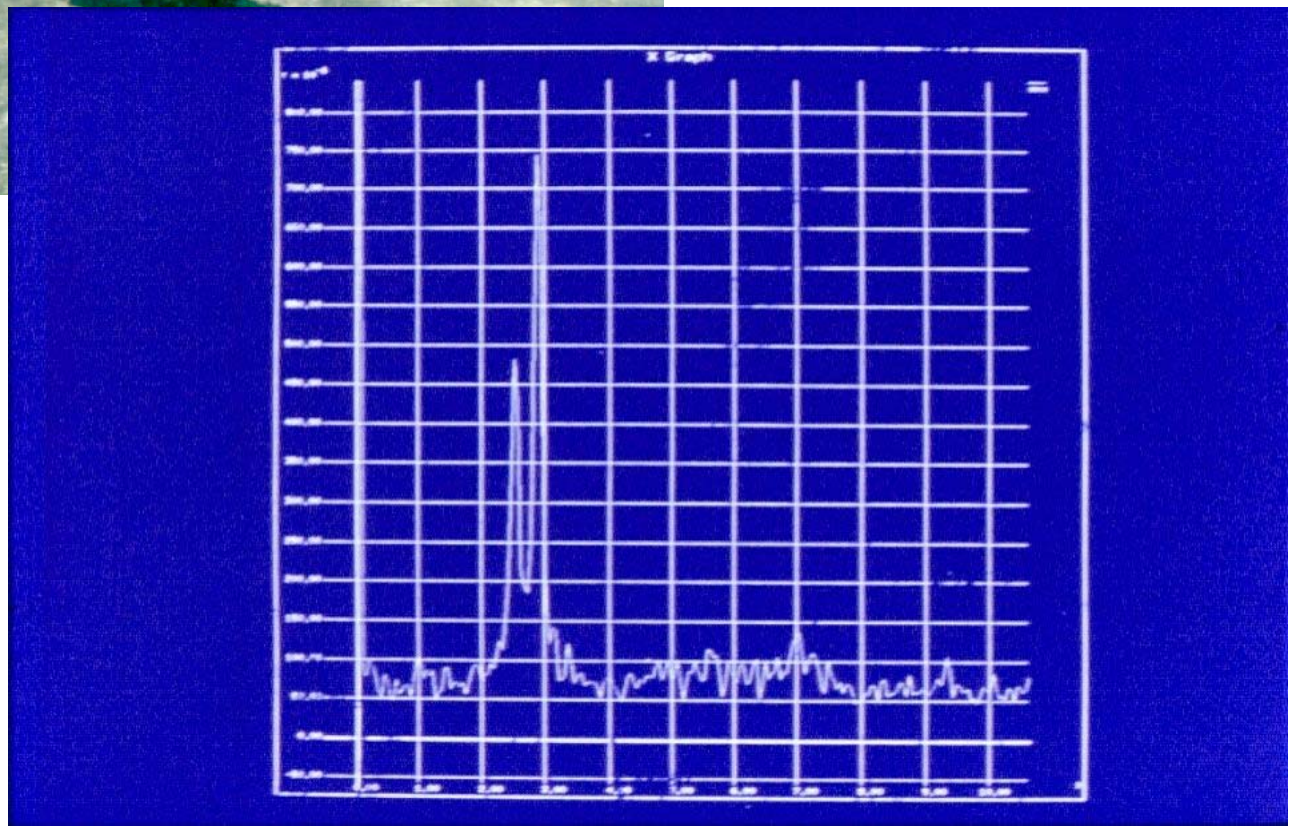

earthquake shaking.
Rotation
50'
Forcing direction
Supporting column
of California at Berkeley



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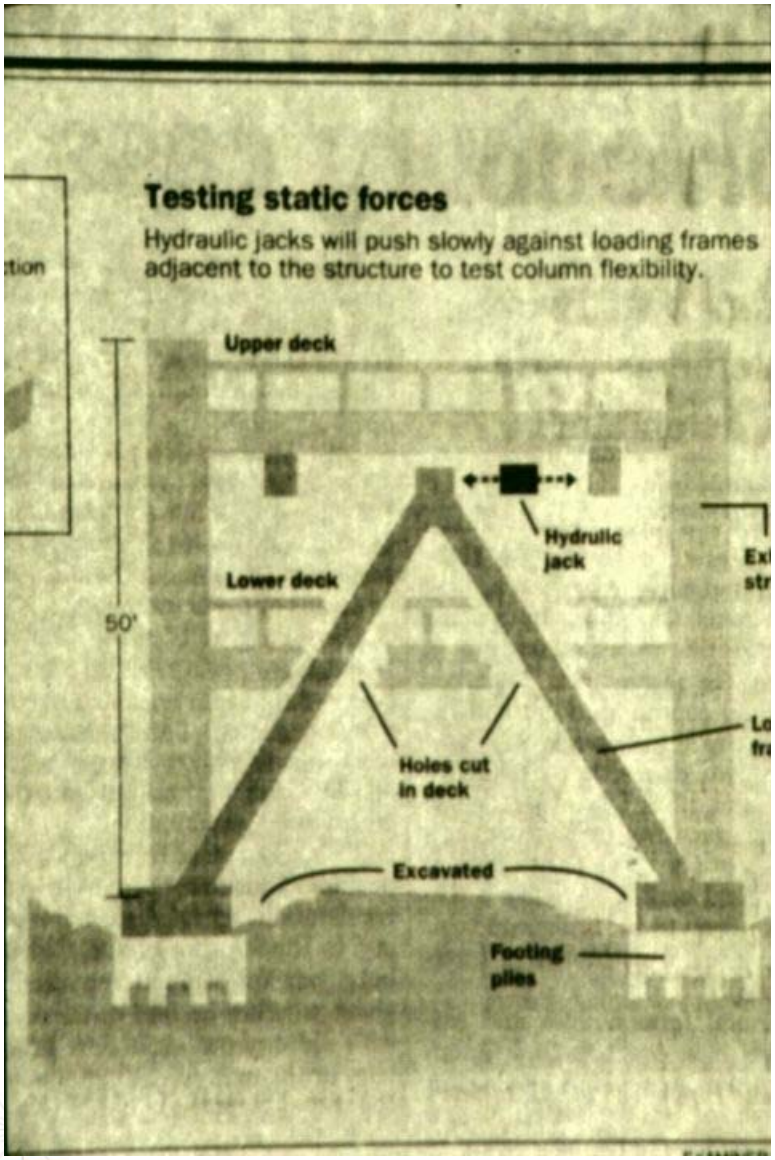
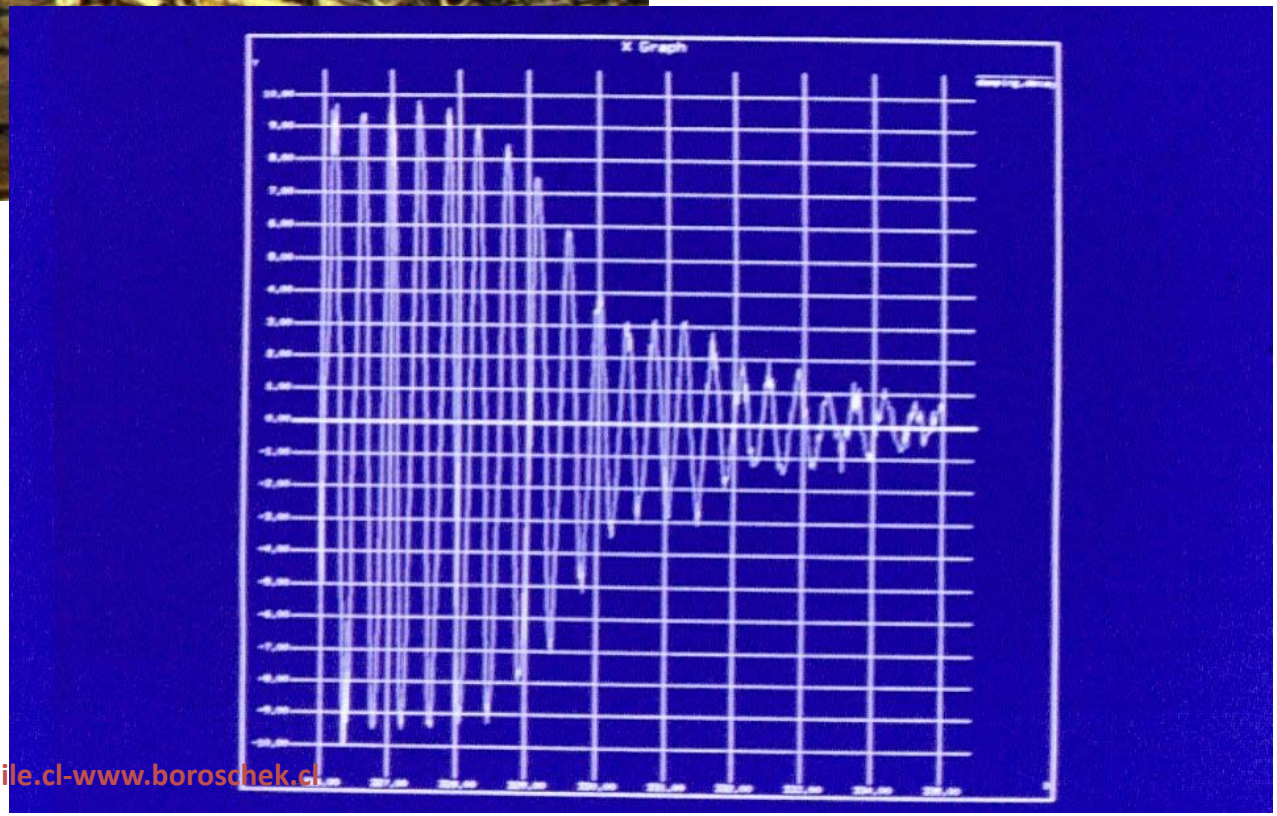

Testing static forces
Hydraulic jacks will push slowly against loading frames adjacent to the structure to test column flexibility.
Upper deck
Hydrulic jack
Lower deck
50'
Holes cut in deck
Excavated
Footing piles



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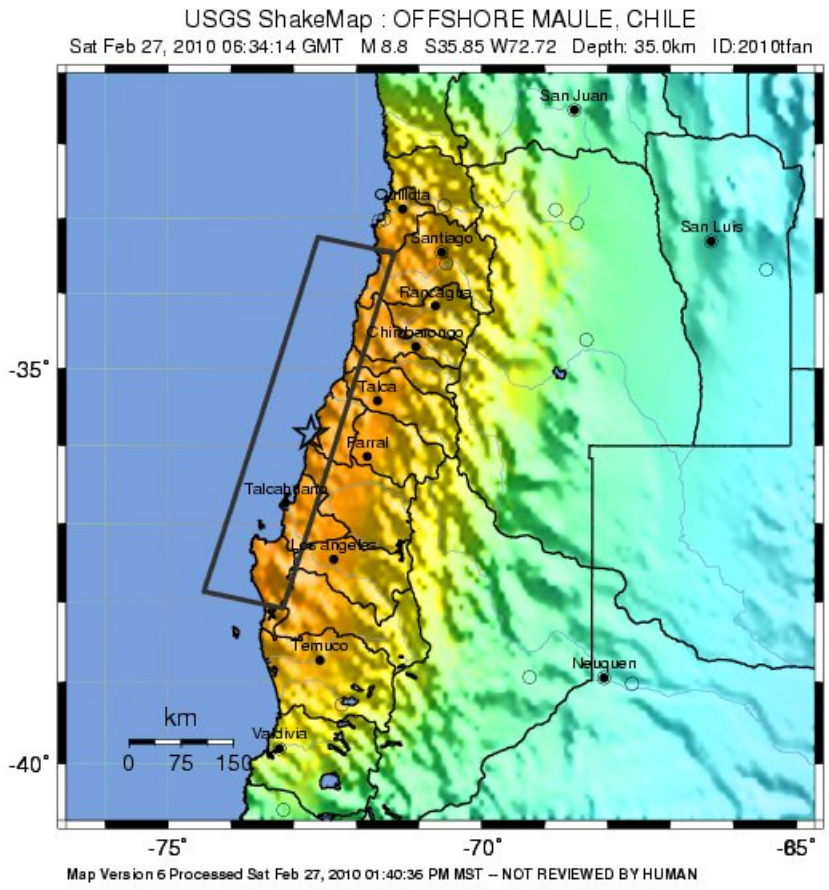
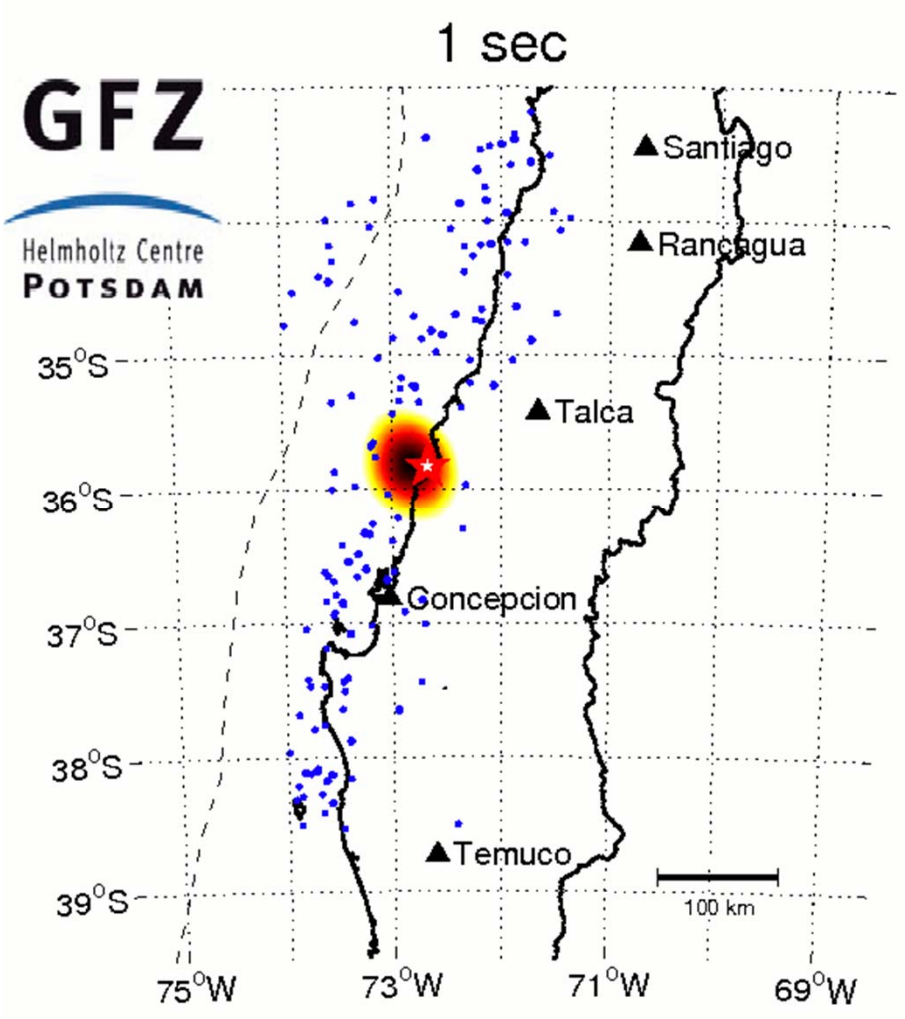


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



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Aftershocks

M8.8 - Offshore Maule, Chile

Aftershock Map - Mainshock and 421 Aftershocks

Last Updated: 18 March 2010, 20:57:06 UTC

Legend

USGS

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DICHATO

BEFORE

AFTER

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Bonett y Blandon

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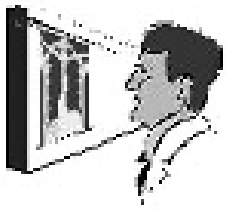
STRUCTURAL HEALTH MONITORING

Pain



Exams

Diagnosis

Vibration Problem

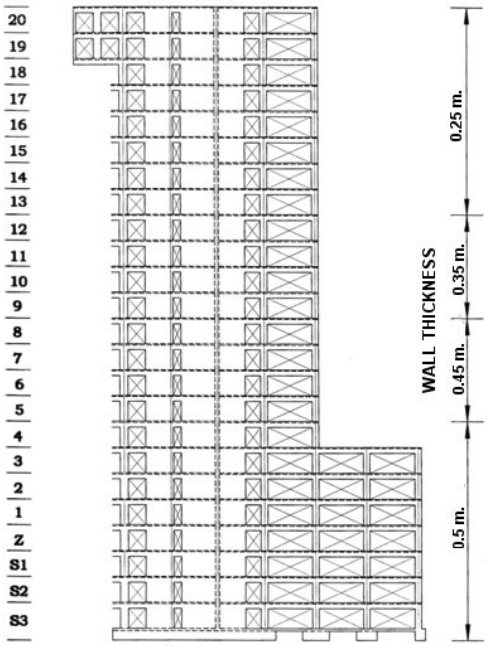
Inspection

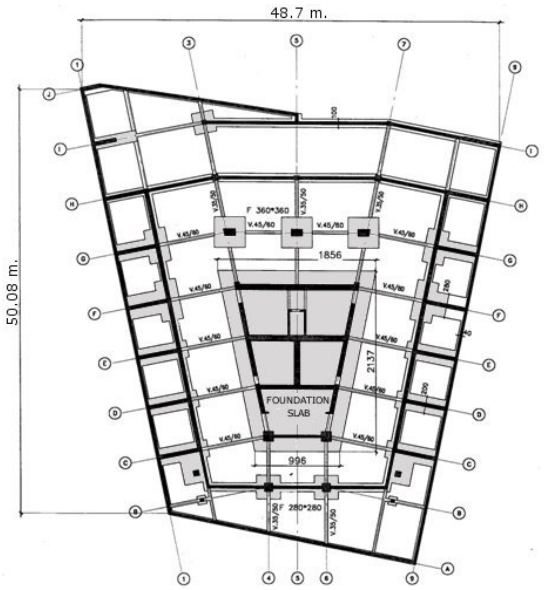
Diagnosis

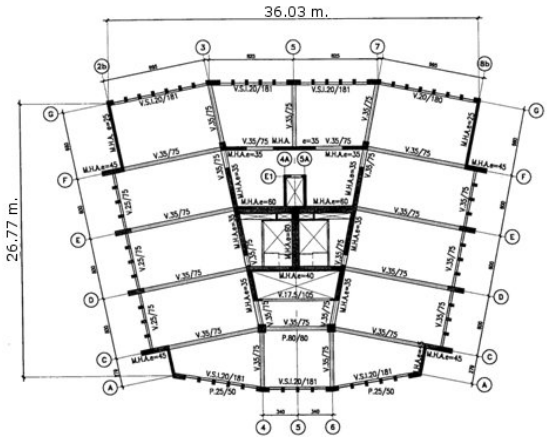
- The Building
  - Constructed in 1987 in Santiago, Chile
  - 20 floors and 85.5 meters high
  - RC wall-frame dual system with a predominance of walls
  - Soil type dense-gravel. (Soil class C, ASCE7-10)



- The Building
  - Walls located mainly at the center, housing the stairs and elevator shafts
  - Foundation slab 1.5 m thick, 305m2, supports the main structural system
  - Total floor area of 28,595 m2
  - Average wall area to plan area ratio: 5%







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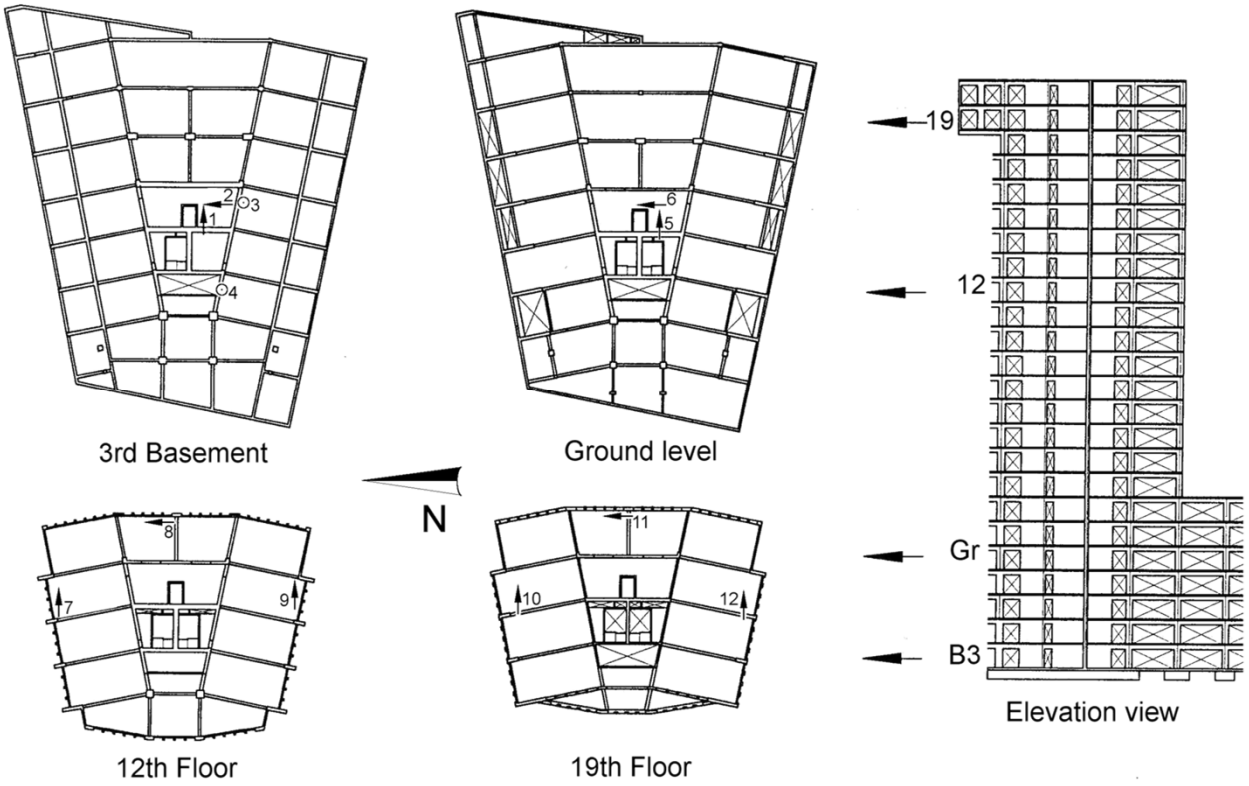
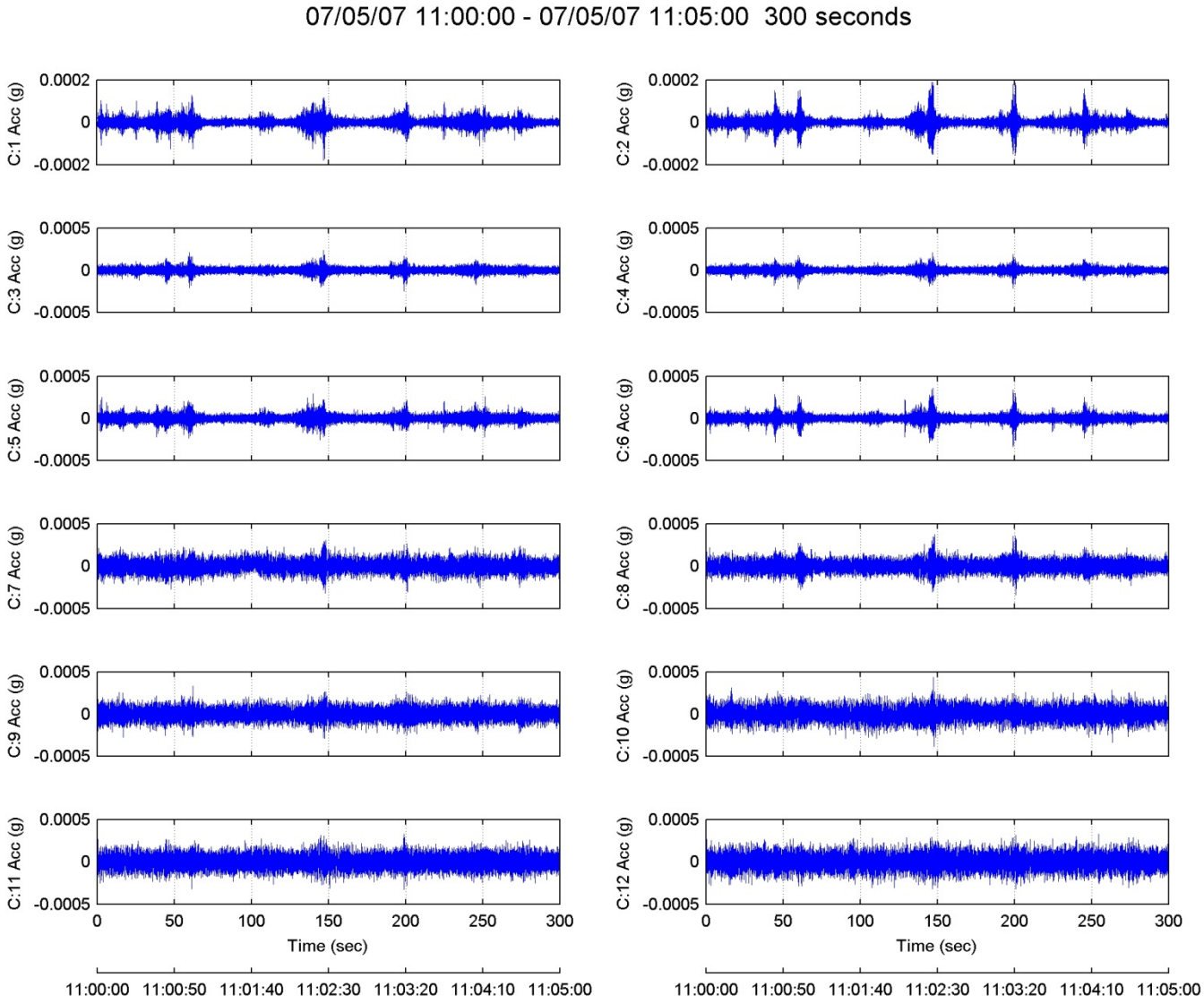
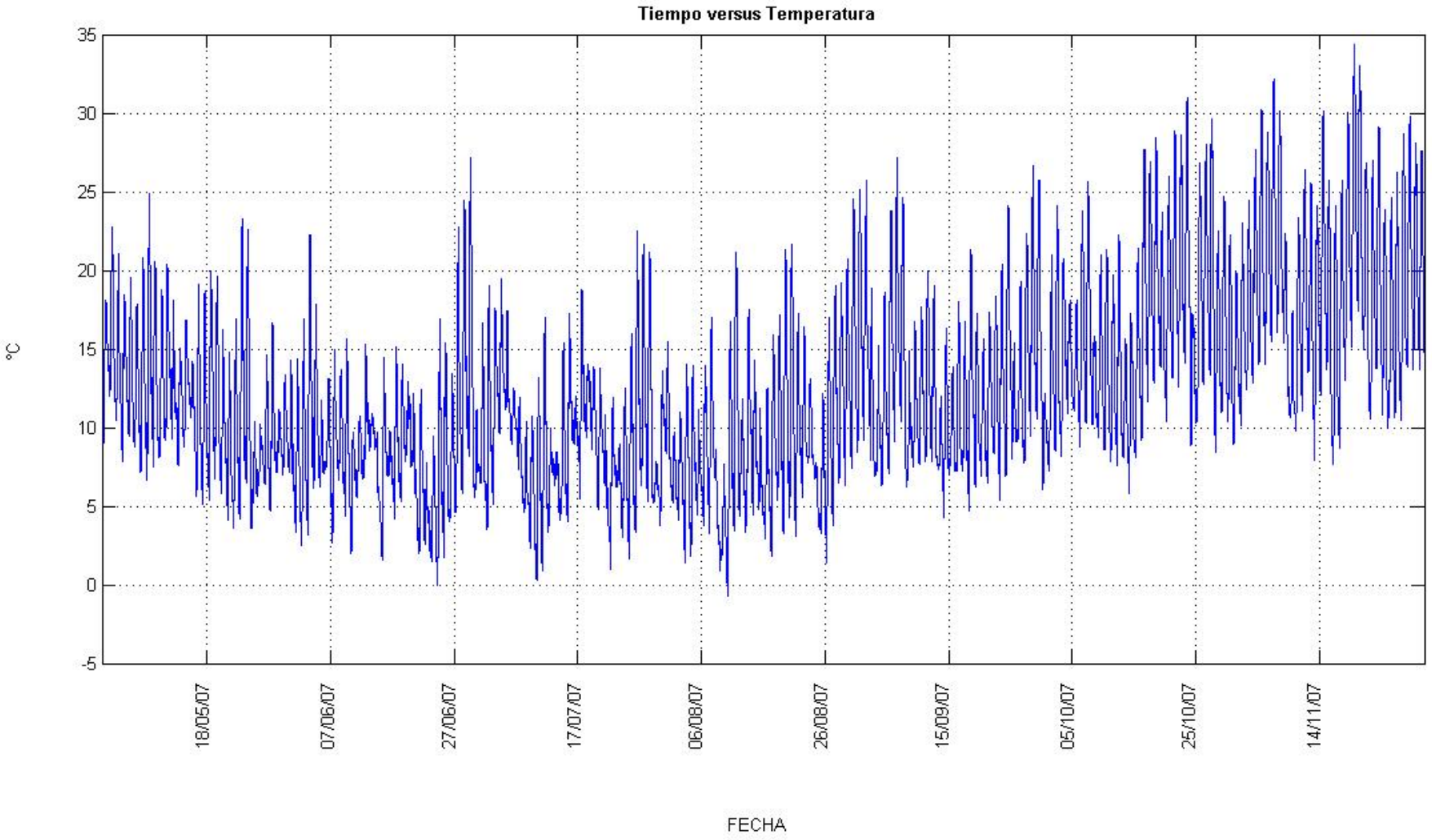
- The Building. Monitoring Network
  - Instrumented with a continuous monitoring network since 1997
  - 12 uniaxial accelerometers are located at 4 different levels
  - The network can record the dynamic response of the building from ambient vibrations to strong shaking during seismic events



AMBIENT VIBRATIONS



TIME - TEMPERATURE



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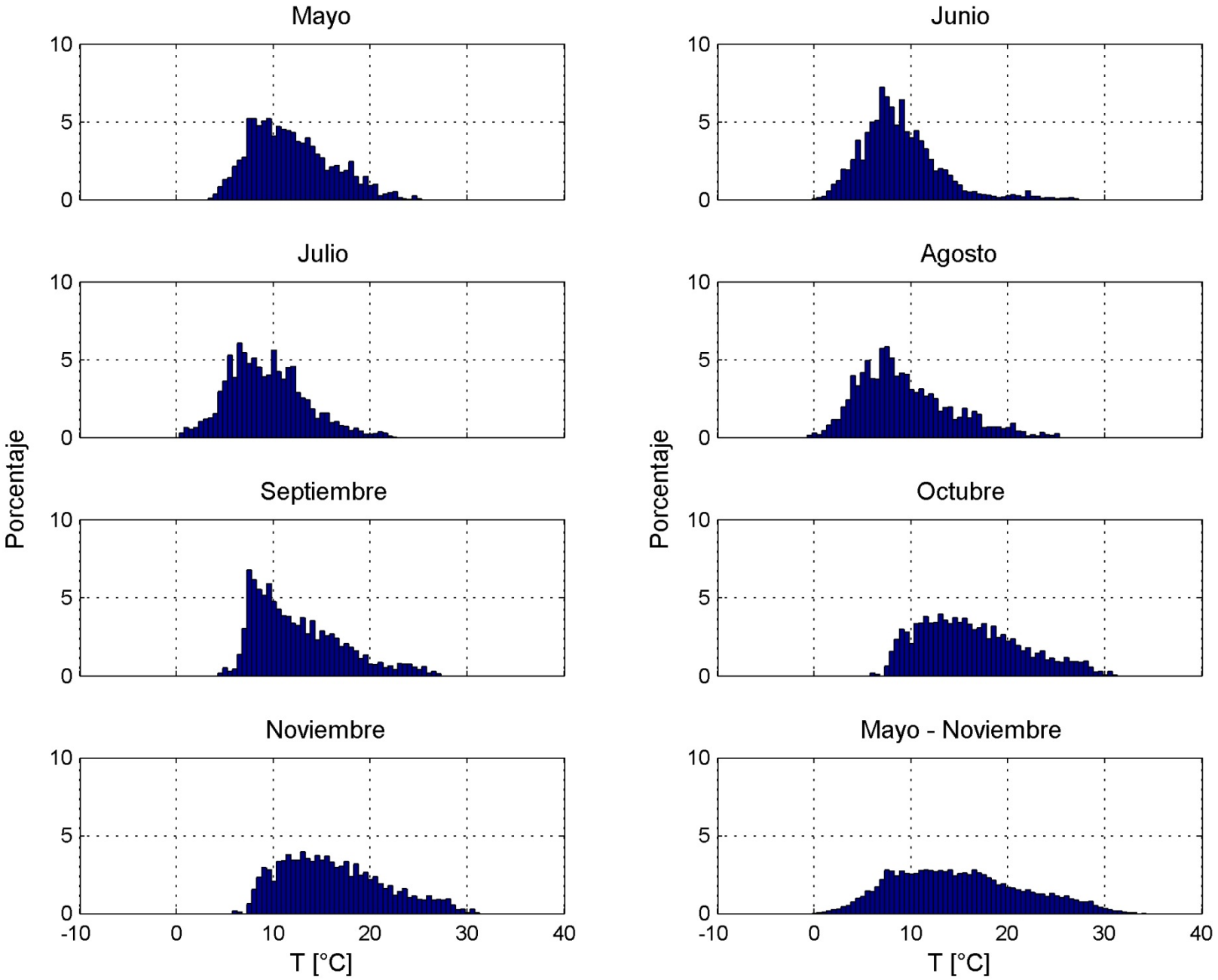
TEMPERATURE



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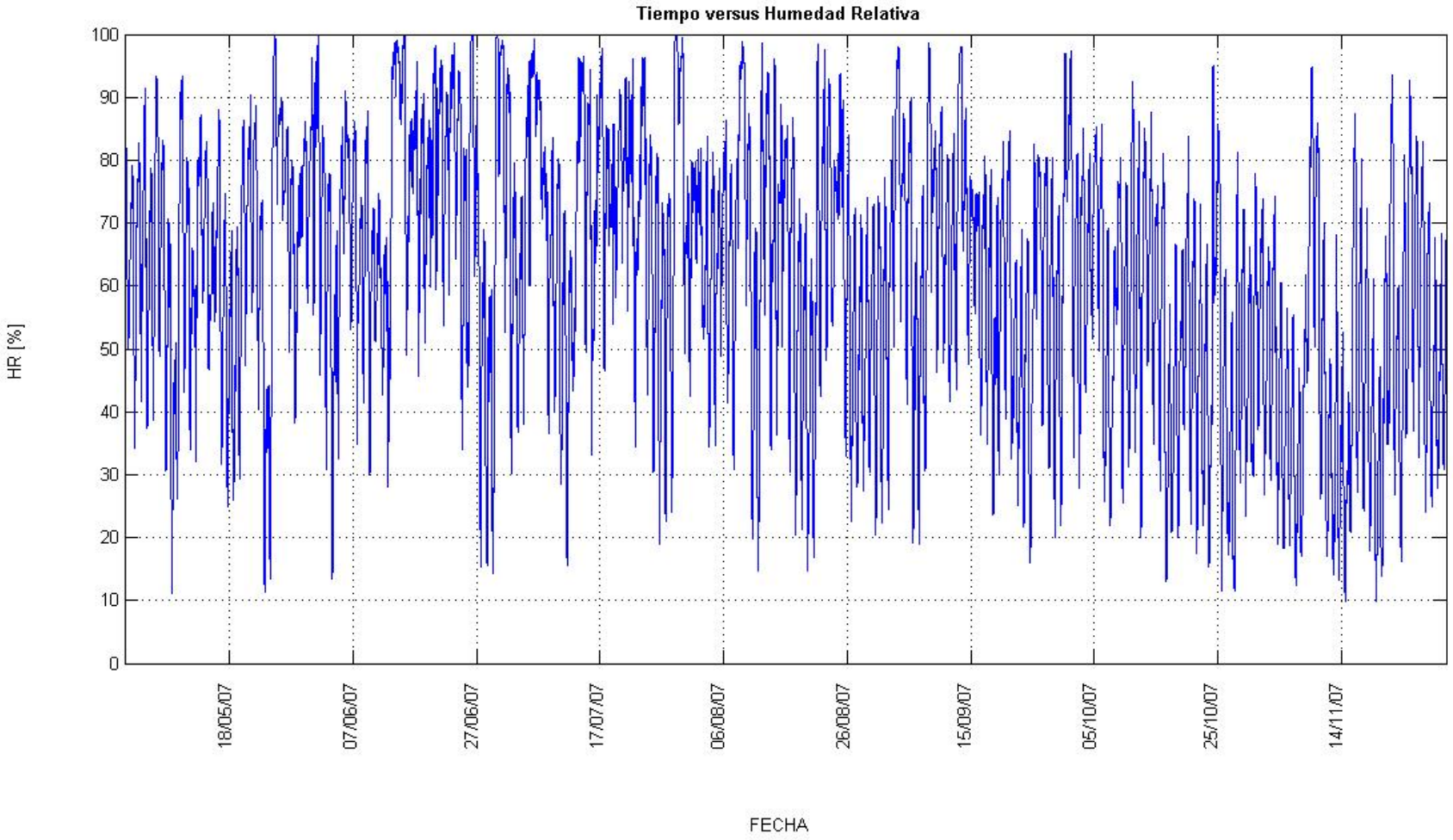
HUMIDITY



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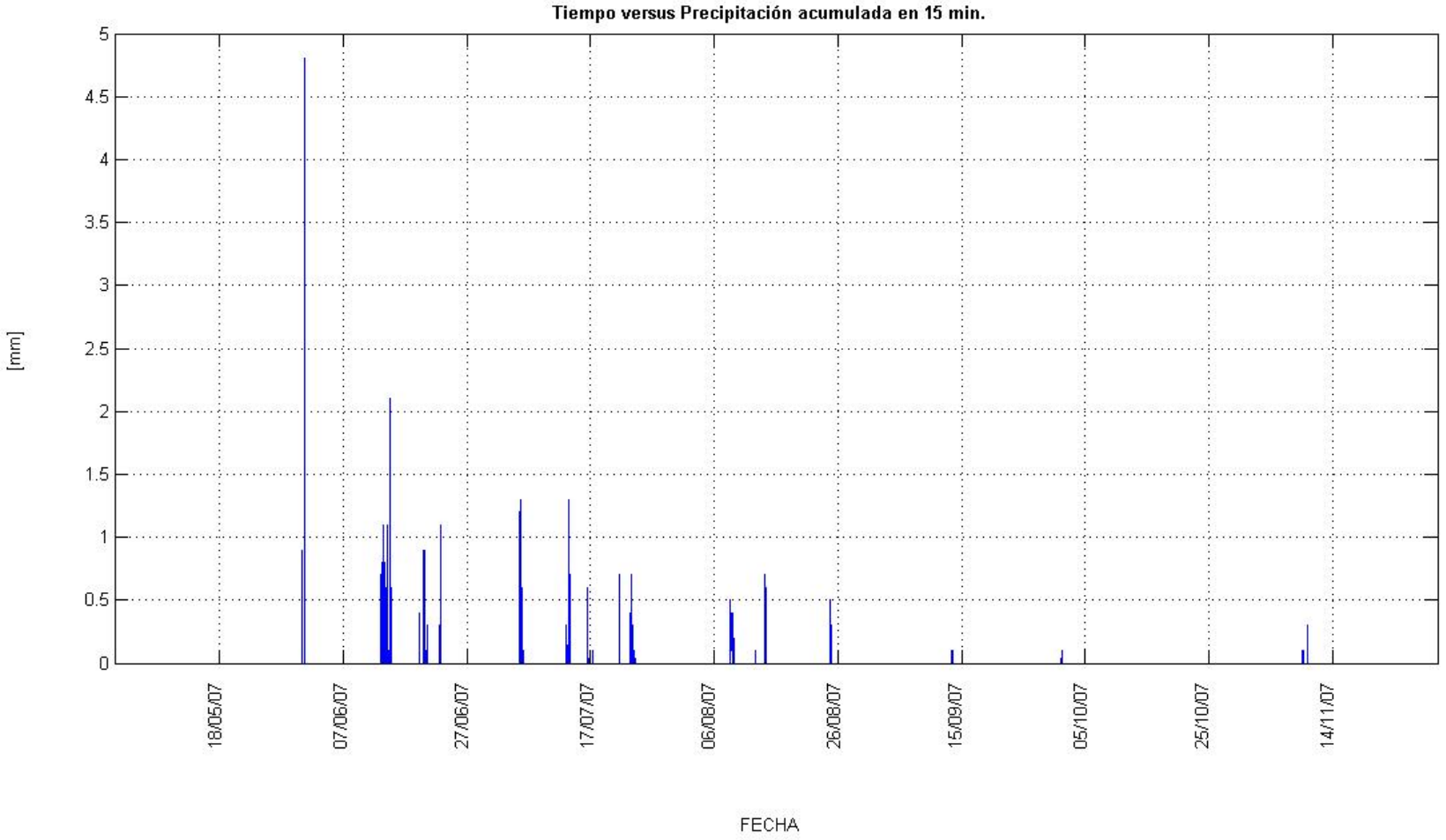
15 MINUTE RAIN MAY - NOV



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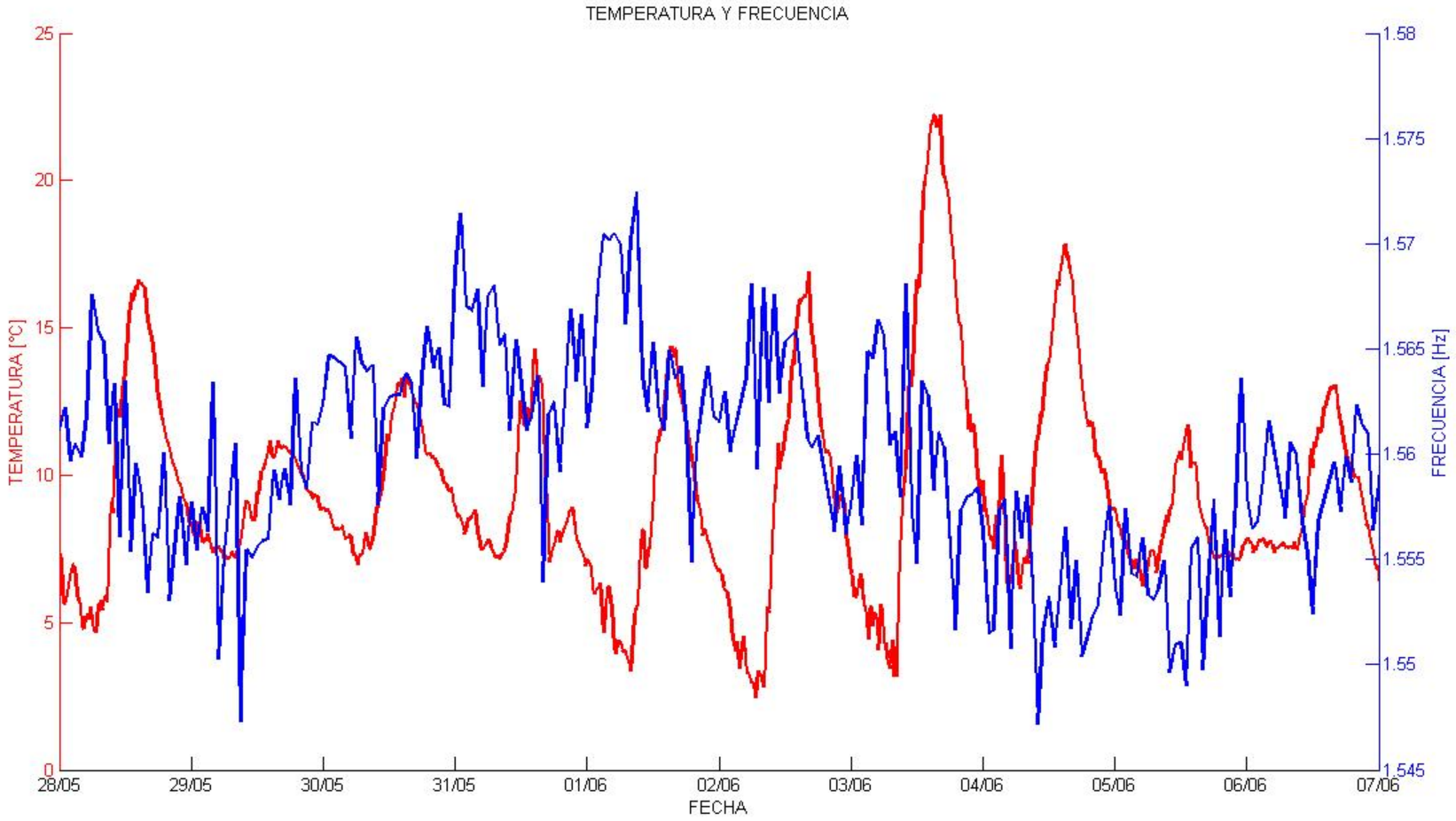
TEMPERATURE AND FREQUENCY



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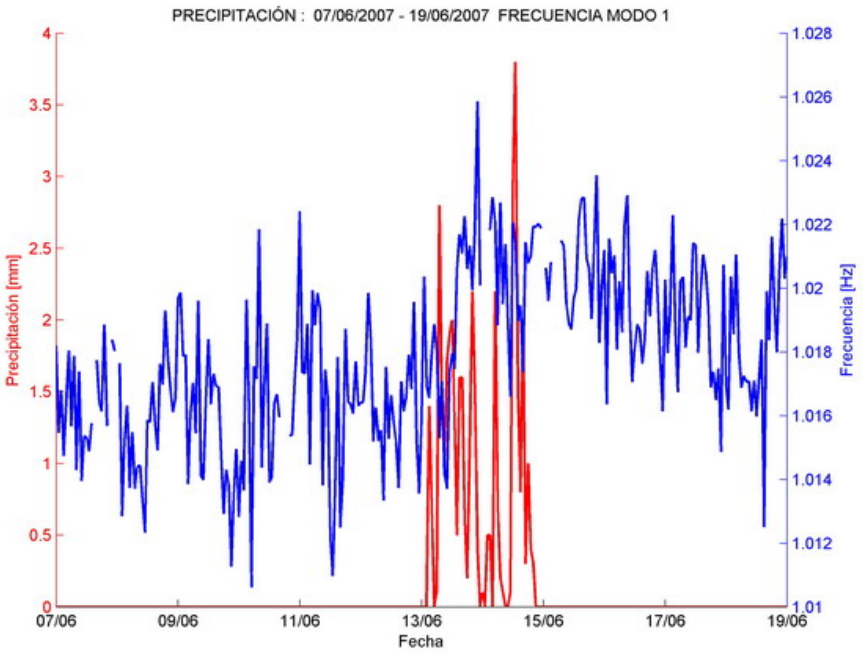
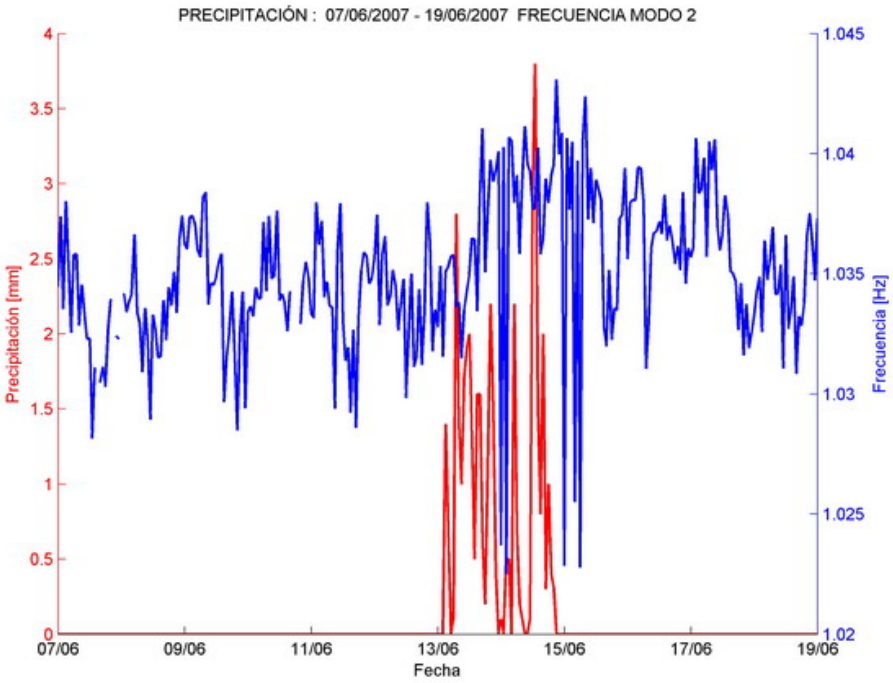
RAIN AND FREQUENCY





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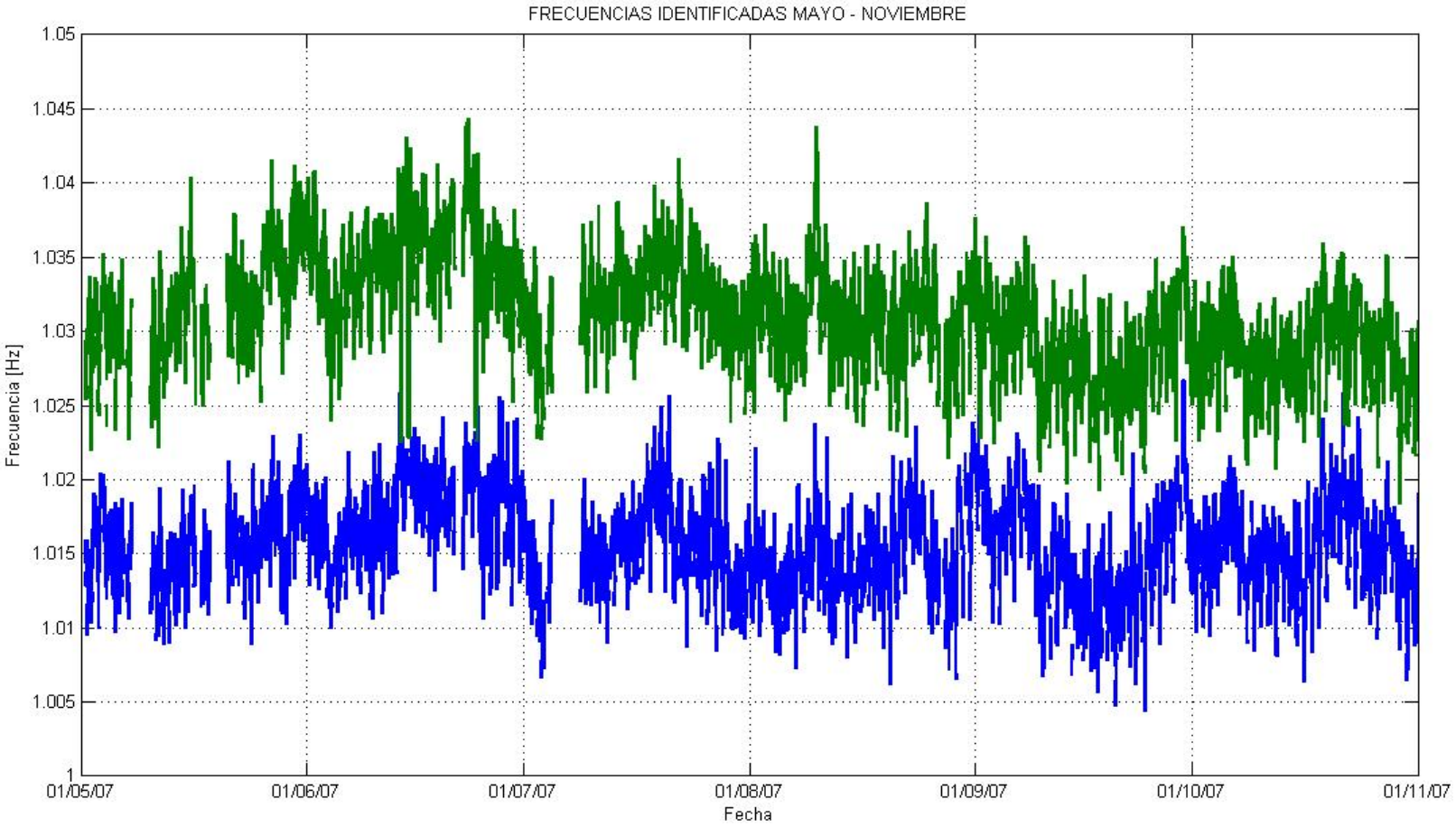
FREQUENCY VARIATION



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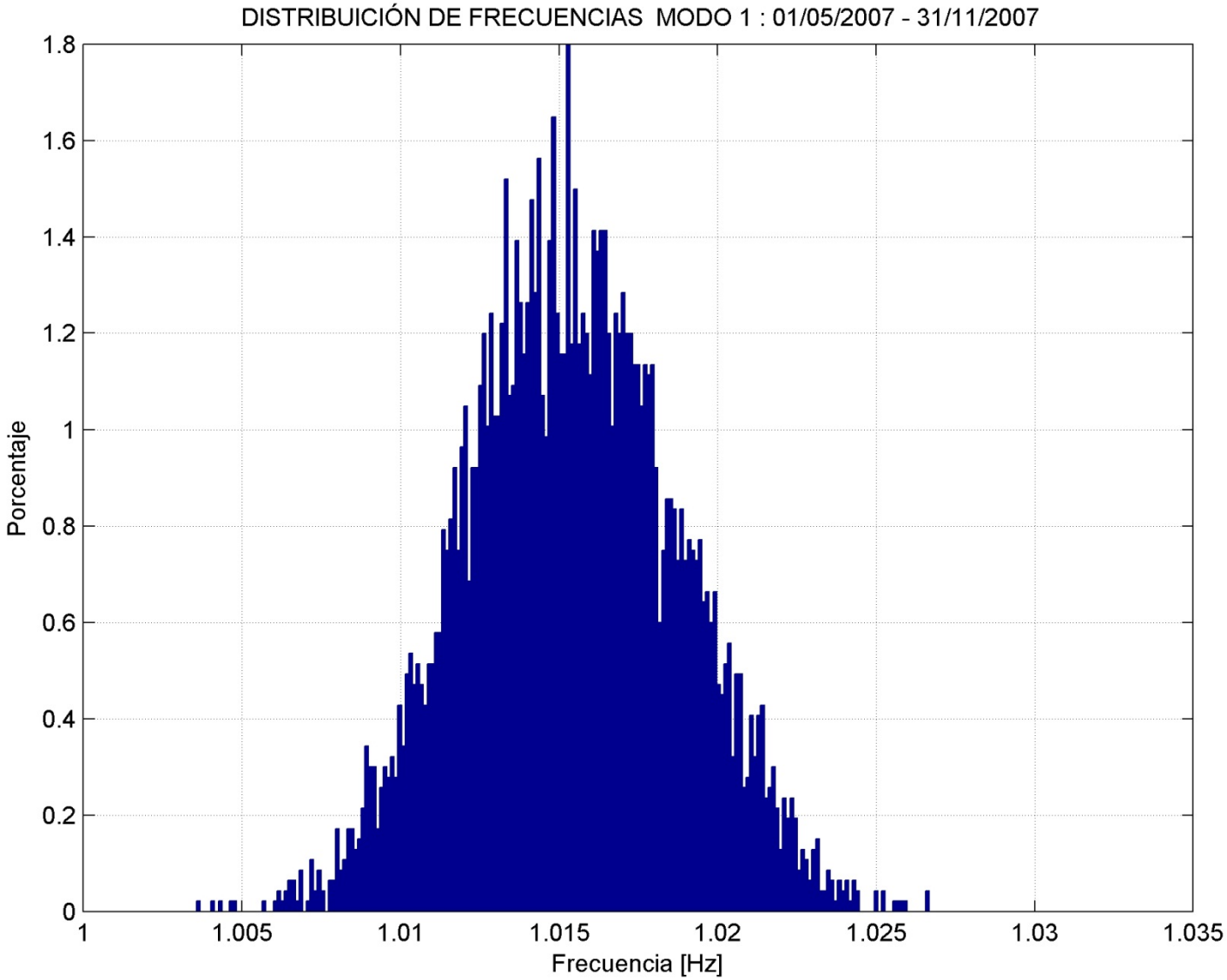
FIRST ODS



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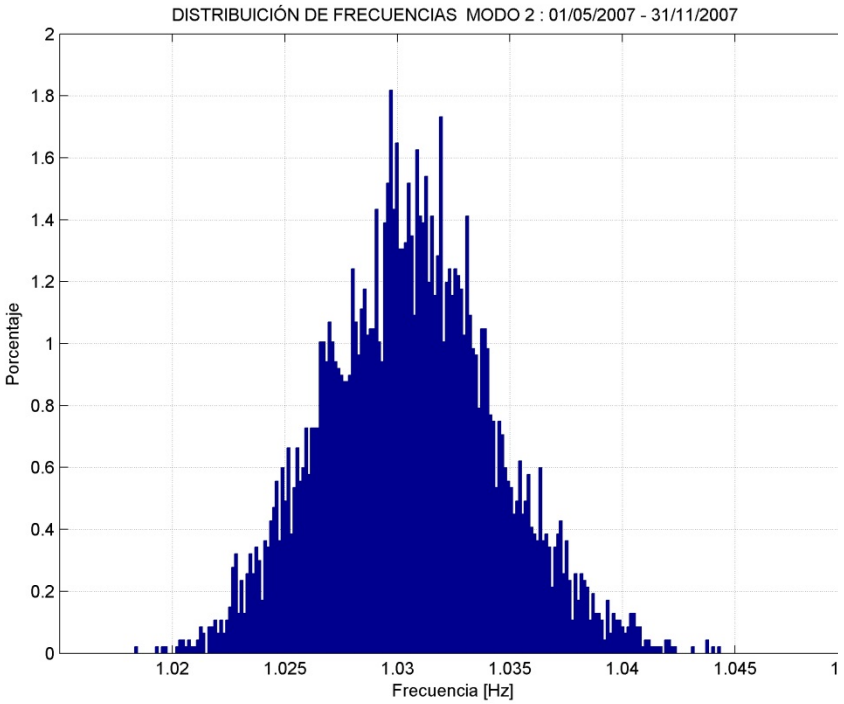

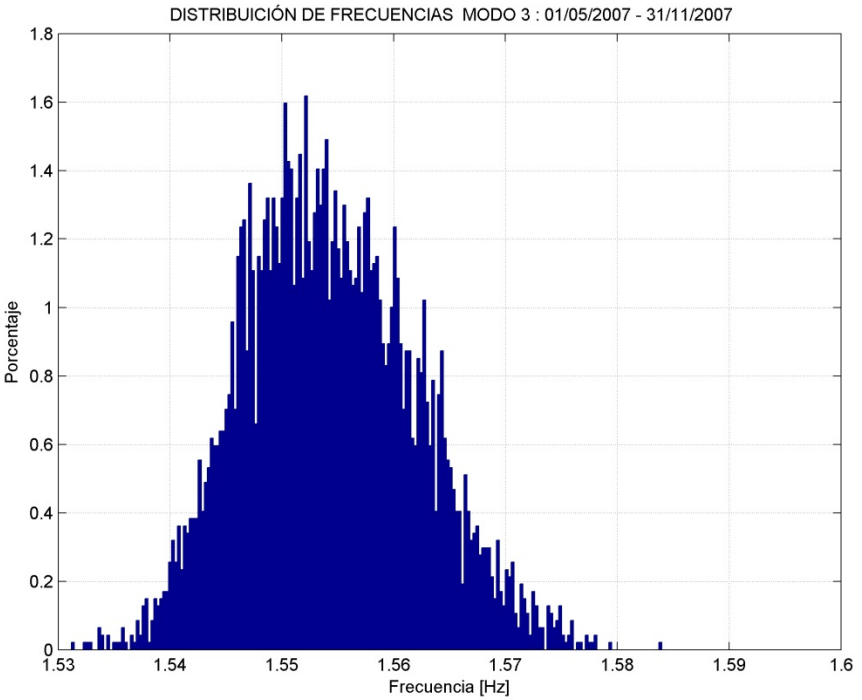

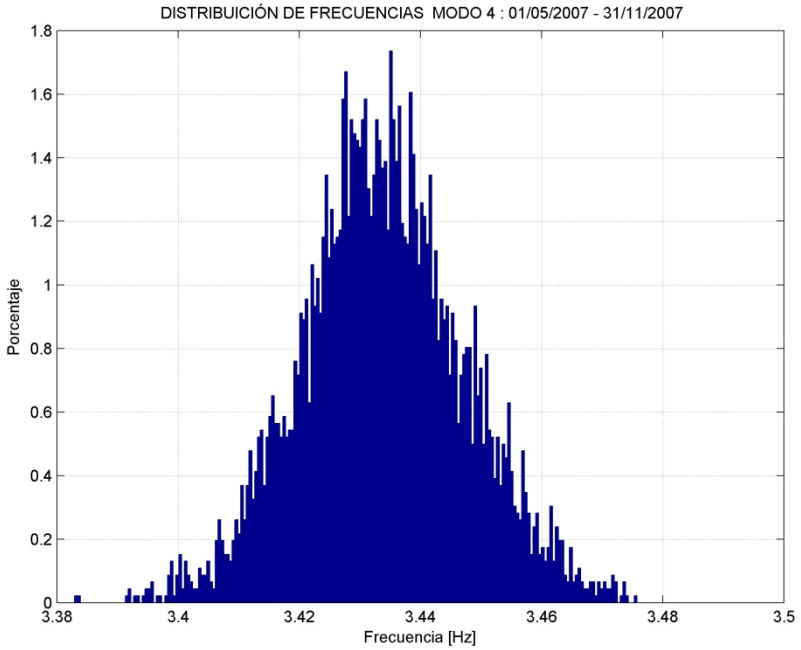

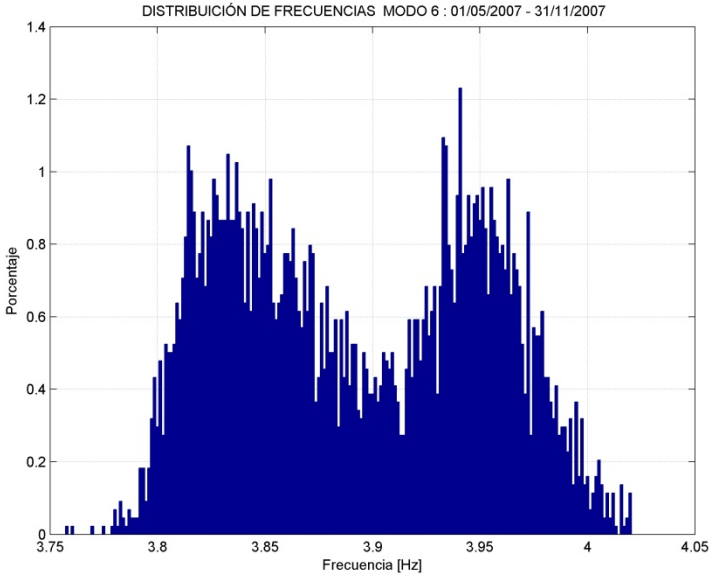

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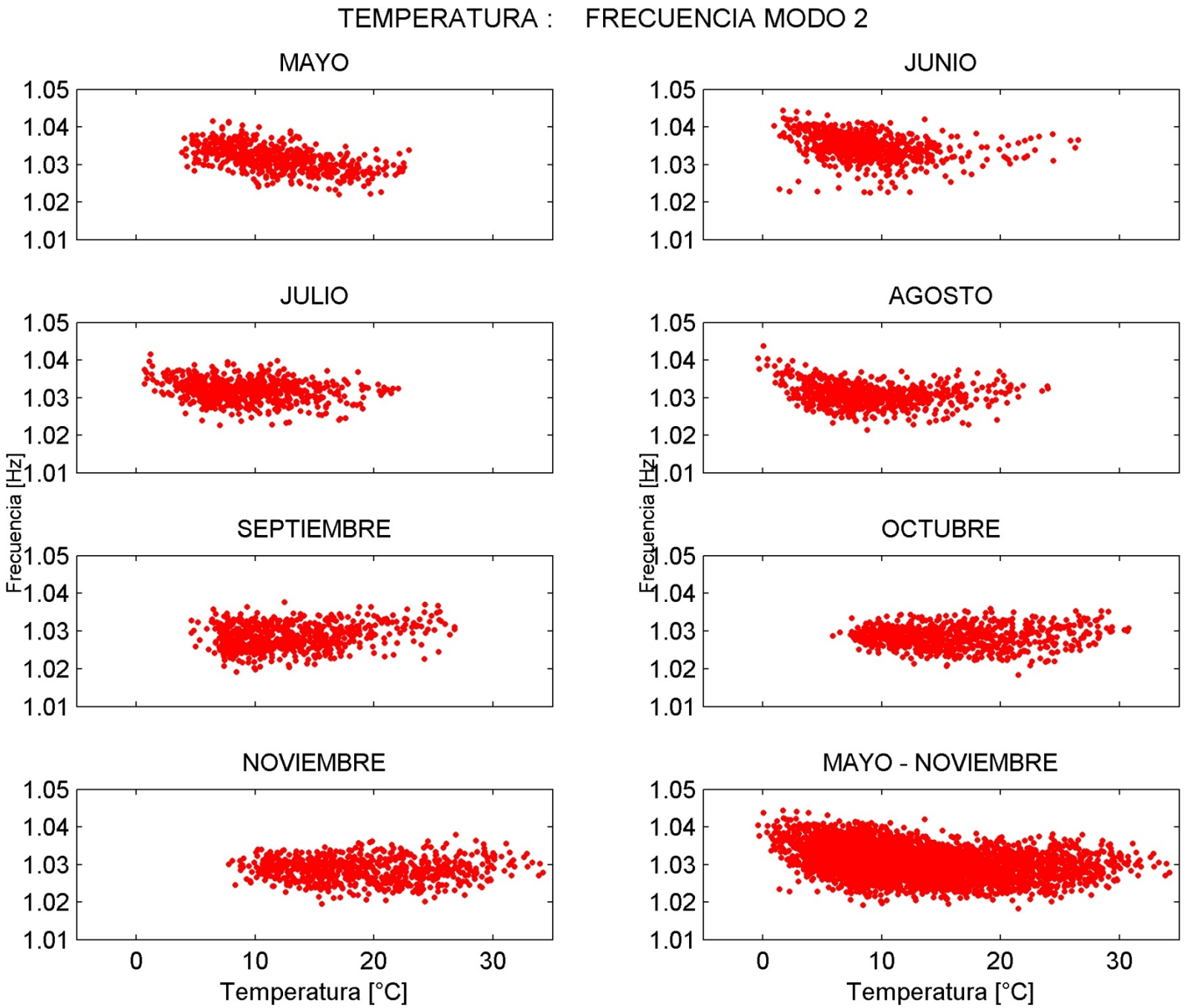

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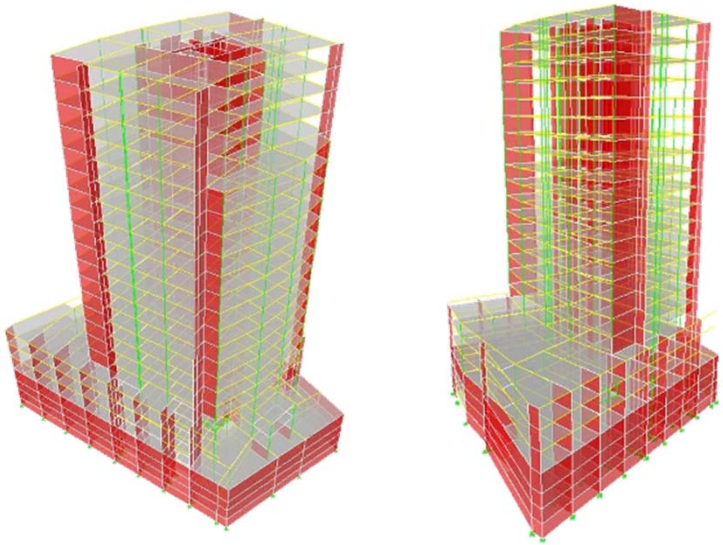
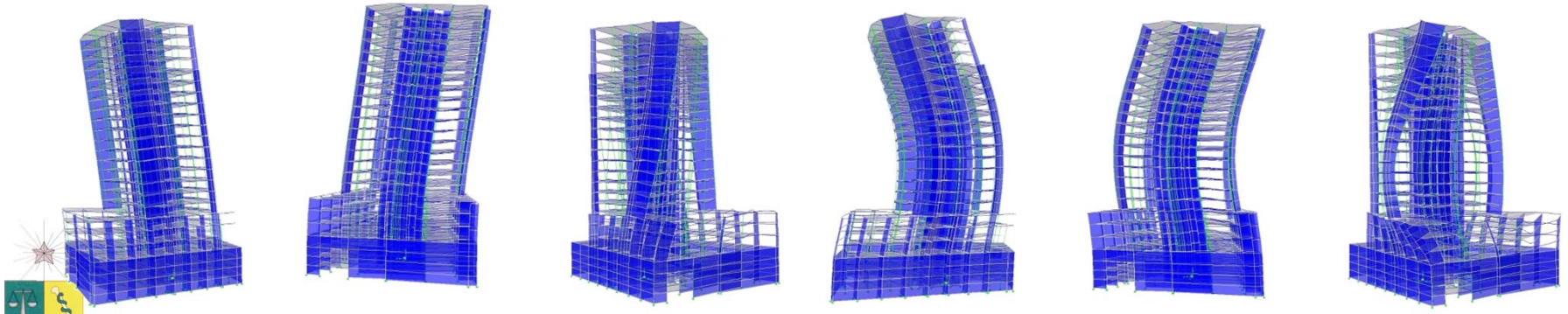
•System Identification Technique. Validation

– For validation purposes, a FE model of the building was developed



Mode	Period [sec.]	Freq [Hz]	Eff. modal mass ratios U_X [%]	U_Y [%]	R_Z [%]
1	0.95	1.05	0.3	51.3	0.0
2	0.92	1.09	50.6	0.2	0.2
3	0.69	1.46	0.1	0.0	39.1
4	0.25	3.94	0.6	16.5	0.0
5	0.25	4.05	15.7	0.5	0.0
6	0.24	4.18	0.1	0.0	10.2
7	0.15	6.85	0.9	0.0	5.8
8	0.12	8.10	0.2	8.1	0.0
9	0.12	8.39	8.0	0.2	0.1
10	0.10	10.34	0.3	0.0	2.2
11	0.08	12.71	0.1	6.4	0.0
12	0.08	13.17	5.7	0.1	0.2
13	0.07	15.06	0.1	0.0	1.9
14	0.06	17.28	0.1	6.8	0.0
15	0.06	18.09	5.1	0.1	0.8

FE MODEL, MODE SHAPES (SOURCE: CSI ETABS)



MODE 1 MODE 2 MODE 3 MODE 4 MODE 5 MODE 6

•Previous Studies

AVERAGE MODAL PARAMETERS FOR AMBIENT CONDITIONS.

Mode	Frequency [Hz]	Damping Ratio (ξ) [%]	Modal shape orientation
1	1.04	1.1	Translational. East-West.
2	1.07	1.0	Translational. North-South.
3	1.63	0.6	Torsional.
4	3.60	1.5	Translational. East-West.
5	3.57	1.5	Translational. North-South.
6	4.8	1.2	Torsional.

MODAL FREQUENCIES COMPARISON
FE MODEL VS AMBIENT VIBRATIONS ID RESULTS

MODE	FE MODEL [Hz]	ID AMB [Hz]	DIFFERENCE [%]
1	1.05	1.04	1.0%
2	1.09	1.07	2.1%
3	1.46	1.63	11.8%
4	3.94	3.6	8.6%
5	4.05	3.57	11.8%
6	4.18	4.8	14.8%

STRONG MOTIONS

- System Identification Technique
  - Parametric Multiple Input – Multiple Output (MIMO) Identification technique
  - It finds the optimal combination of modal parameters that best fits the measured response

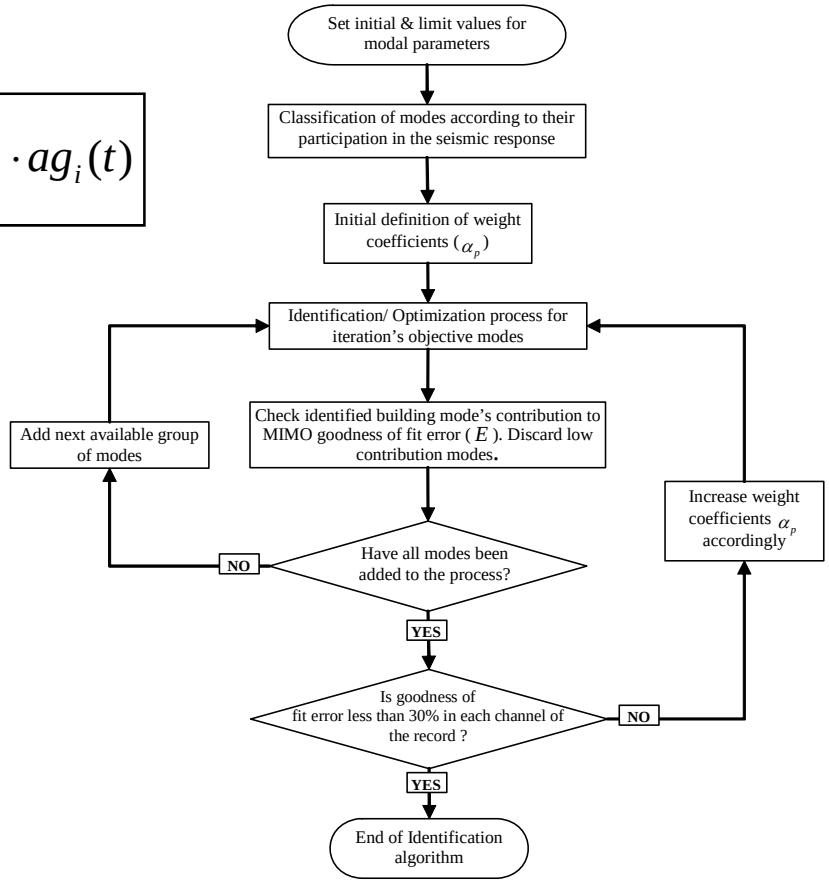
$$\ddot{y}_j(t) + 2 \cdot \omega_j \cdot \xi_j \cdot \dot{y}_j(t) + \omega_j^2 \cdot y_j(t) = \sum_{i=1}^{k} L_{j,i} \cdot ag_i(t)$$

$$a_p(t) = \sum_{j=1}^{N} \phi_{j,p} \cdot \ddot{y}_j(t)$$

Modal equilibrium equations

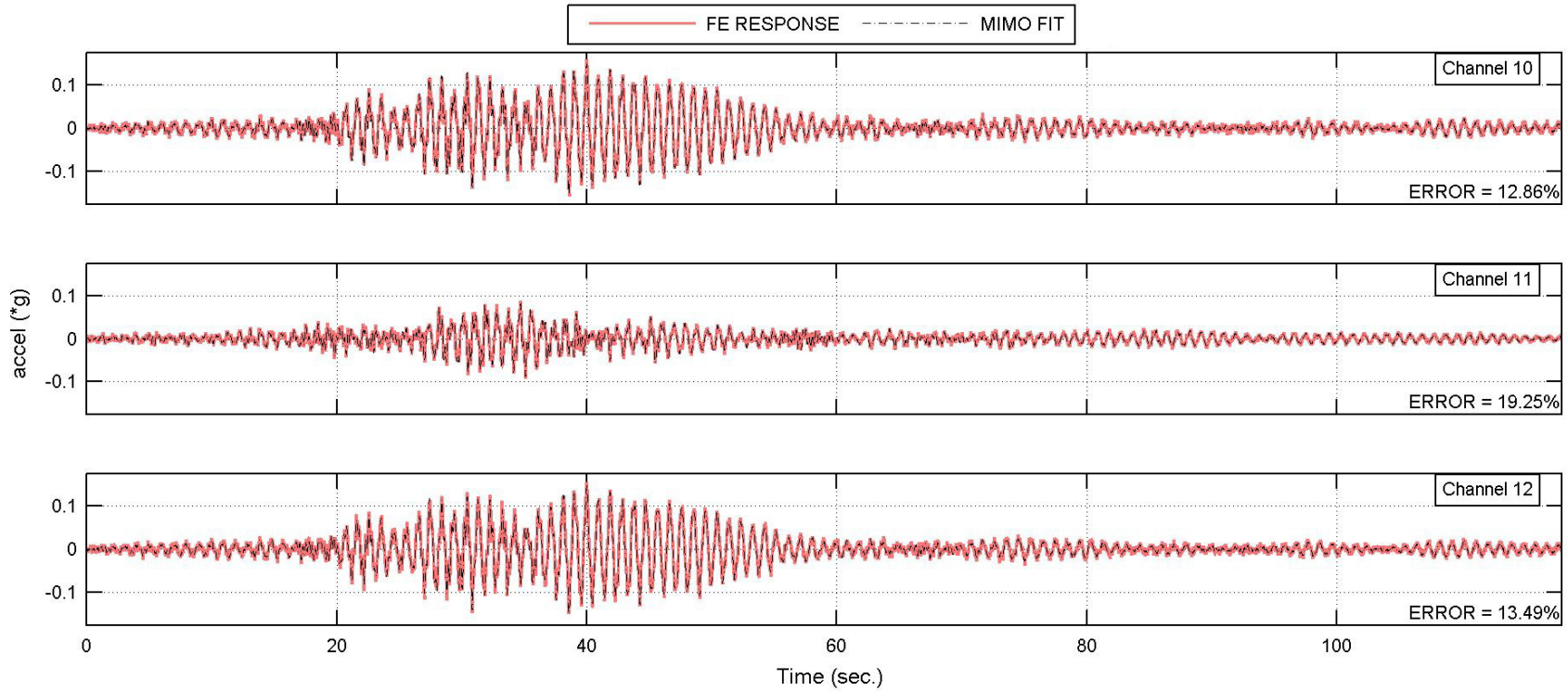
$$E = \sqrt{\frac{\sum_p \alpha_p \cdot \sum_t \left(a_{0,p}(t) - a_p(t) \right)^2}{\sum_p \alpha_p \cdot \sum_t \left(a_{0,p}(t) \right)^2}}$$

Objective function



•System Identification Technique. Validation

– Time- history analysis results from the FE model were contaminated with a 10% amplitude noise before the identification process



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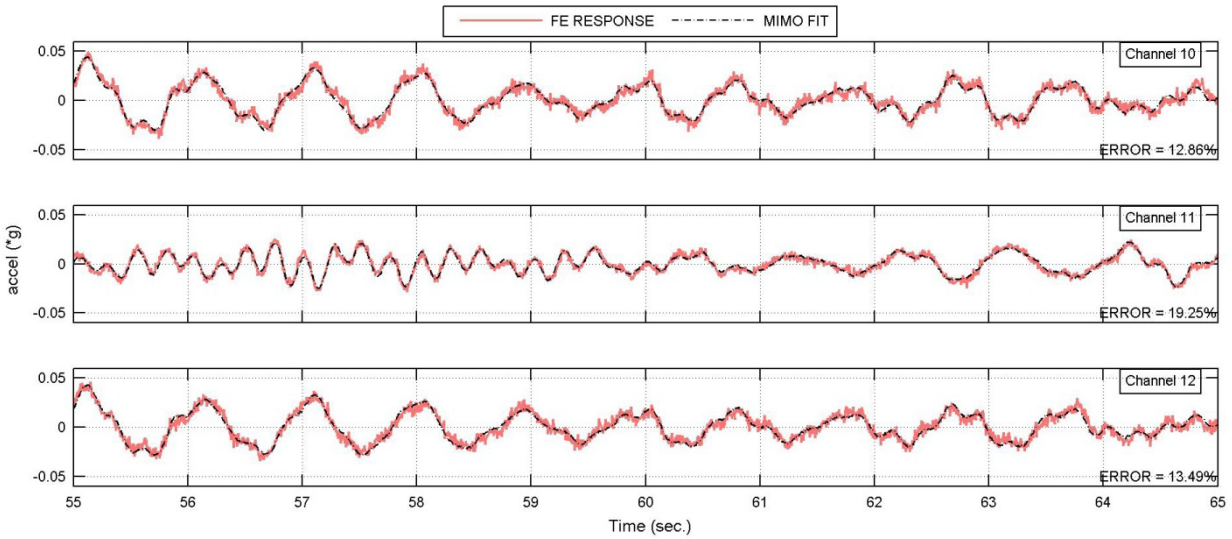
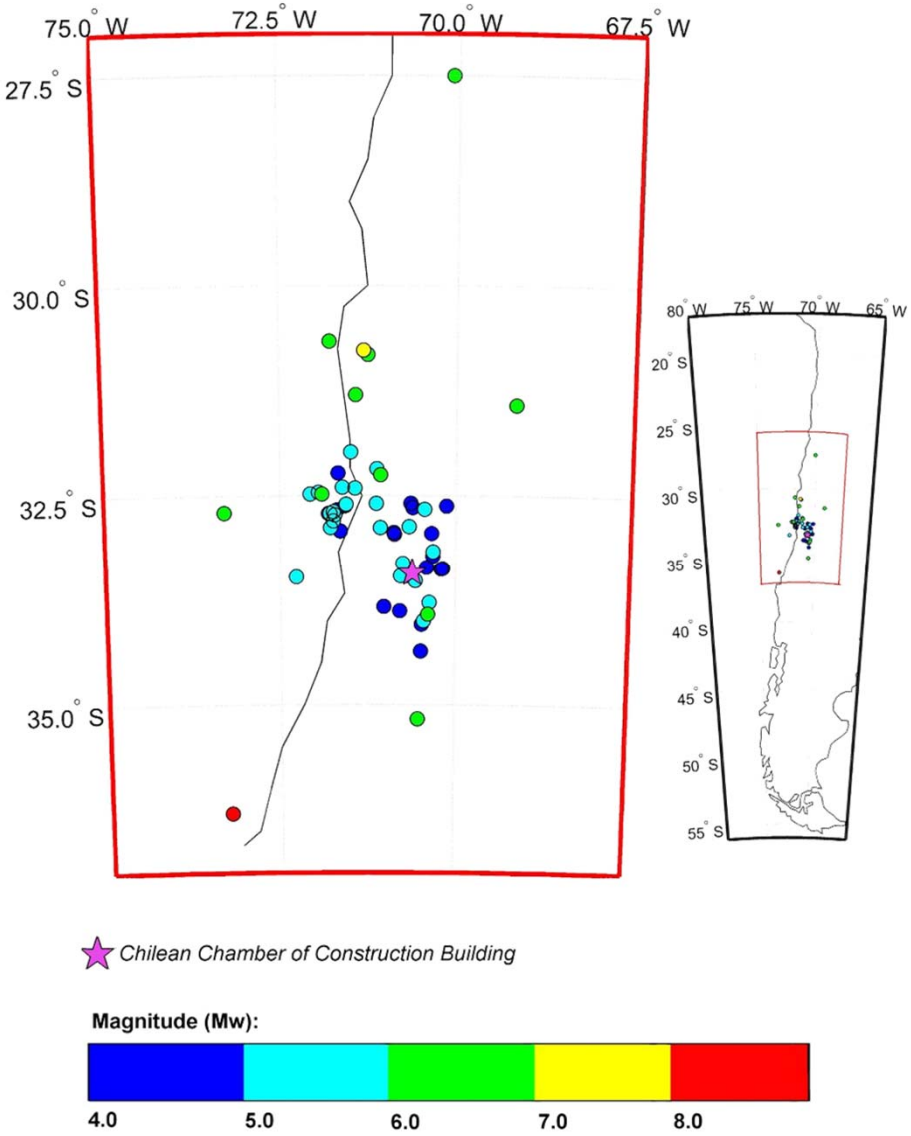


	FE computer model		Identified by MIMO		Relative Difference (%)	
Mode	Freq [Hz.]	ξ [%]	Freq [Hz.]	ξ [%]	Freq	ξ
1	1.05	1.00	1.05	1.00	0.0%	0.2%
2	1.09	1.30	1.09	1.33	0.0%	2.1%
3	1.46	0.50	1.46	0.51	0.0%	1.7%
4	3.94	3.00	3.94	2.93	0.0%	2.3%
5	4.05	2.40	4.05	2.39	0.0%	0.4%
6	4.18	0.80	4.18	0.78	0.0%	2.0%
7	6.85	1.00	6.85	1.05	0.0%	4.7%
8	8.10	3.00	8.10	3.12	0.0%	4.0%

- Seismic Records

- 55 seismic records were analyzed, dating from 1997 to 2010.
- Magnitude of corresponding seismic events range between 4.2 and 8.8 Mw
- Recorded Peak Ground Accelerations range from 0.001g to 0.14g.
- Recorded Peak Structural Accelerations range from 0.002g to 0.31g



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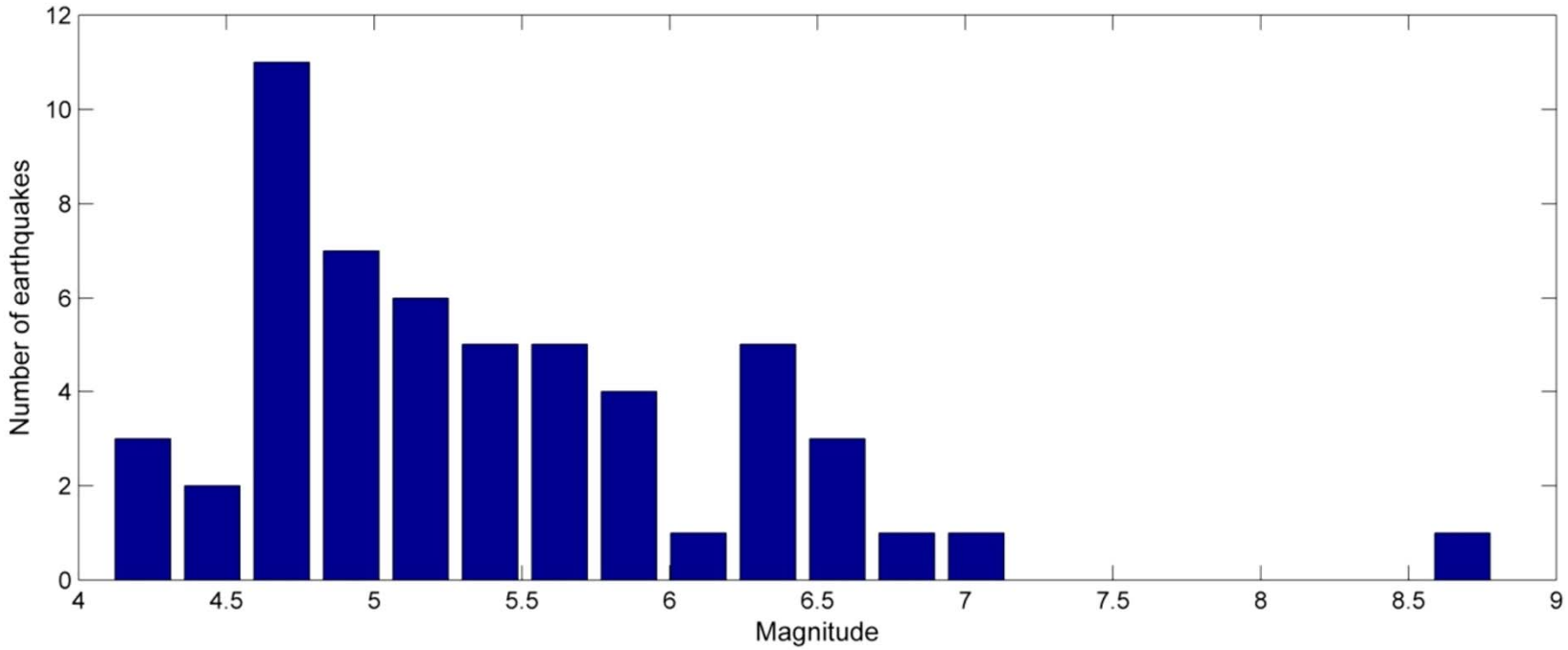
Seismic Records



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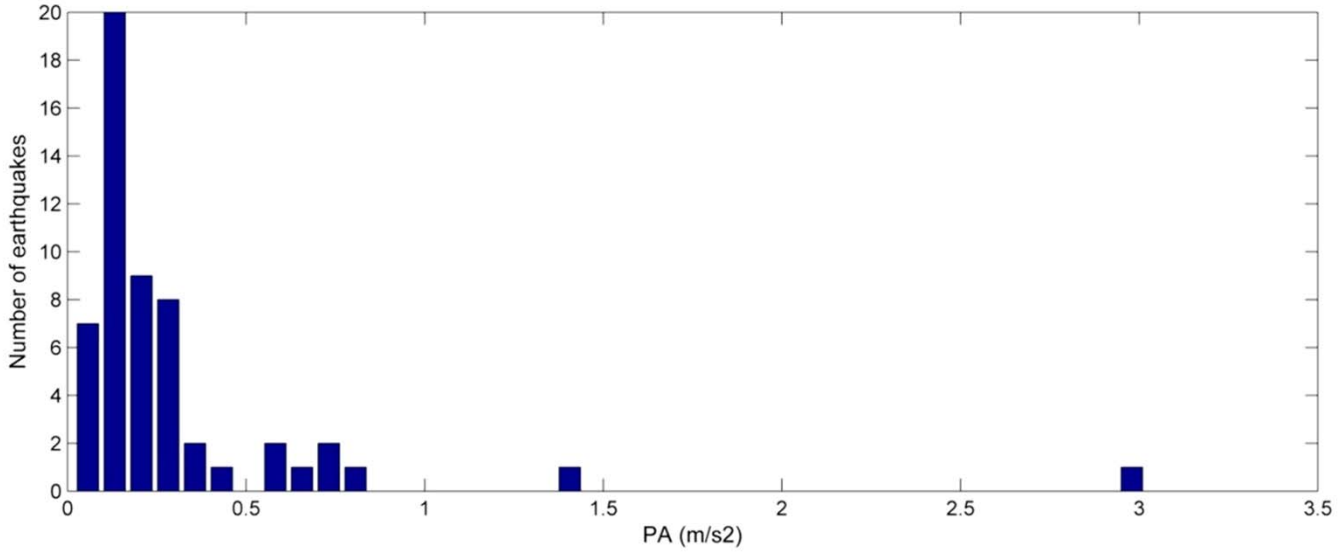
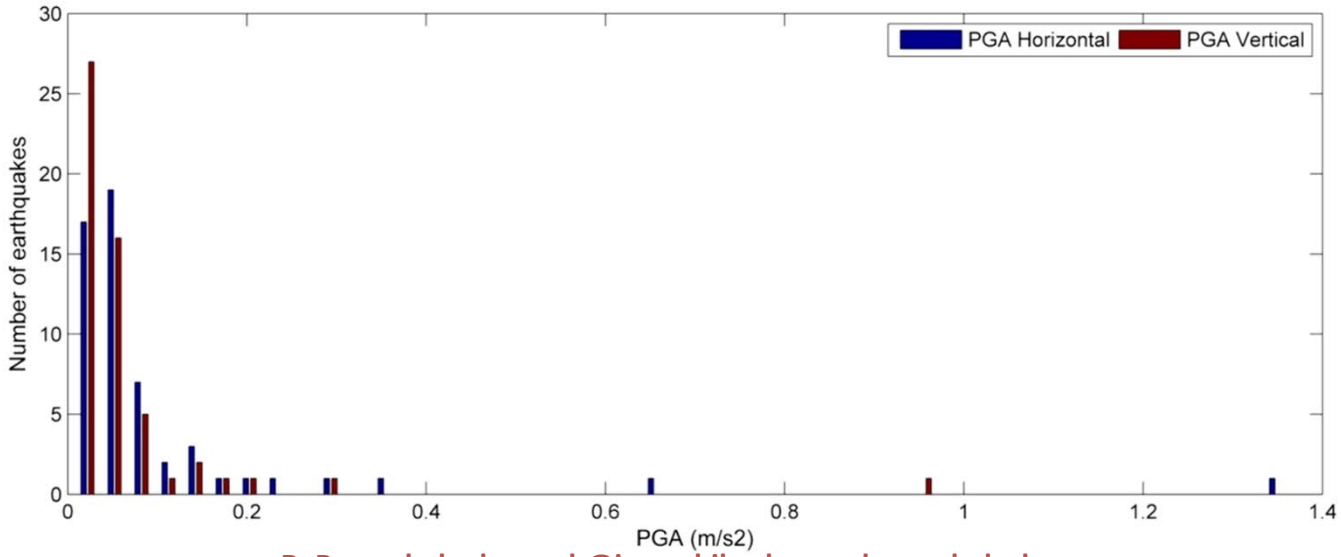
Seismic Records





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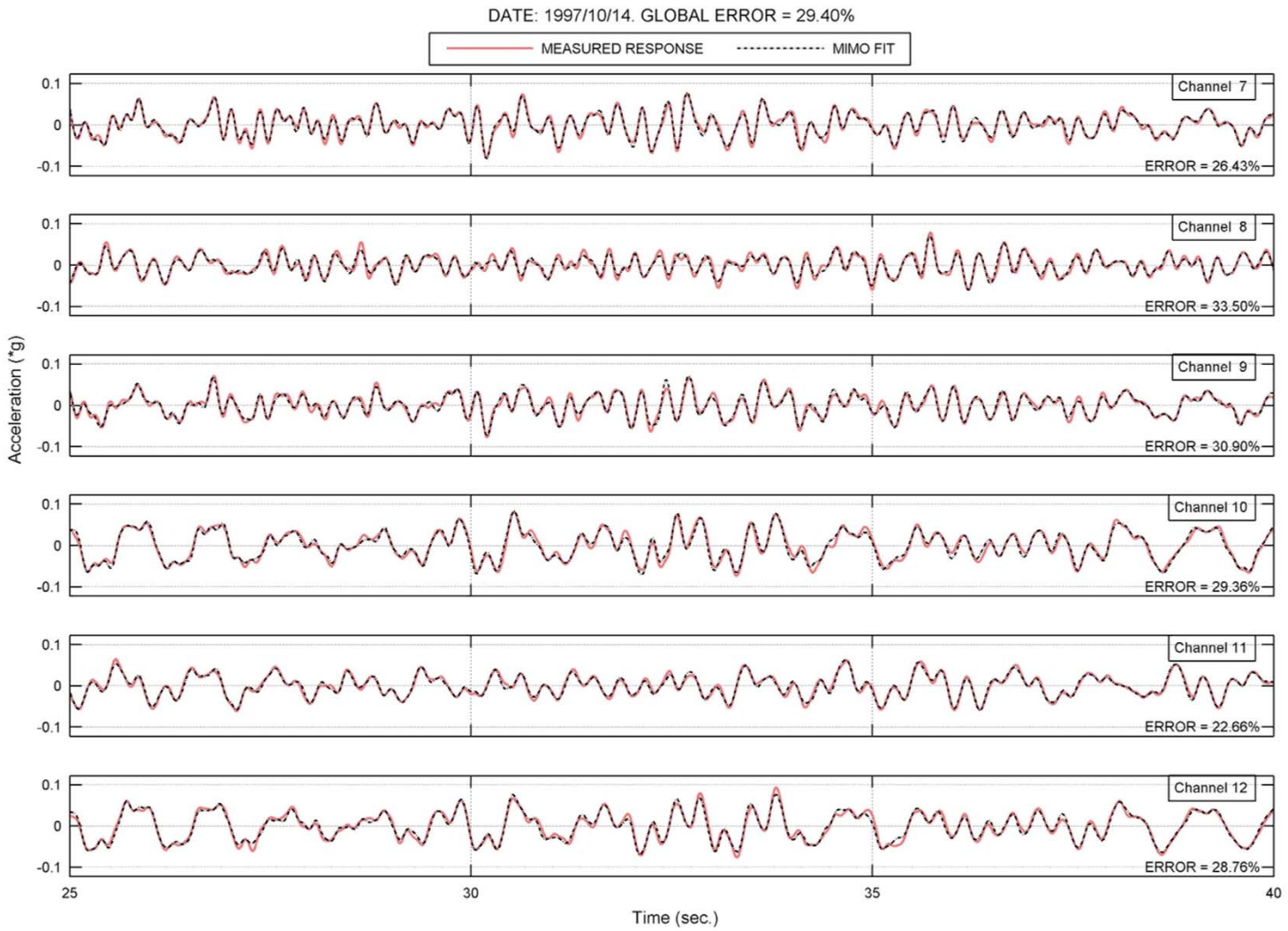
- MIMO Analysis. Response Fit



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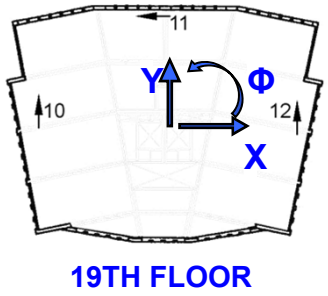
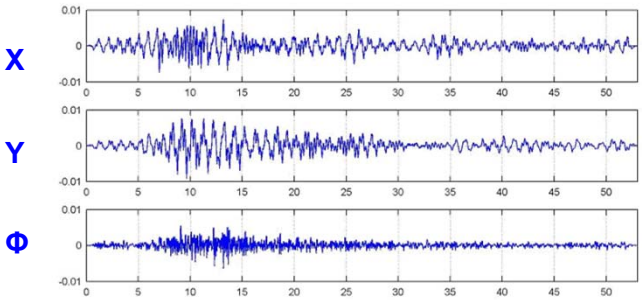
- # MIMO Analysis. Severity of Shaking
  - Different criteria were tested to evaluate the severity of shaking: PGA, PA, etc
  - The “modal amplitude” definition had the best correlation to identified modal parameters

$$RMS_{\text{modal,j}} = \sqrt{\sum_{t}\left(\left[\vec{a}_{19_{\text{th}}\ \text{floor}}(t)\bullet\vec{\theta}_j\right]_{\left[f_j-\Delta f_j,\, f_j+\Delta f_j\right]}\right)^2}$$

→ **MODAL AMPLITUDE**



19TH FLOOR



Carreno R. - Boroschek R. “Modal parameter variation due to earthquakes of different intensities”. XXIX IMAC. February 2011

- # MIMO Analysis. Severity of Shaking
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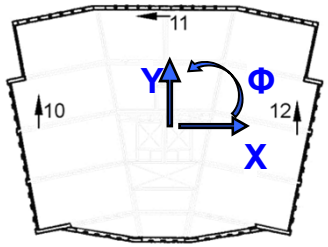
$$RMS_{\text{modal,j}} = \sqrt{\sum_{t}\left(\left[\vec{a}_{19_{\text{th}}\ \text{floor}}(t)\bullet\vec{\theta}_j\right]_{\left[f_j-\Delta f_j,\, f_j+\Delta f_j\right]}\right)^2}$$

→ **MODAL AMPLITUDE**



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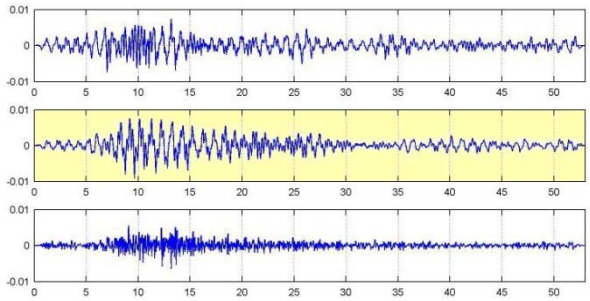
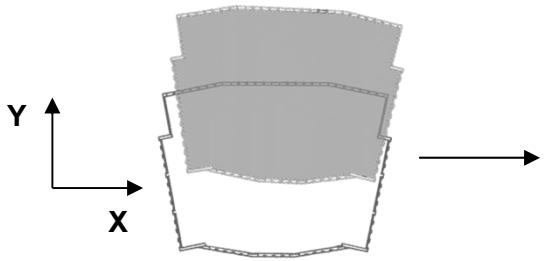
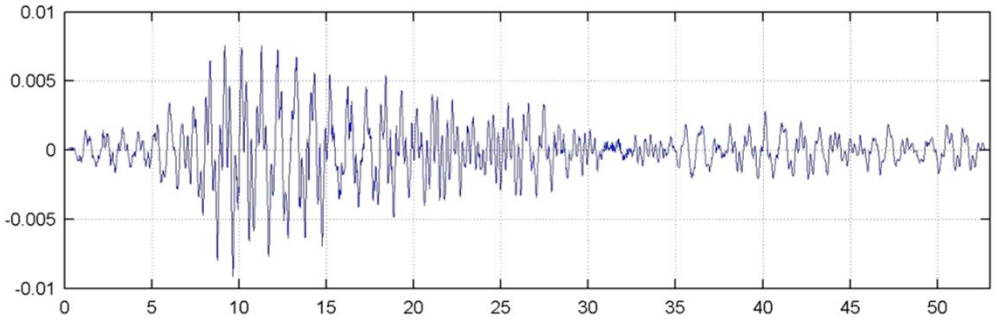


EXAMPLE: Mode 1 → freq : 1.04 Hz)



mode shape
19th floor



R. Boroschek rborosch@ing.uchile.cl-www.boroschek.cl

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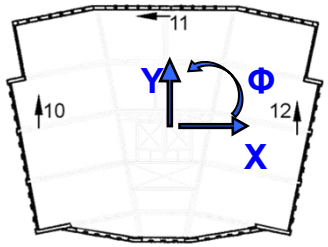

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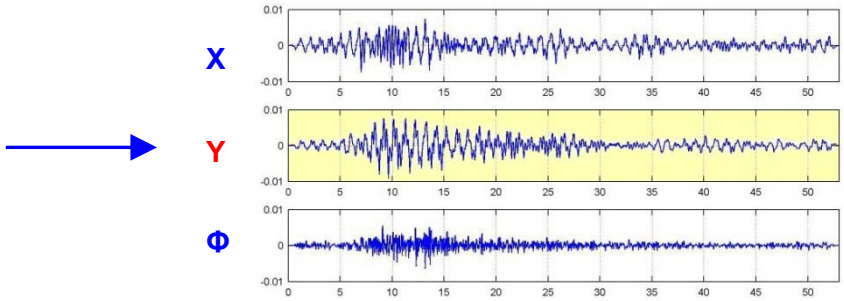

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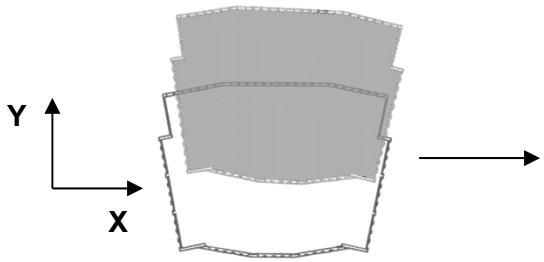

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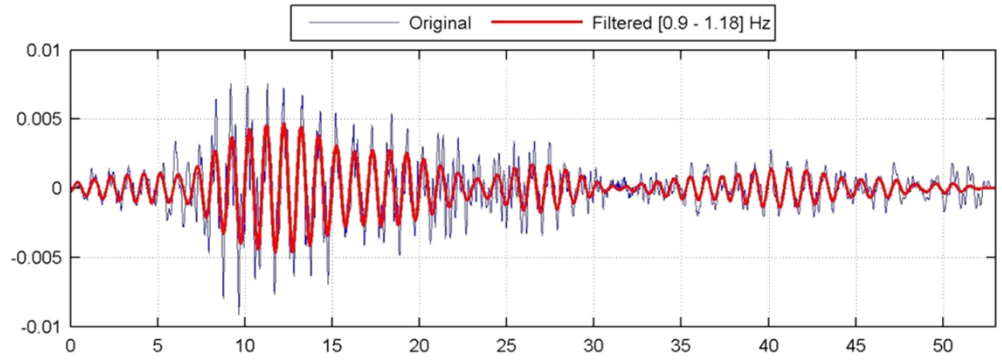

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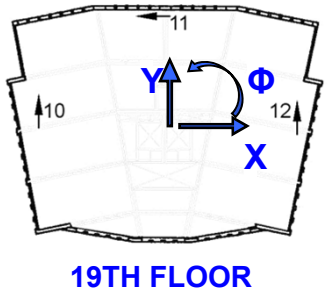

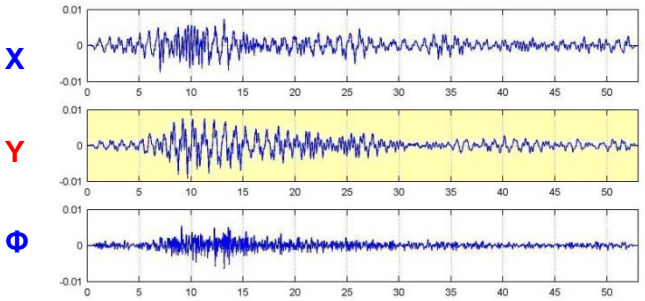

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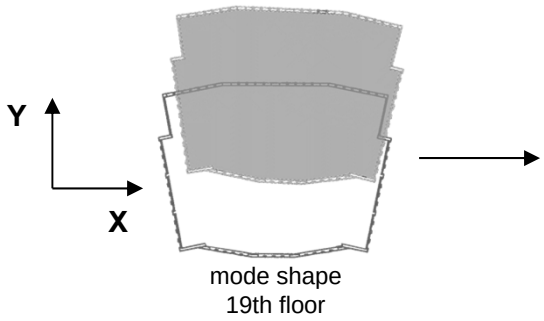

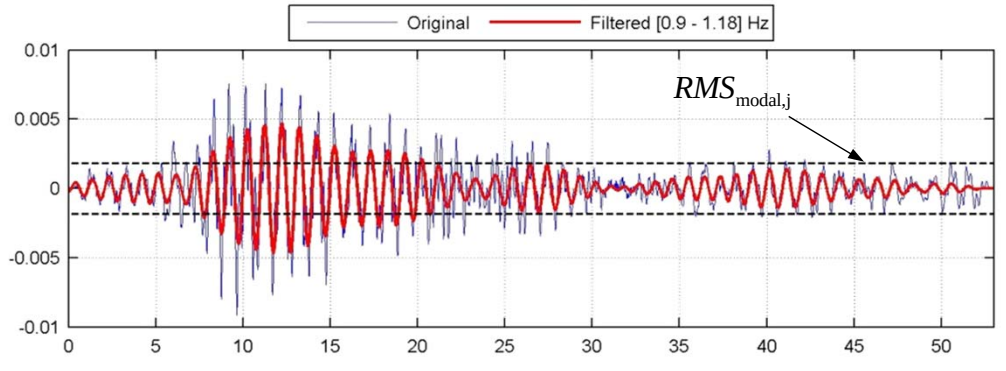

R. Boroschek rborosch@ing.uchile.cl-www.boroschek.cl

- The 2010 South-Central Chile EQ
  - Occurred on February 27th 2010, with a Magnitude of 8.8 Mw
  - Only this event caused visible damage on the building and permanent variation in its modal parameters
  - The building only suffered minor and moderate damage, mostly in non-structural elements (partition walls, ceilings, etc), in addition to some shear cracks on the perimeter façade elements

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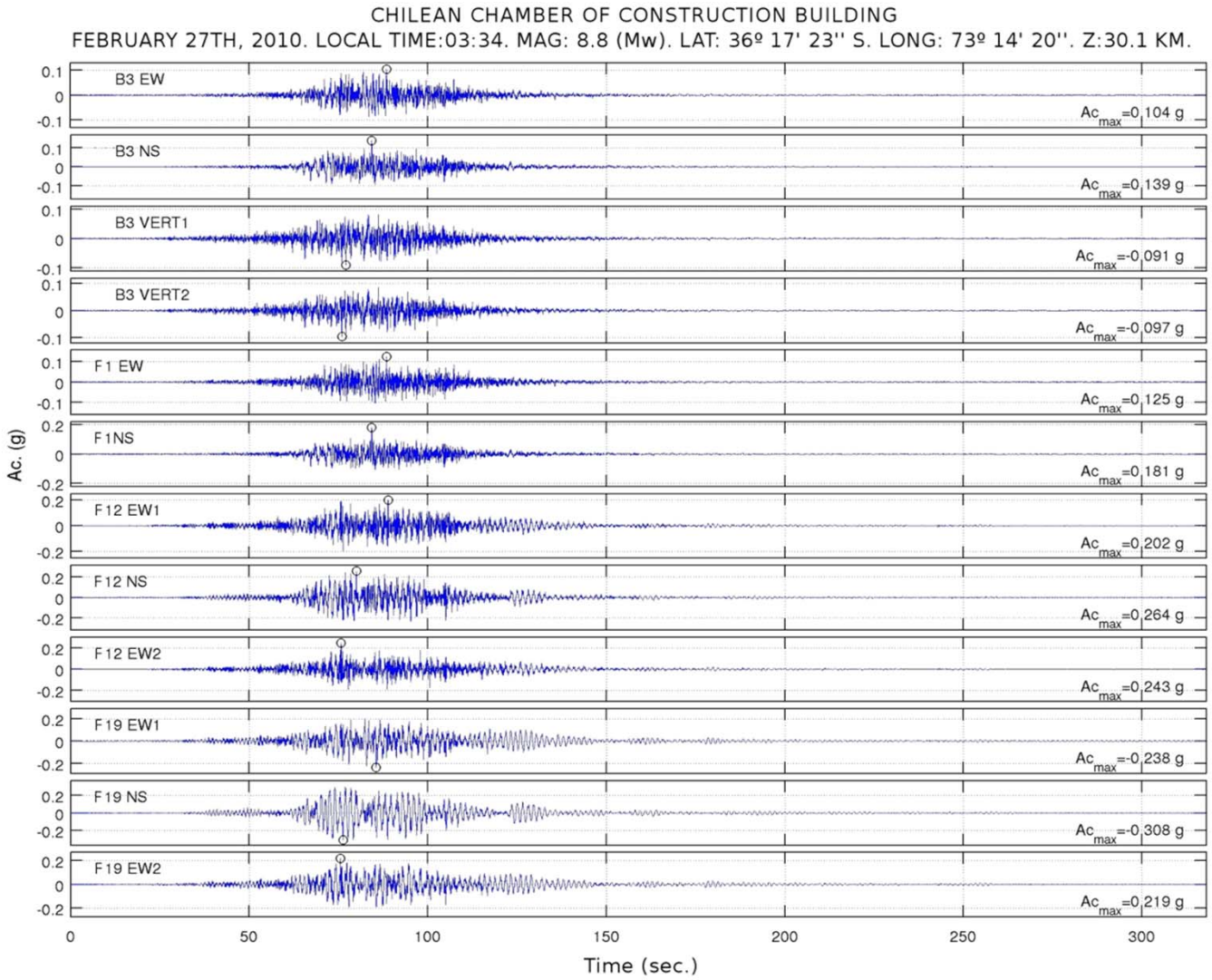

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•The 2010 South-Central Chile EQ. Modal Parameters

- Using the MIMO algorithm, modal parameter variation during the event was determined by dividing the seismic record into small windows
- Modal frequencies showed a maximum decrease of 35% from initial values during the event and 21% decrease at the end
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MODAL FREQUENCIES

MIMO ID DURING THE EVENT

Mode	Start [Hz]	Minimum [Hz]	End [Hz]
1	0.99	0.64	0.79
2	0.98	0.61	0.74
4	3.72	2.44	3.02
5	3.36	2.31	2.65

AMBIENT VIBRATIONS (SSI)

Mode	Before EQ [Hz]	After EQ [Hz]
1	1.01	0.84
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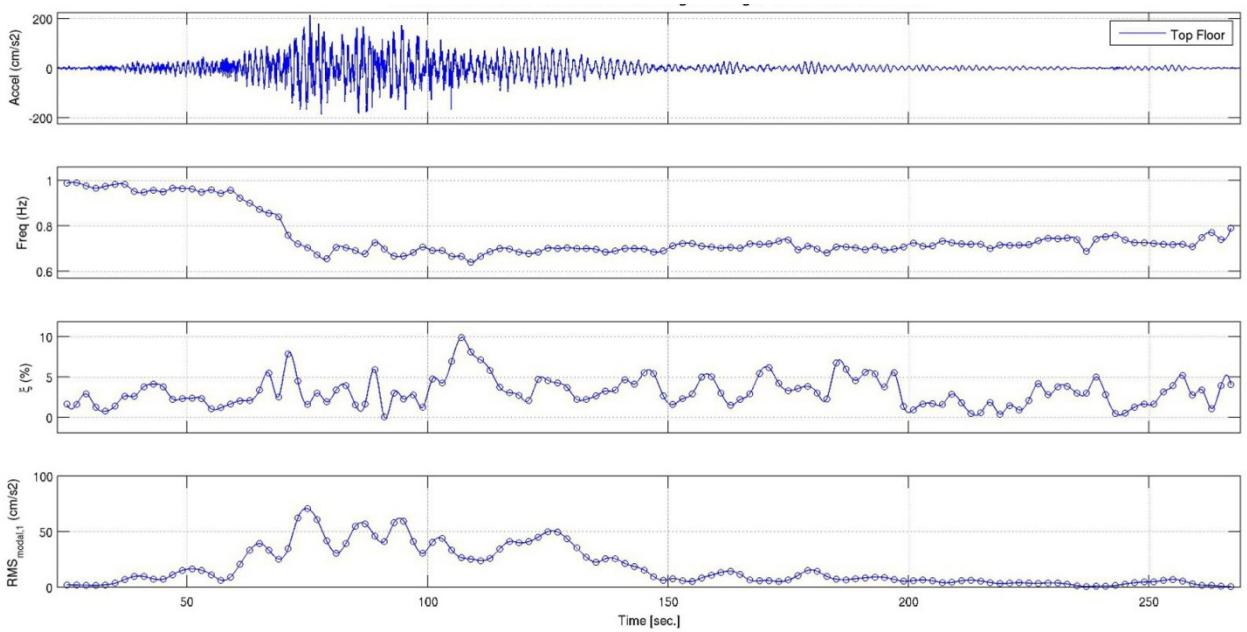

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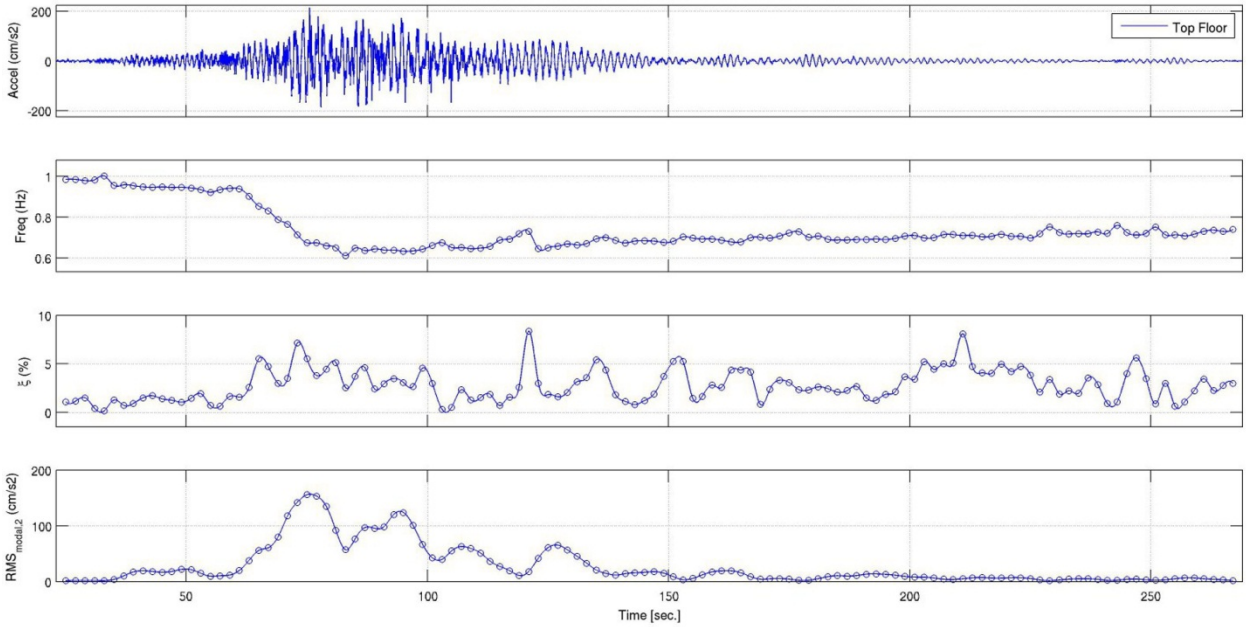

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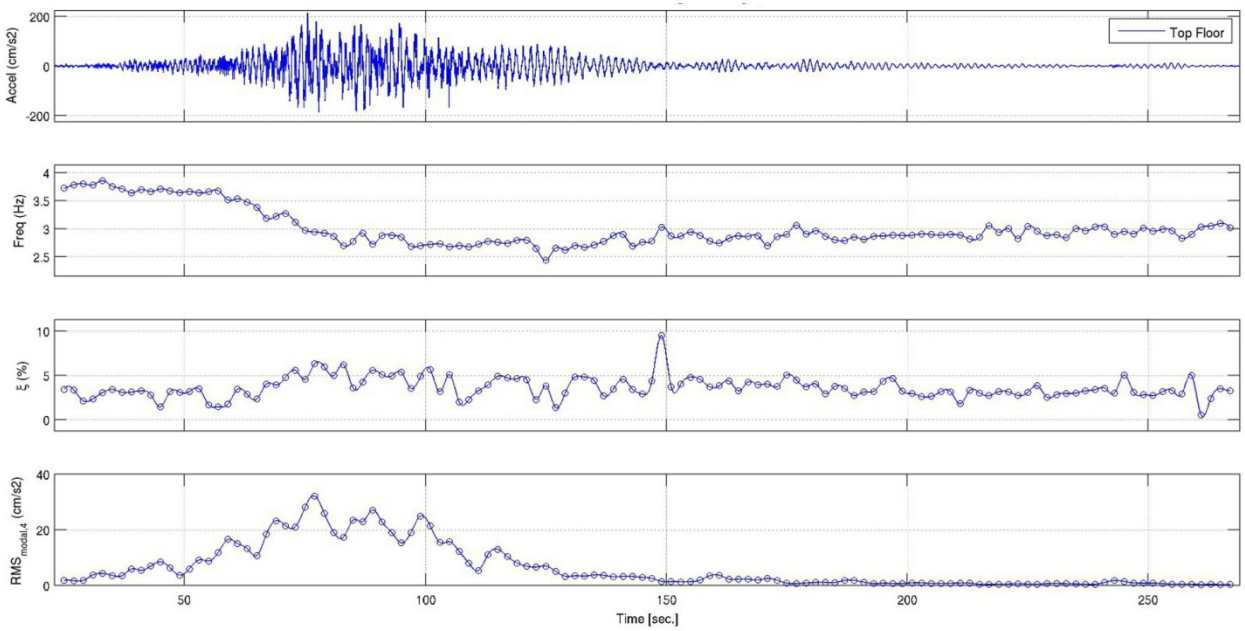

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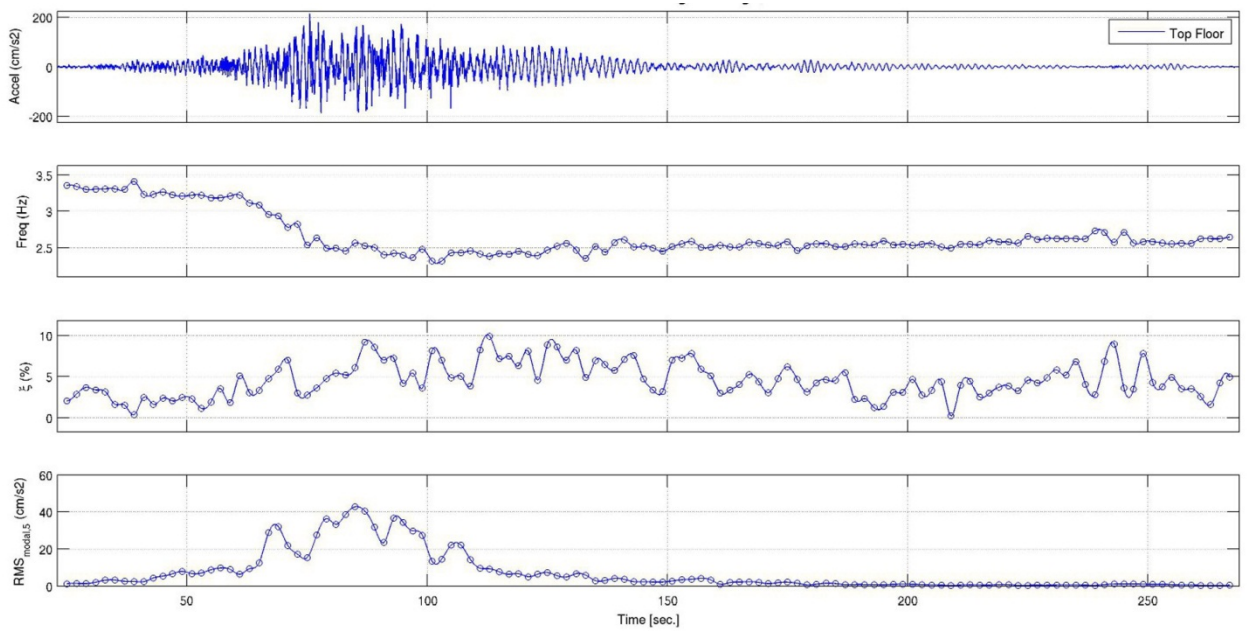

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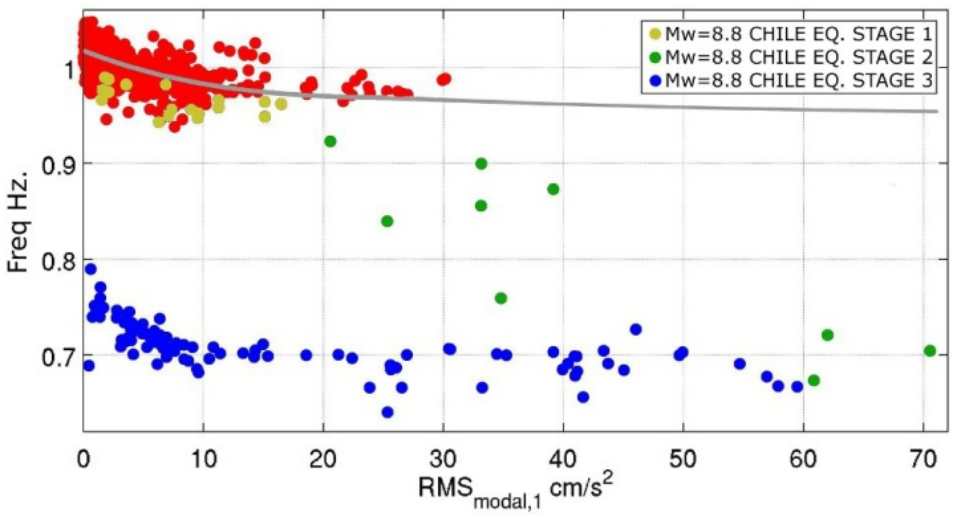
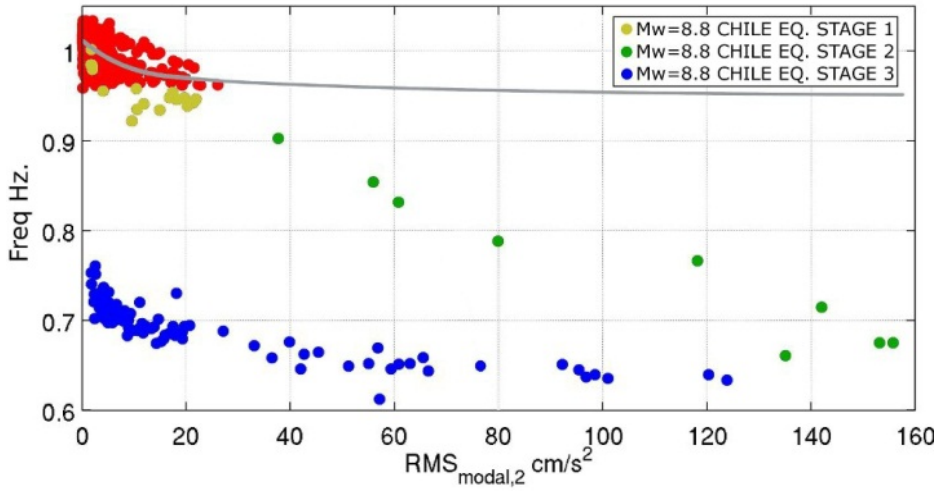
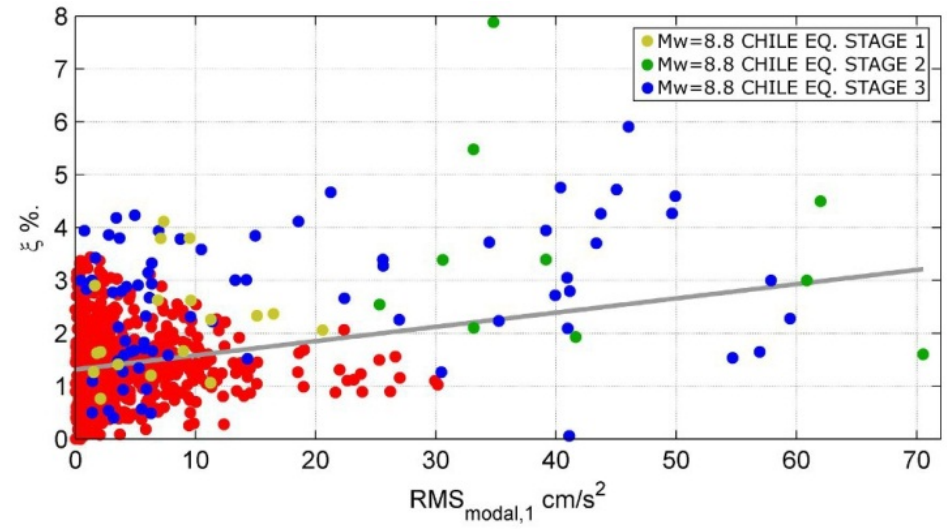
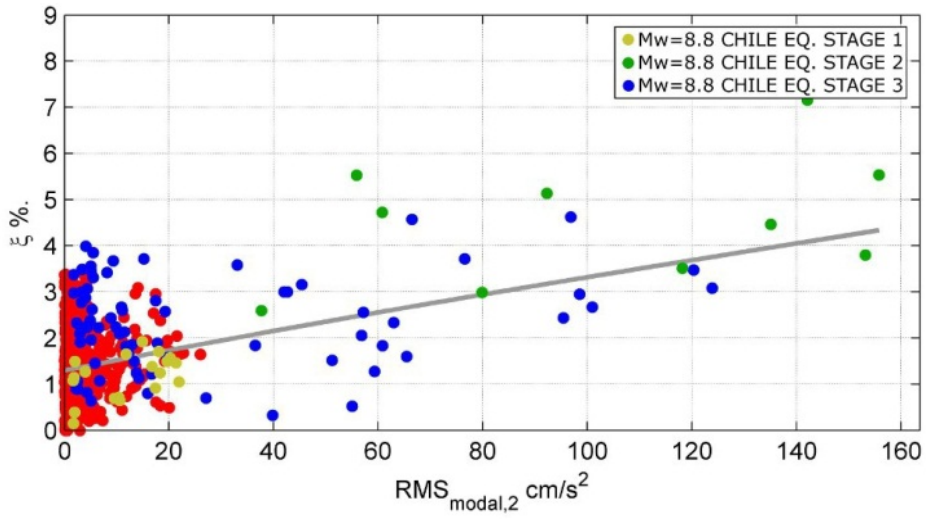
MIMO Analysis. Severity of Shaking vs Modal Parameters









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Torre Central Building, Santiago.

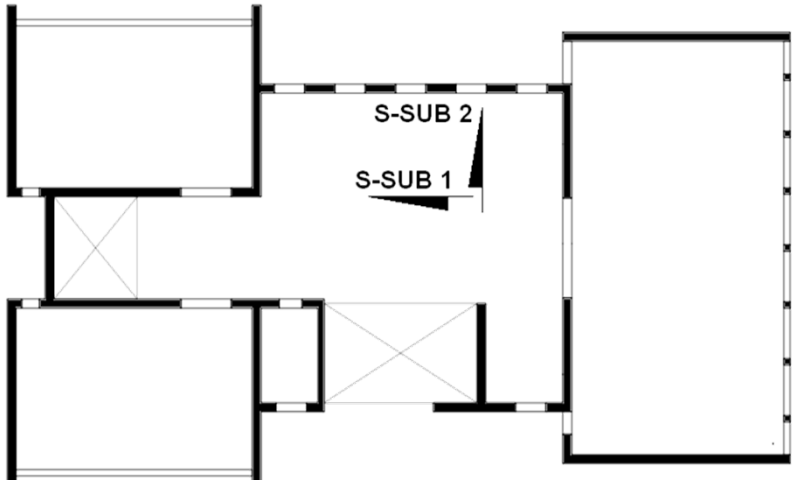



- Construction 1962
-Continuous SHM since 2009
- 9 story + 1 underground
- Structural System: Concrete Structural Wall
- Height: 30 m

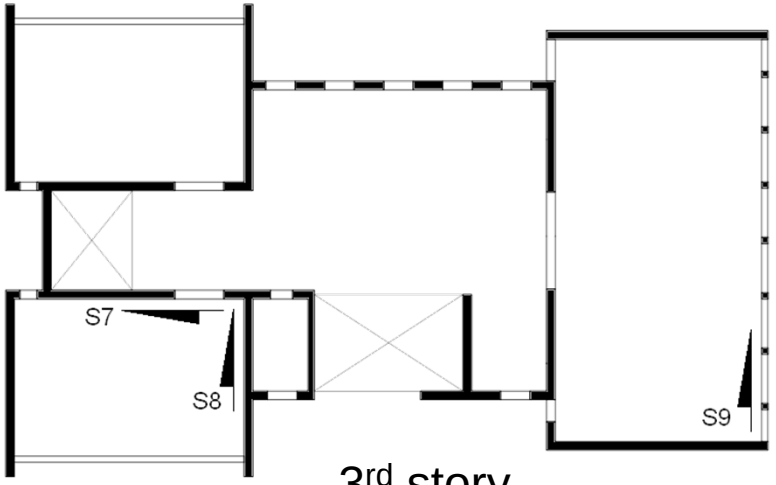
- Plan 30 x 19 m
-Total Plan Area: 4600 square m
- Wall Thickness: 0.35 m
- Average Wall/Plan Area= 7.7 %

Torre Central building, Santiago.

Sensor Location.



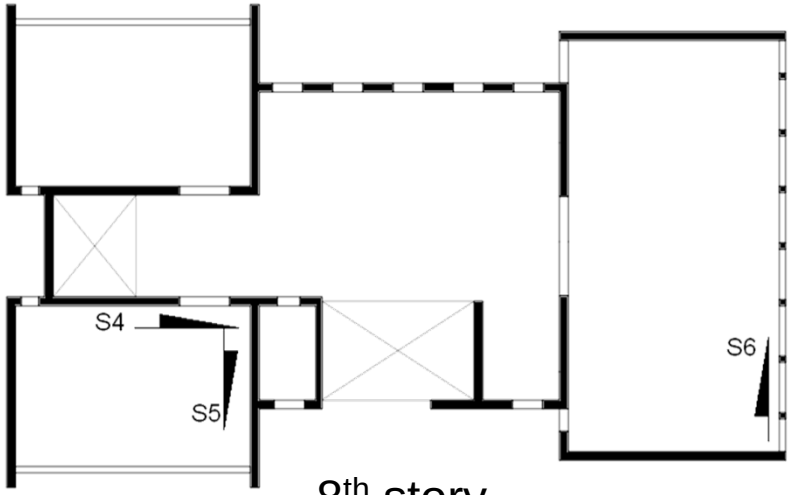
1st underground



3rd story

Continuous Web Based Monitoring System
Installed 2009.

(i) 8 accelerometers
(ii) 2 humidity sensors (-10, -20 m.)
(iii) Meteorology station : temperature, rainfall, wind speed (other environmental parameters).



8th story

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Torre Central building, Santiago.

Remote-continuous structural health monitoring network.

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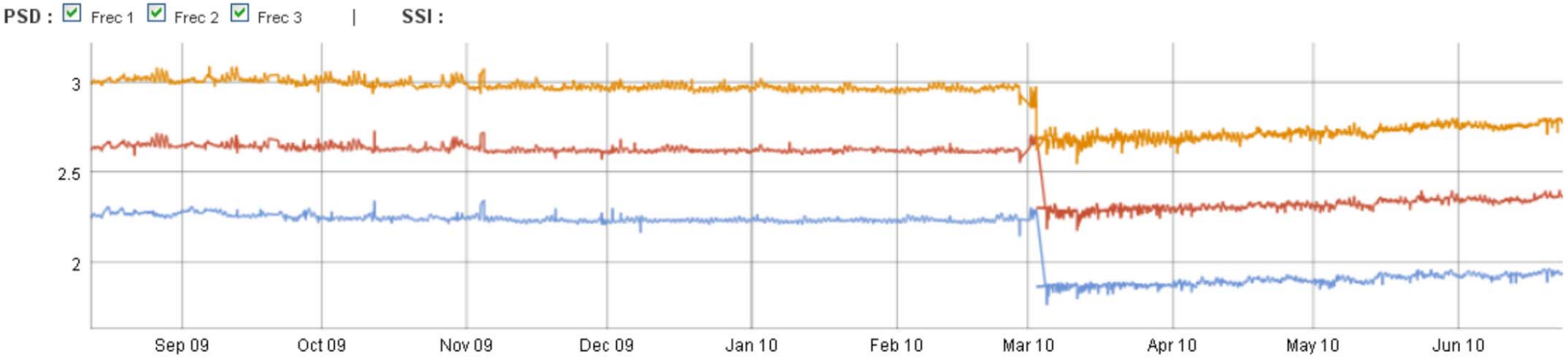
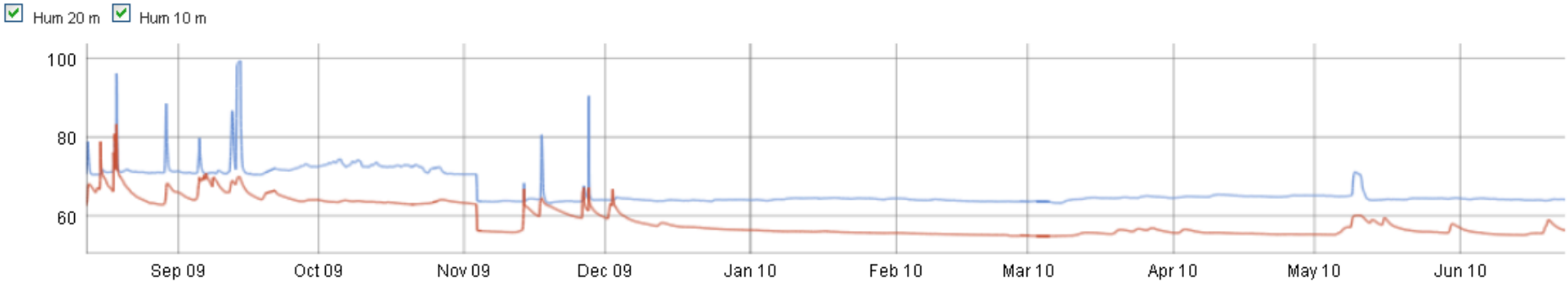
Torre Central building, Santiago.

Modal properties variation via WEB

Frequency variation



Soil saturation



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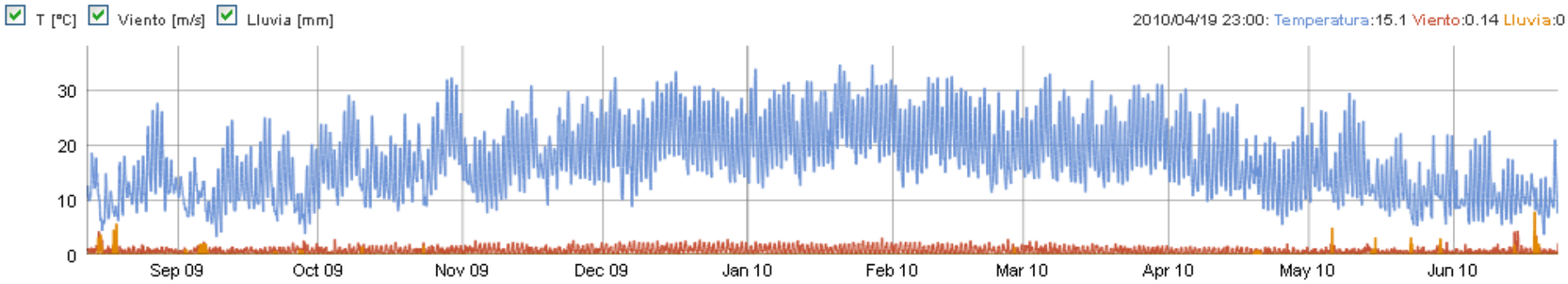
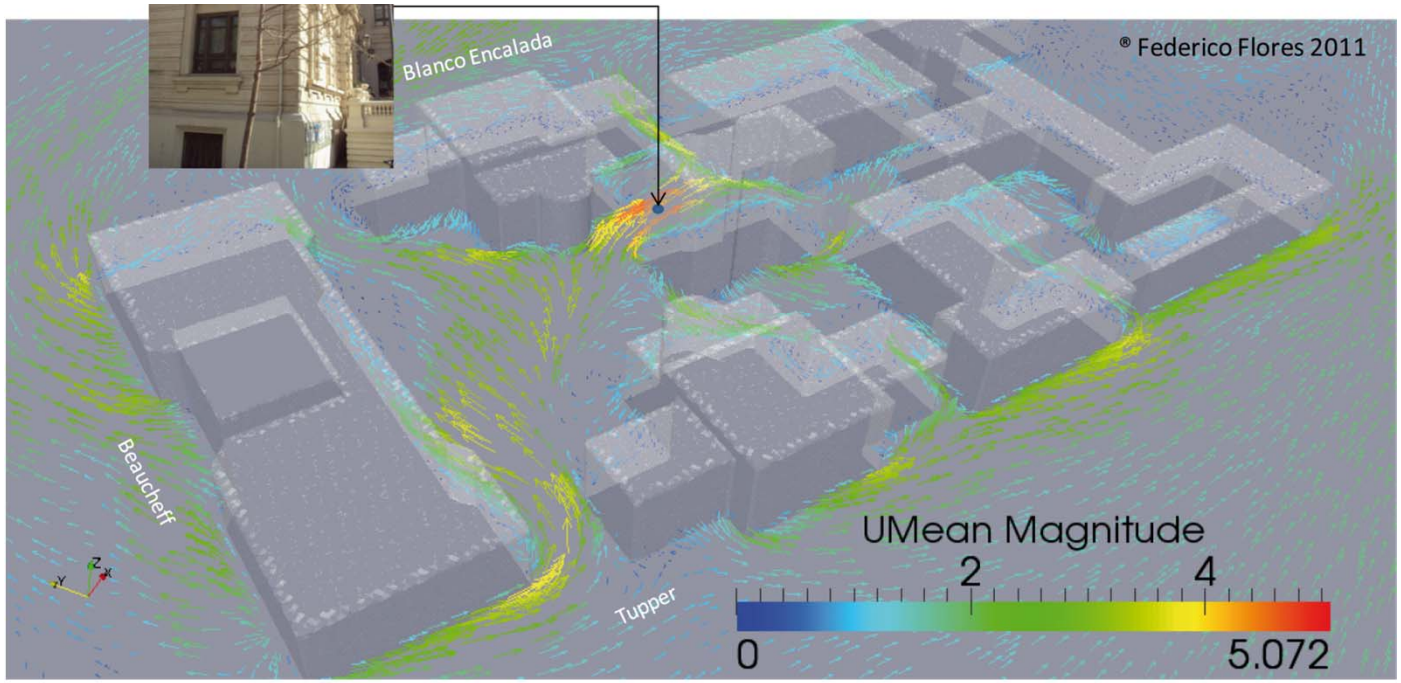
Modal properties variation via WEB
Environmental Parameters

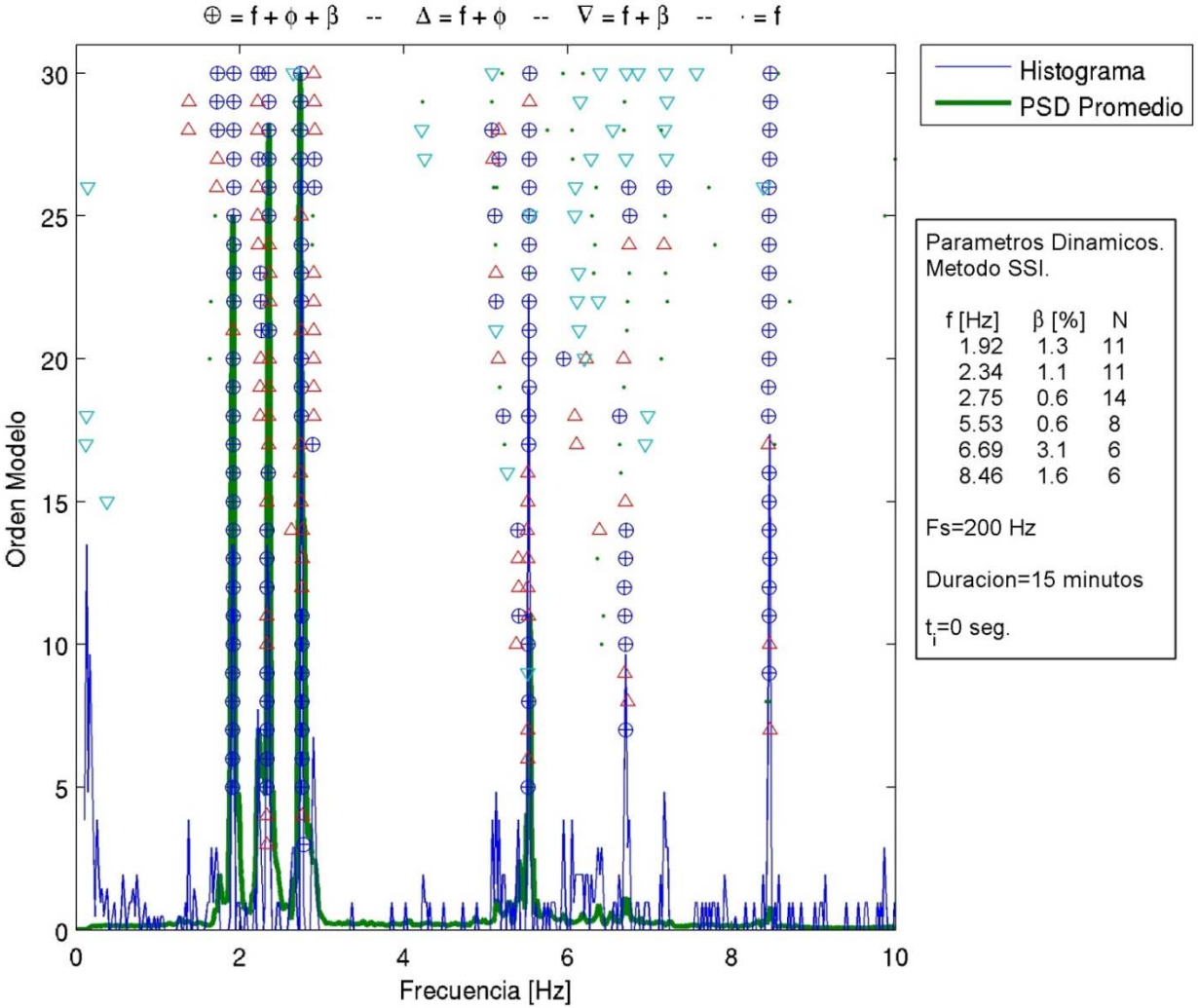




Viento promedio (2 hrs) a 3 m sobre la superficie simulado empleando OpenFOAM en modo LES. Flujo incidente: 4 ms^{-1} desde el Suroeste (45° con Tupper)

Torre Central building, Santiago.

Ambient vibration. Stabilization Diagram. SSI Method.



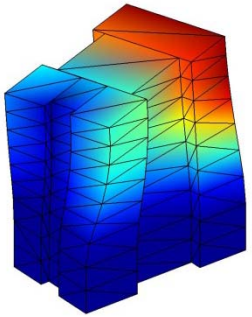
Parametros Dinamicos.
Metodo SSI.

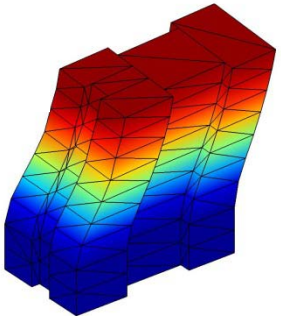
f [Hz]	β [%]	N
1.92	1.3	11
2.34	1.1	11
2.75	0.6	14
5.53	0.6	8
6.69	3.1	6
8.46	1.6	6

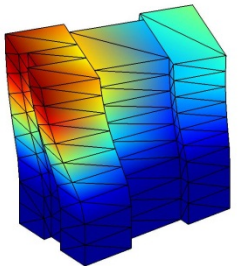
Fs=200 Hz

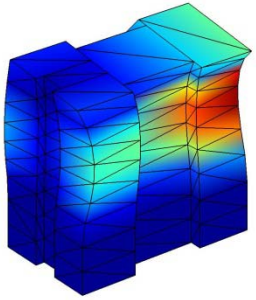
Duracion=15 minutos

t_i=0 seg.









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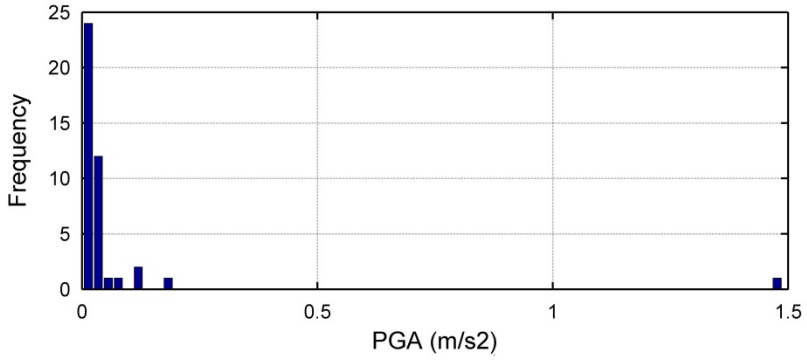
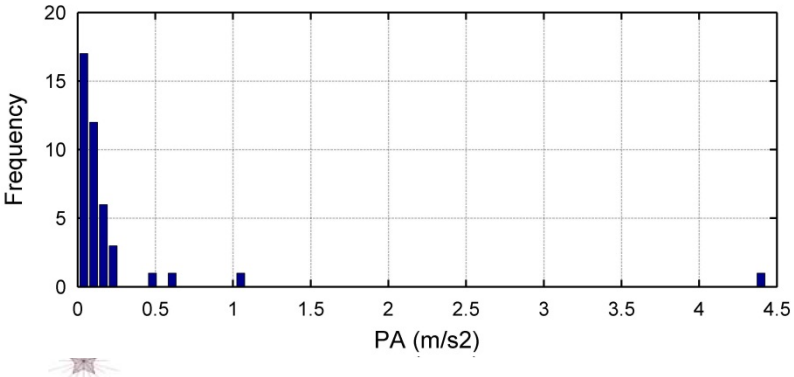
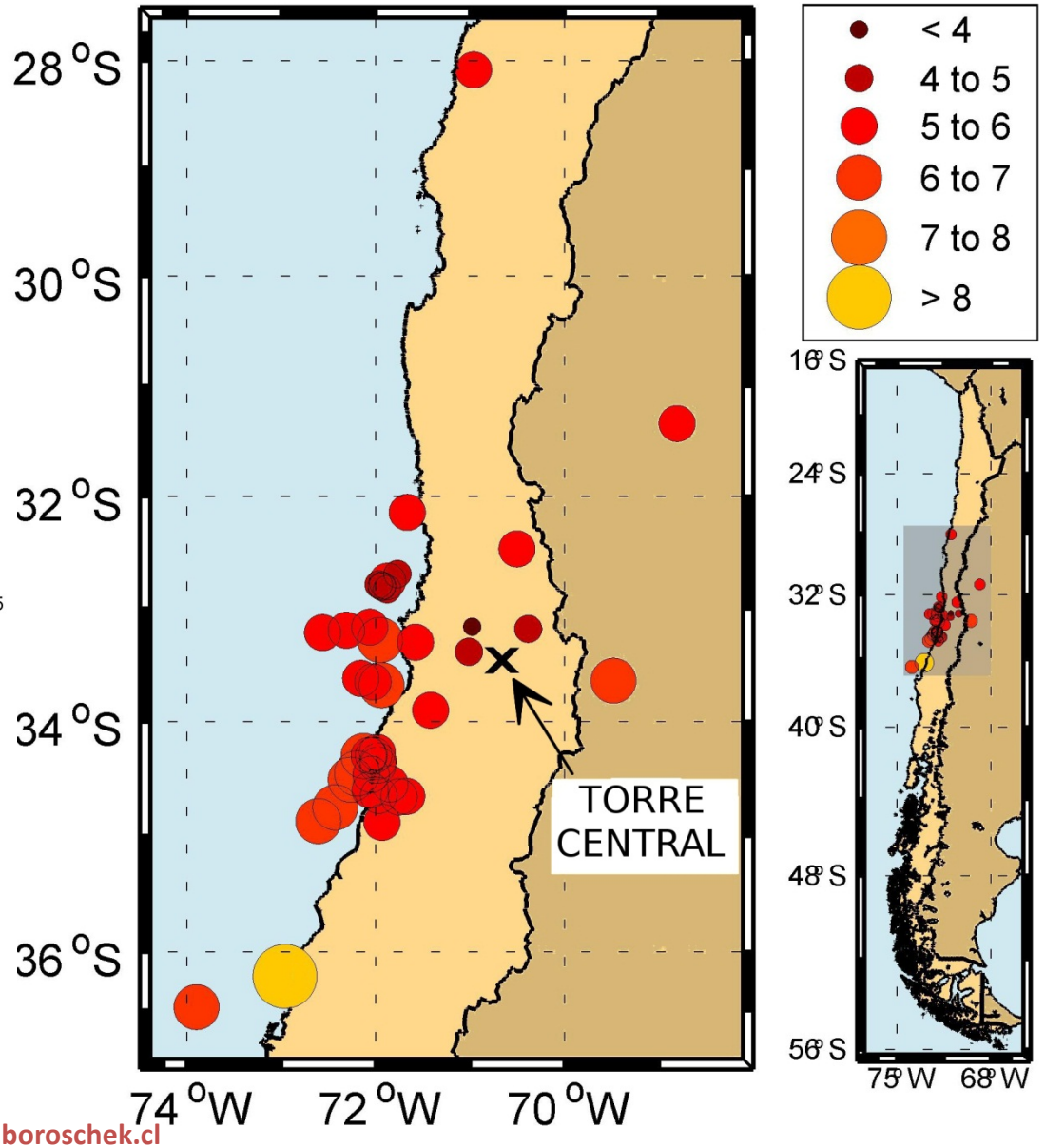
EQ RECORDS

- From 9/2009 to 5/2010
- 12 Main Shocks
- 30 Aftershocks
- PGA: 0.03-0.15 g
- Max Accel: 0.08 – 0.44 g``







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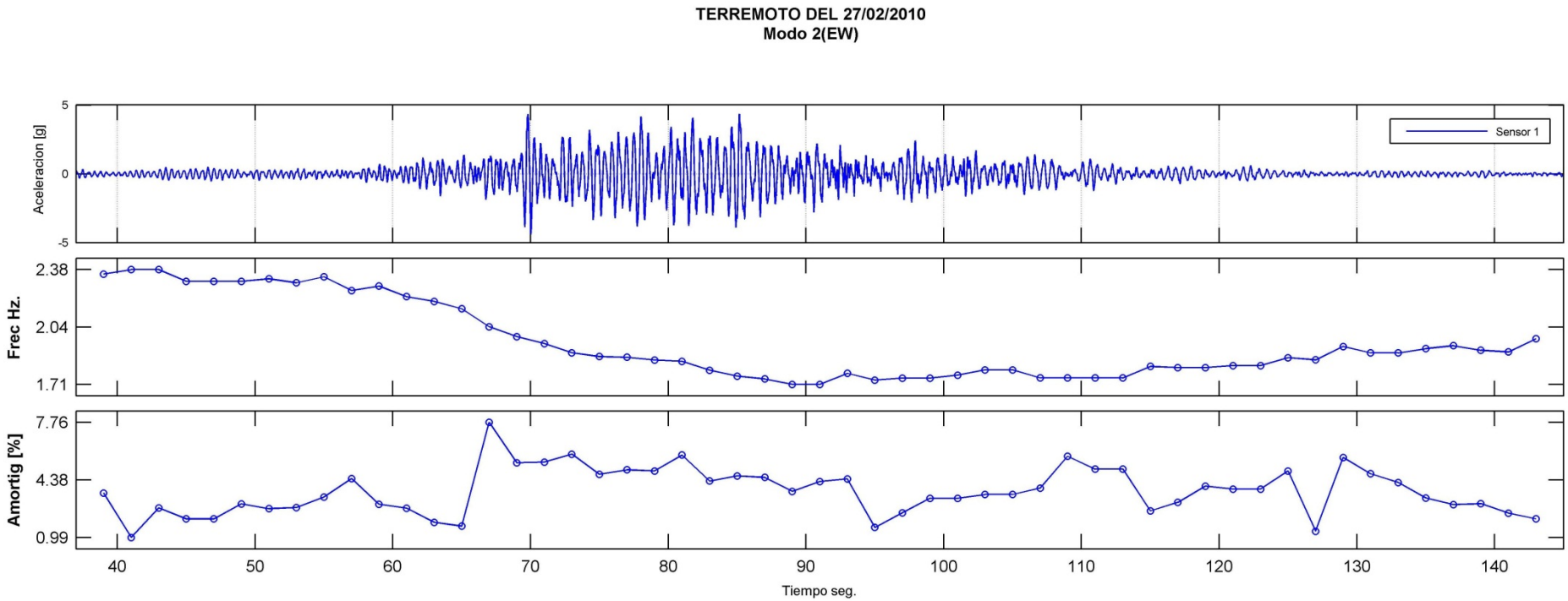
Torre Central Building, Santiago.

Frequency variation during Earthquake. MIMO Method.

MODE 1



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Torre Central building, Santiago.

Modal Properties Variation

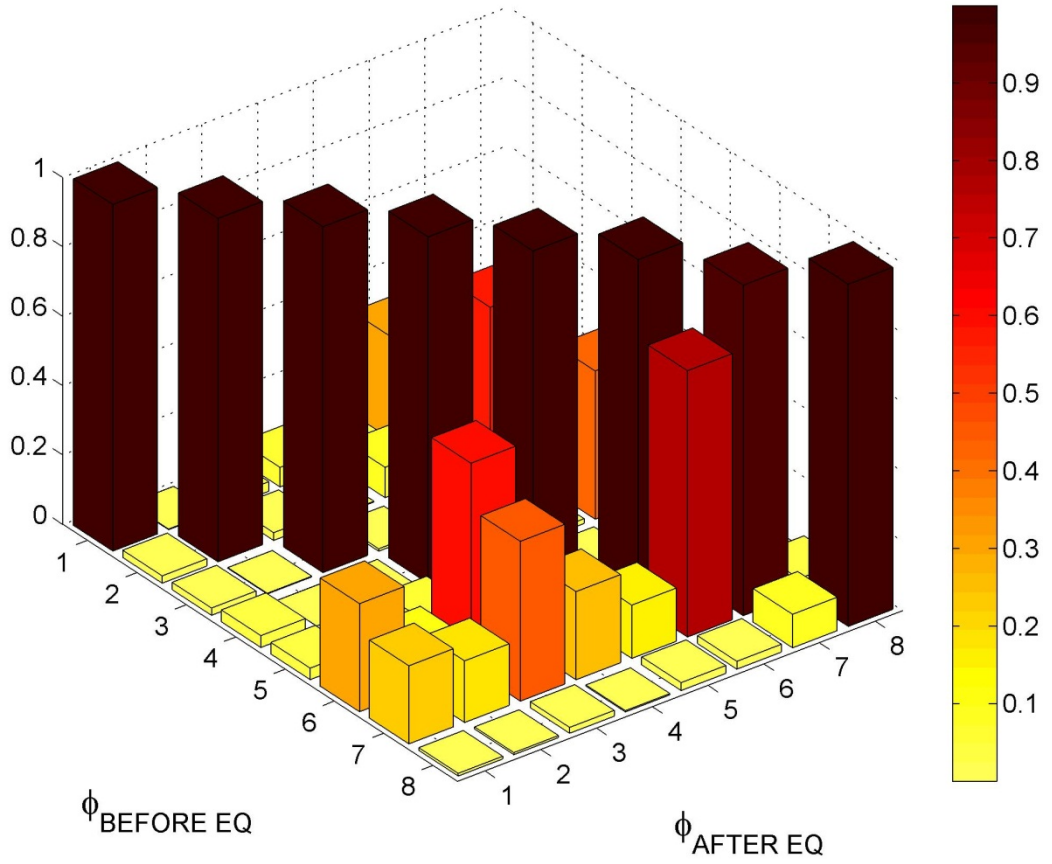
Period Variations (T)

Mode	Period (s) Pre-Earthquake	Period (s) Post-Earthquake	Difference (%)
1	0.45	0.53	18.62
2	0.38	0.44	13.97
3	0.34	0.37	10.86
4	0.16	0.18	15.50
5	0.13	0.15	12.08
6	0.13	0.14	12.38
7	0.12	0.13	8.81
8	0.11	0.12	8.64
		Mean variación (%)	12.61

Damping ratio variations (β)

Mode	Damping. (%) Pre-Earthquake	Damping. (%) Post-Earthquake	Difference (%)
1	0.7	0.7	0.0
2	0.7	0.7	0.0
3	0.7	0.8	14.3
4	1.2	0.9	25.0
5	1.5	1.3	13.3
6	0.9	1.0	11.1
7	1.1	1.3	18.2
8	1.4	1.9	35.7
		Mean Variación (%)	14.70

MAC VALUES PRE AND POST EQ



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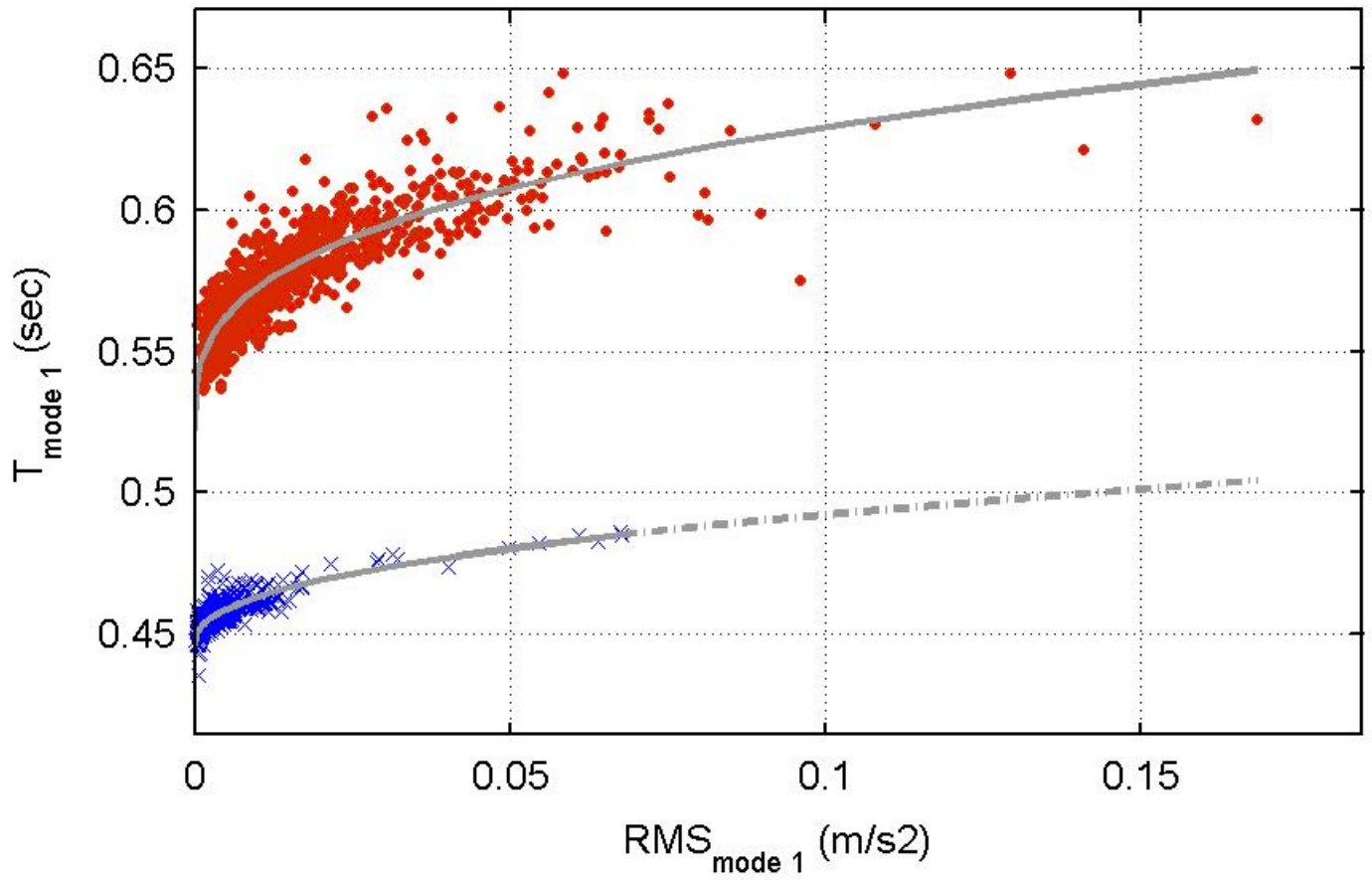
PERIOD VARIATION WITH INTESITY AND DAMAGE
MODE 1



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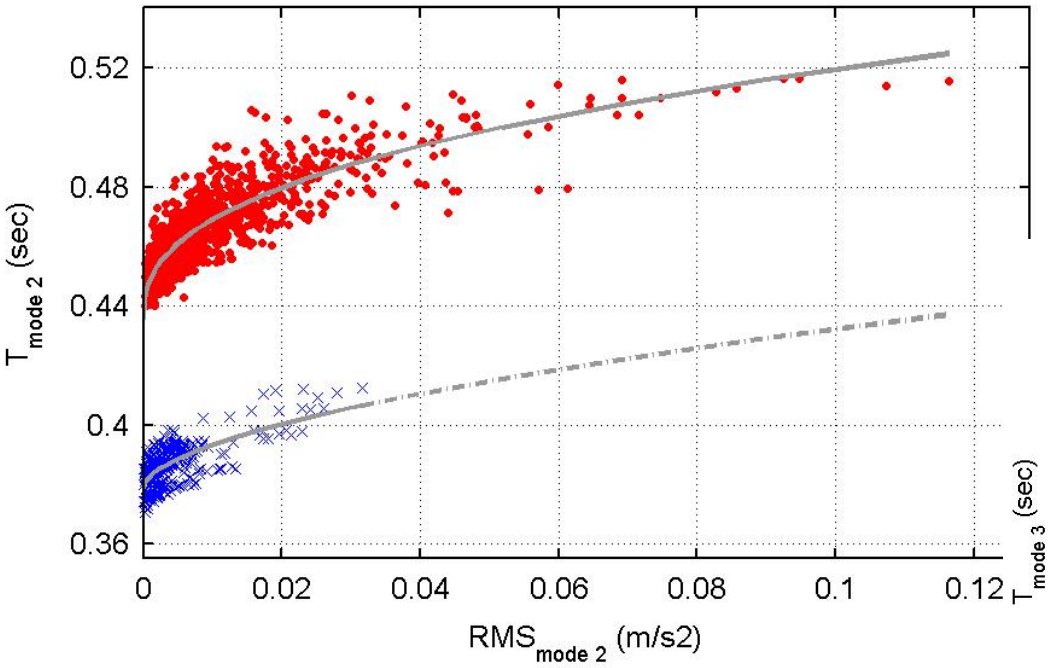
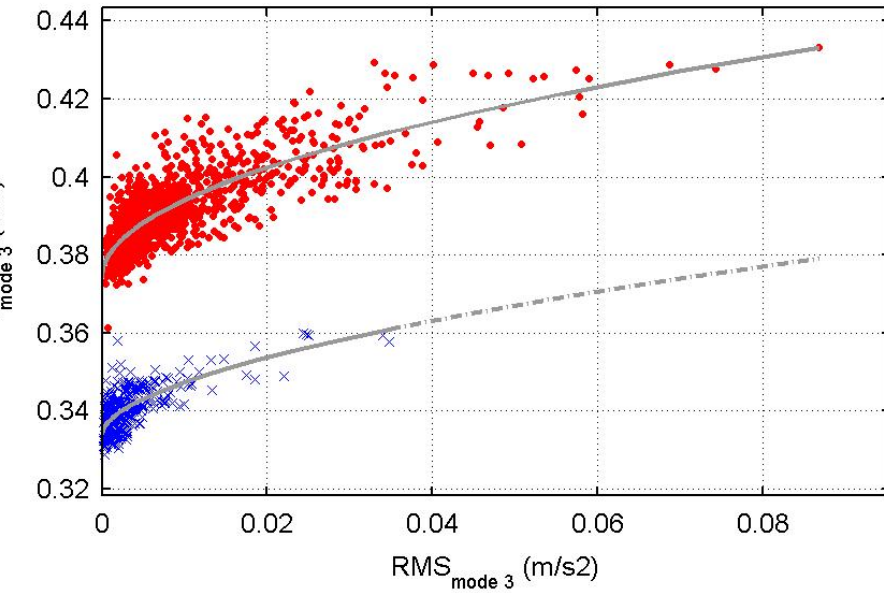
PERIOD VARIATION WITH INTESITY AND DAMAGE
MODE 2 AND 3





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Modal Properties of a High Rise Building Under Construction

Tomás R. Núñez (1) | Rubén L. Boroschek (2).

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Objetive

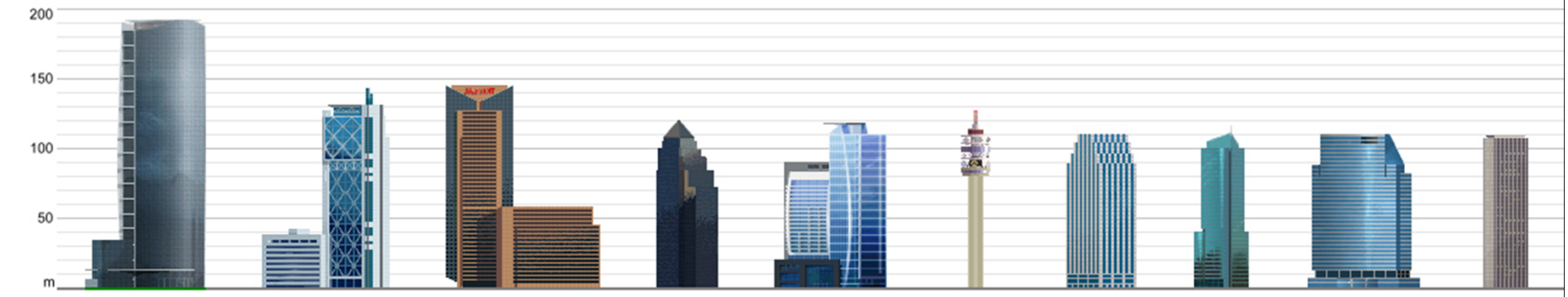
Present the results of a continuous vibration monitoring system on a high rise building under construction process.

Objective of the Monitoring:

- Design Model Validation
- Damping Estimation

Name	Parque Central Torre Oeste	Parque Central Torre Este	Torre Colpatria	Torre Titanium La Portada	Centro de Comercio Internacional	Centro Financiero Confinanzas	Torre de Cali	Torre Banco Mercantil
City	Caracas DC	Caracas DC	Bogota DC	Santiago RM	Bogota DC	Caracas DC	Cali VALLE	Caracas DC
Country	Venezuela	Venezuela	Colombia	Chile	Colombia	Venezuela	Colombia	Venezuela
Illustrator	Daniel Ugas	Daniel Ugas	Chibcha	Marciano	Chibcha	Chibcha	Chibcha	Chibcha
Status	built	built	built	construction	built	built	built	built
Built	1984	1979	1979	2009	1977	1994	1980	1984
Floors	56	56	50	52	50	45	44	40
Use	office	office	office	office	office	office	hotel	office
Antenna Spire Roof	225 m	225 m	196 m	191.7 m		190 m	183 m	179 m

CHILE



	Torre Titanium La Portada	Telefonica Tower	Boulevard Kennedy	Torre de la Industria	Isidora 3000	Torre Entel	Torre Centenario	Torre Alameda	Edificio Millenium	Torre Santa María
Name										
City	Santiago RM	Santiago RM	Santiago RM	Santiago RM	Santiago RM	Santiago RM	Santiago RM	Santiago RM	Santiago RM	Santiago RM
Country	Chile	Chile	Chile	Chile	Chile	Chile	Chile	Chile	Chile	Chile
Illustrator	Marciano	Marciano	Francisco Canas	Francisco Canas	Marciano	Francisco Canas	Francisco Canas	Marciano	Marciano	Marciano
Status	construction	built	built	built	built	built	built	built	built	built
Built	2009	1996	1999	1994	2008	1974	2000	1996	2000	1981
Floors	52	33	40	33	31	19	31	30	31	29
Use	office	office	mixed use	office	mixed use	communication	office	office	office	office
Antenna						127.5 m				
Spire		142 m								
Roof	191.7 m	132 m	120.5 m	120 m	118 m	115 m	113 m	110 m	110 m	109 m

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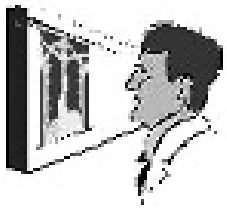
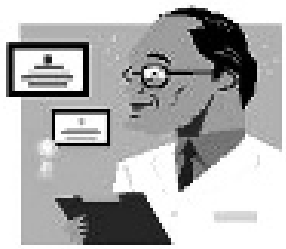
Why ?

Pain



Exams



Diagnosis

Vibration Problem

Inspection

Diagnosis

“Structural Patient”

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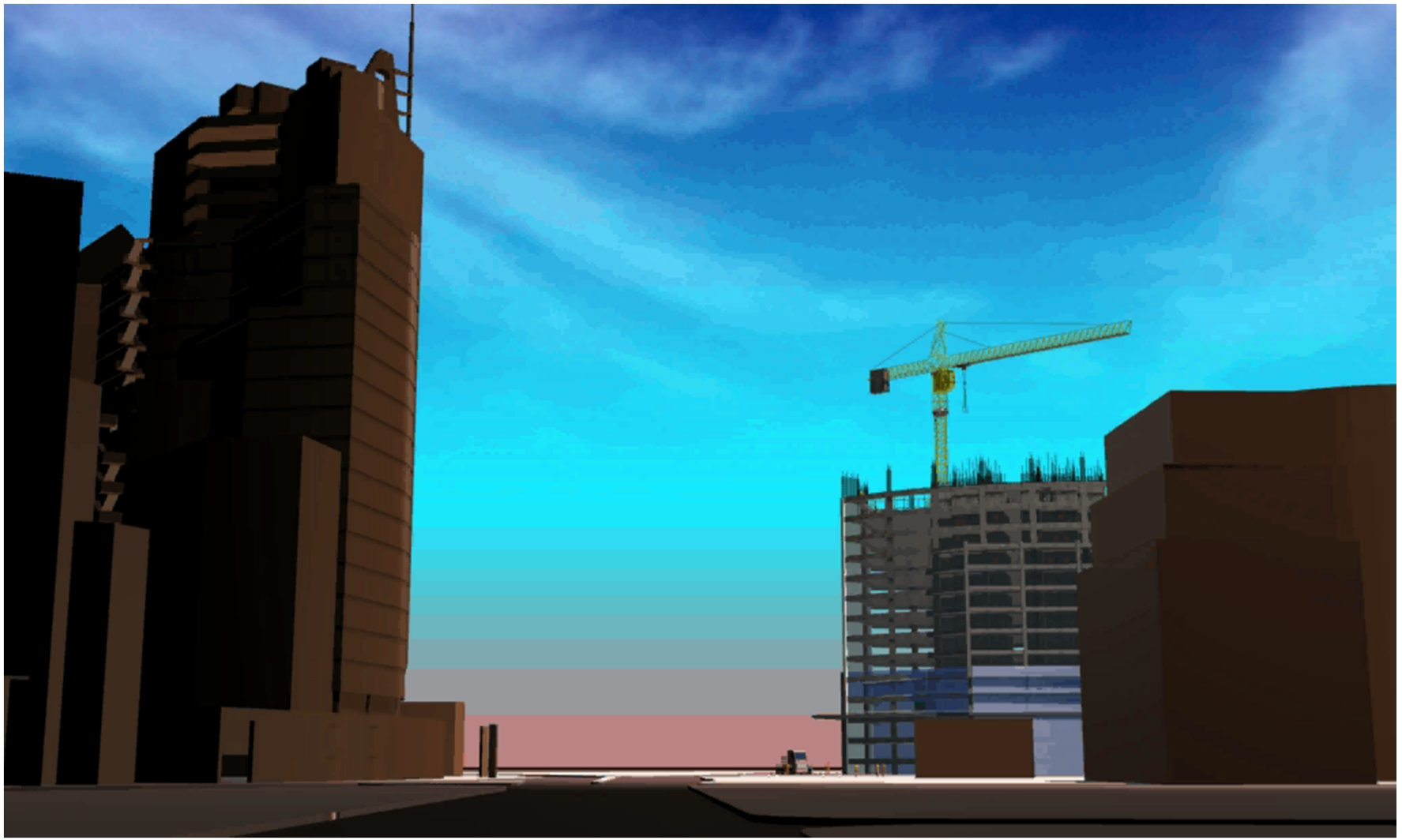
Titanium La Portada Building

-Tallest building in Chile, 196 [m] height.

- 55 stories, 7 underground levels and 126,000 m2.

- Reinforced concrete walls core and concrete frames located around the perimeter

CONSTRUCTION



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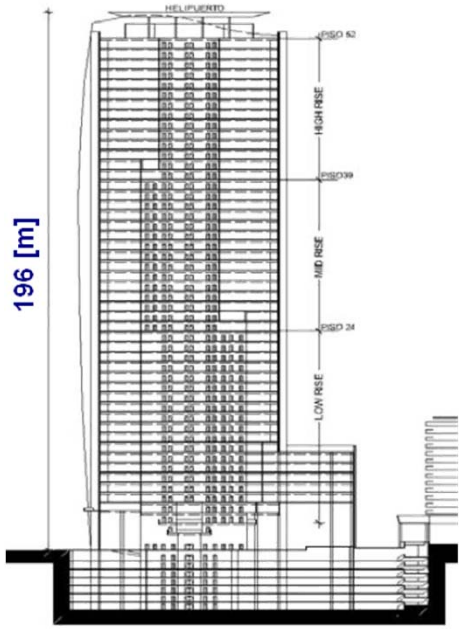
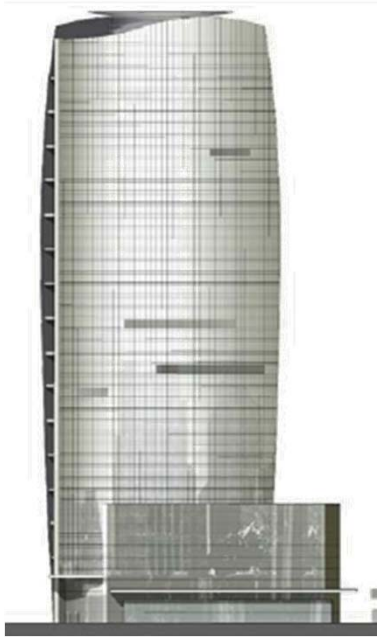
Titanium La Portada Building



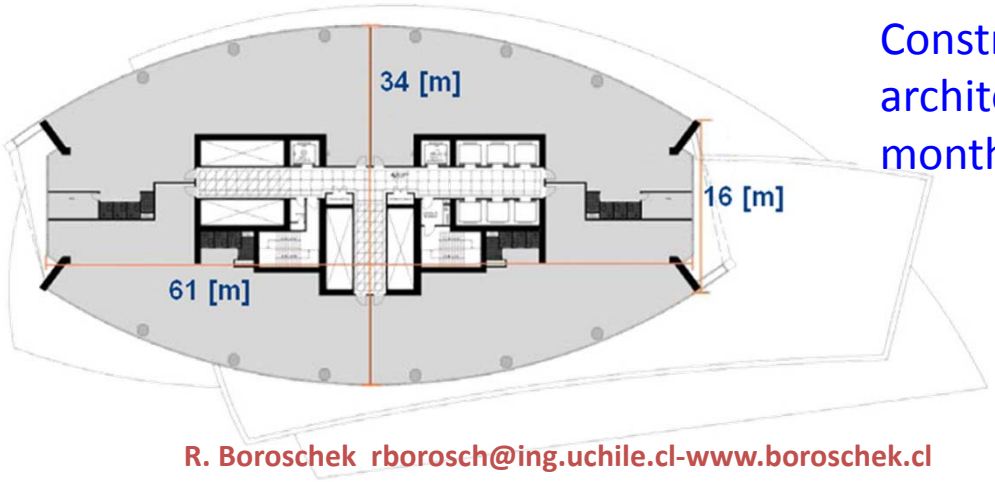


Construction process consists in the concreting of the core and perimeter columns and beams, after which the prefabricated slabs are supported by this system.

Construction duration without architectural finishing: 20 months aprox.

Construction duration with architectural finishing: 26 months aprox.

Typical floor



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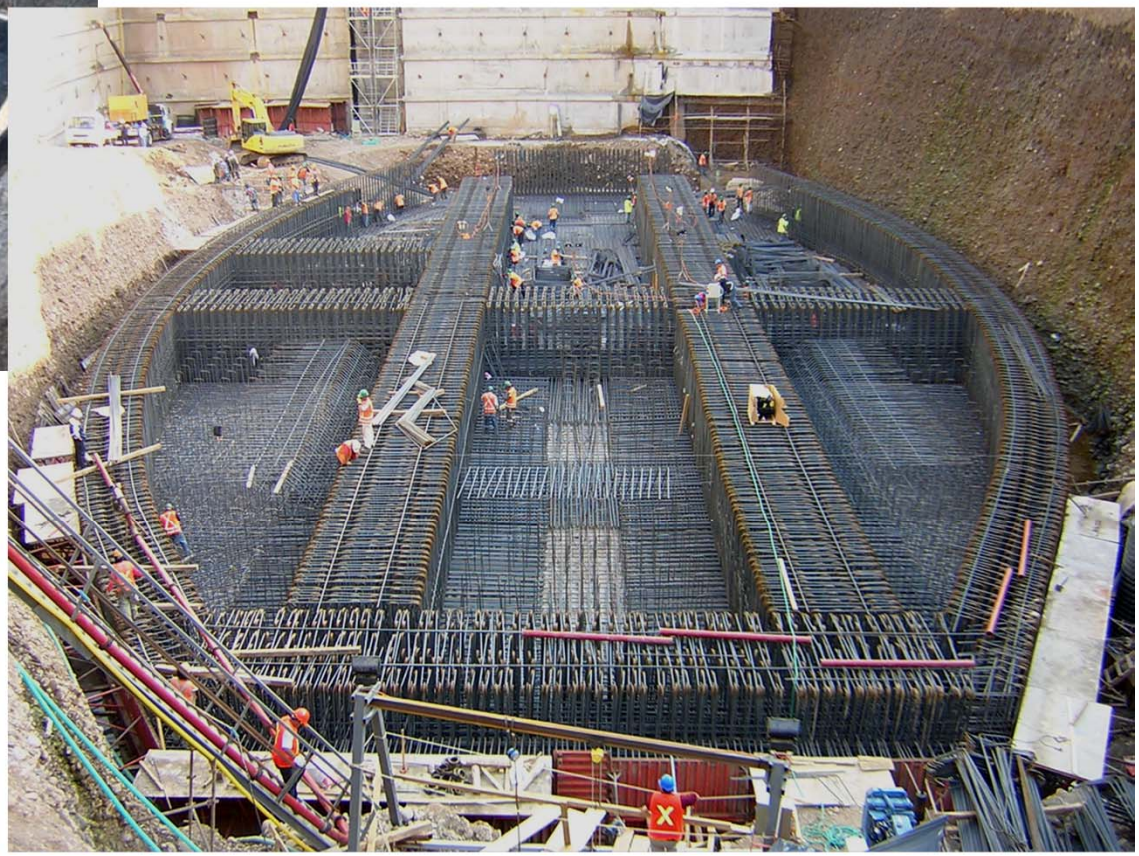
Titanium La Portada Building



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Titanium La Portada Building

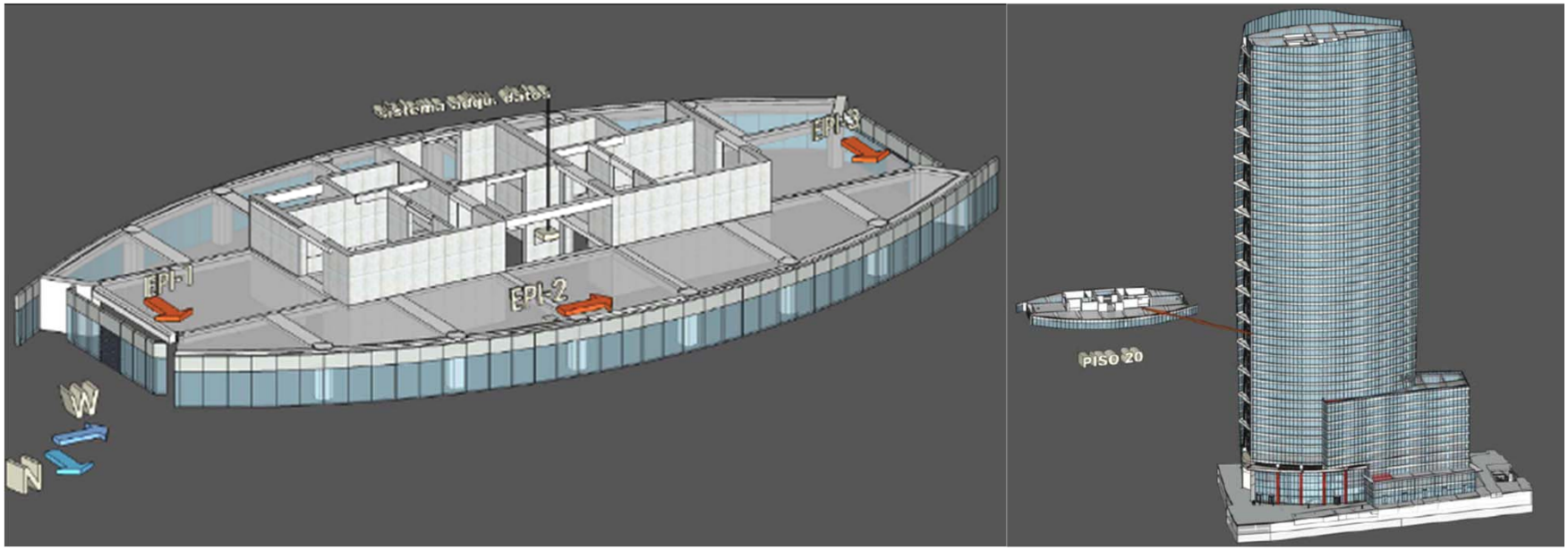
octagonal section

Typical column section

No	Story Range	Dimension [cm] Central Columns	Dimension [cm] Perimetral Colums	Shape	Concrete Type
1	S-7 - S-4	100/140	100/140	Rectangular	H60-90C
2	S-3 - S-1	100/120	100/120	Rectangular	H60-90C
3	1 - 5	115/115	110/110	Octagonal	H60-90C
4	6 - 15	110/110	110/110	Octagonal	H60-90C
5	16 - 20	110/110	105/105	Octagonal	H40-90C
6	21 - 25	105/105	100/100	Octagonal	H40-90C
7	26 - 30	100/100	95/95	Octagonal	H40-90C
8	31 - 35	95/95	90/90	Octagonal	H40-90C
9	36 - 46	90/90	85/85	Octagonal	H40-90C
10	47 - 52	85/85	80/80	Octagonal	H40-90C

HISTERETIC DAMPERS

Monitoring Network.



- 3 accelerometers on the 20th story

- Frequency rate: 100 Hz

- Modal properties (frequency + damping) obtained every 10 minutes

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HISTERETIC DAMPERS

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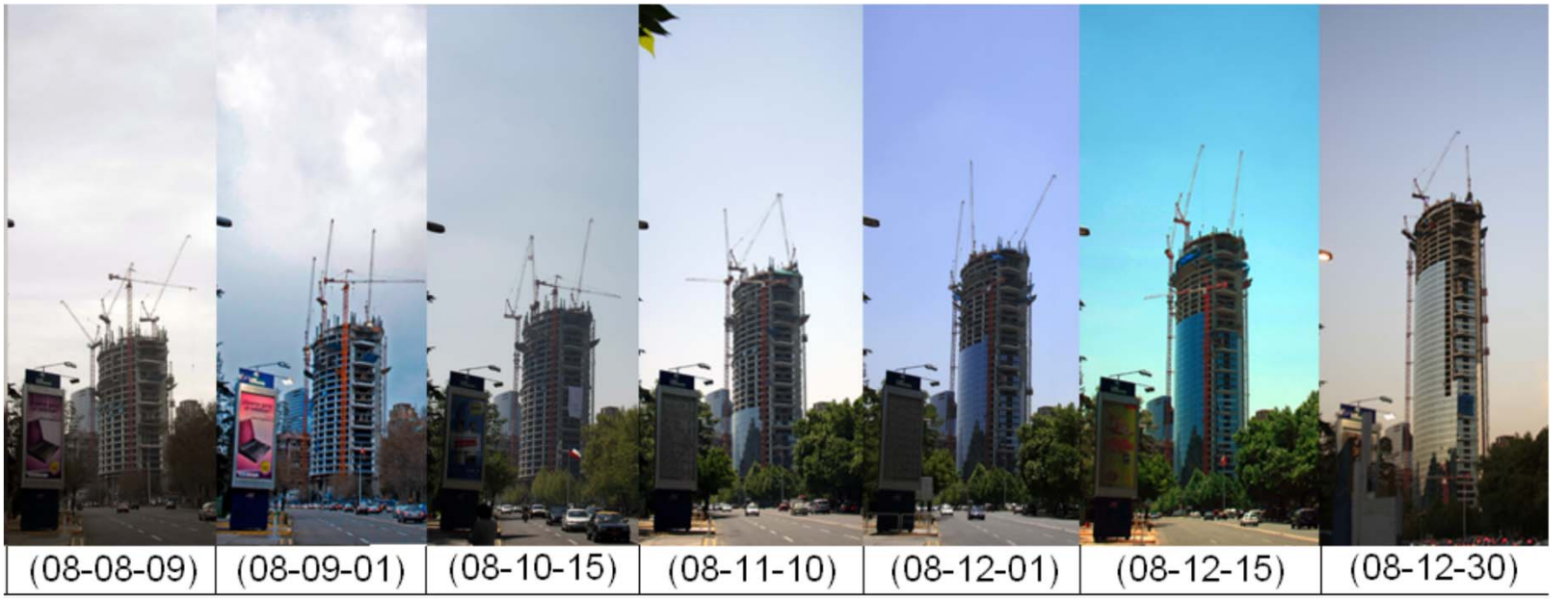
Monitoring Under Construction



2 studies:

(a) 5 month continuous under construction monitoring

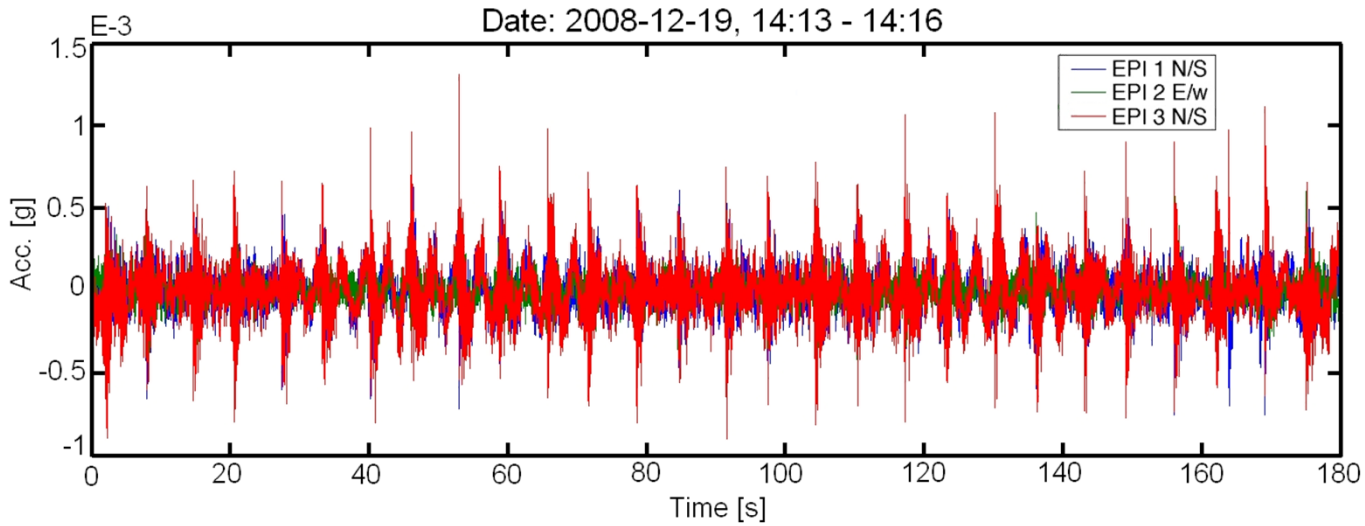
(b) Records every 2 or 3 stories during 5 construction stages

Construction Process: Monitoring Difficulties

- High transient vibration due to impact.

- Continuous and permanent variations of mass and stiffness.

- Operation of small and large machinery like cranes, concrete pumping and others.



Concrete pumping impacts

All this activities affects the system identification processes producing non stationary signals

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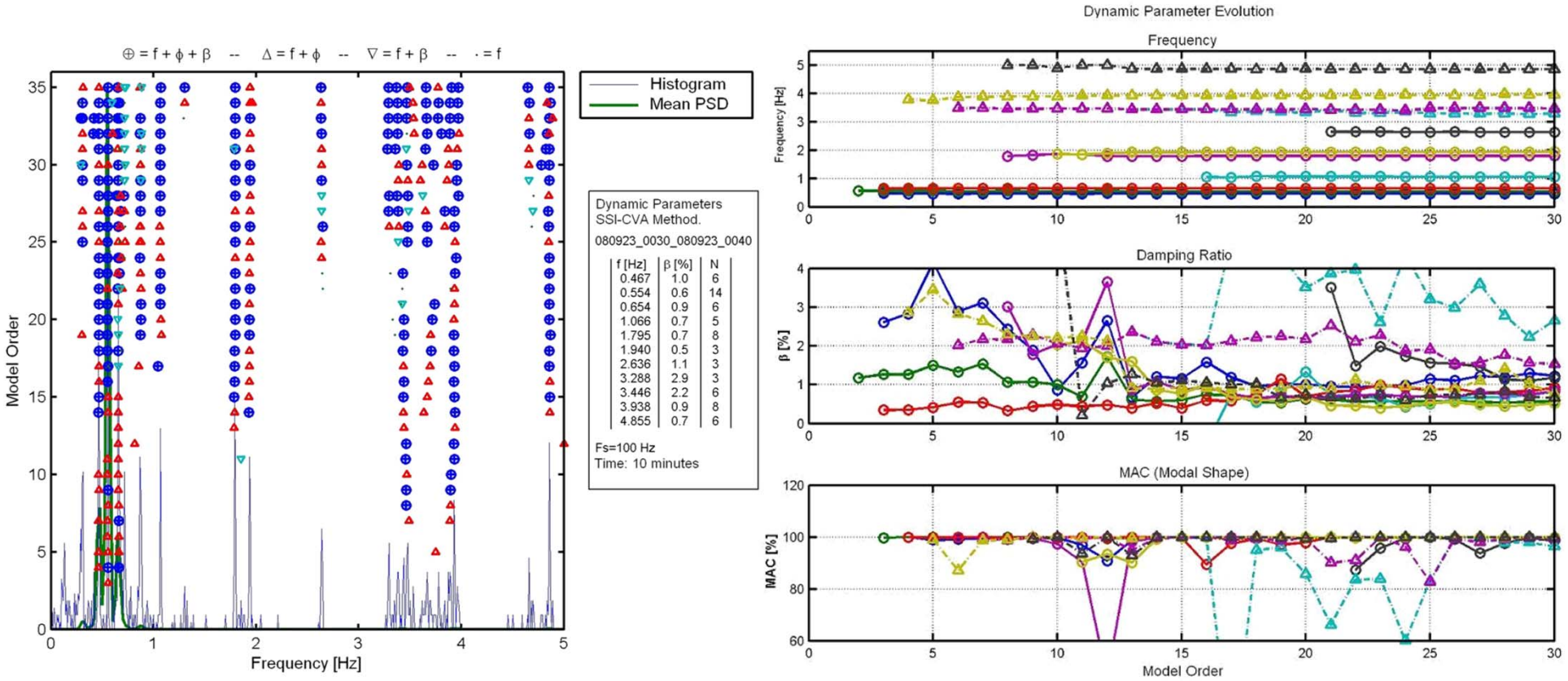
System Identification Techniques

SSI



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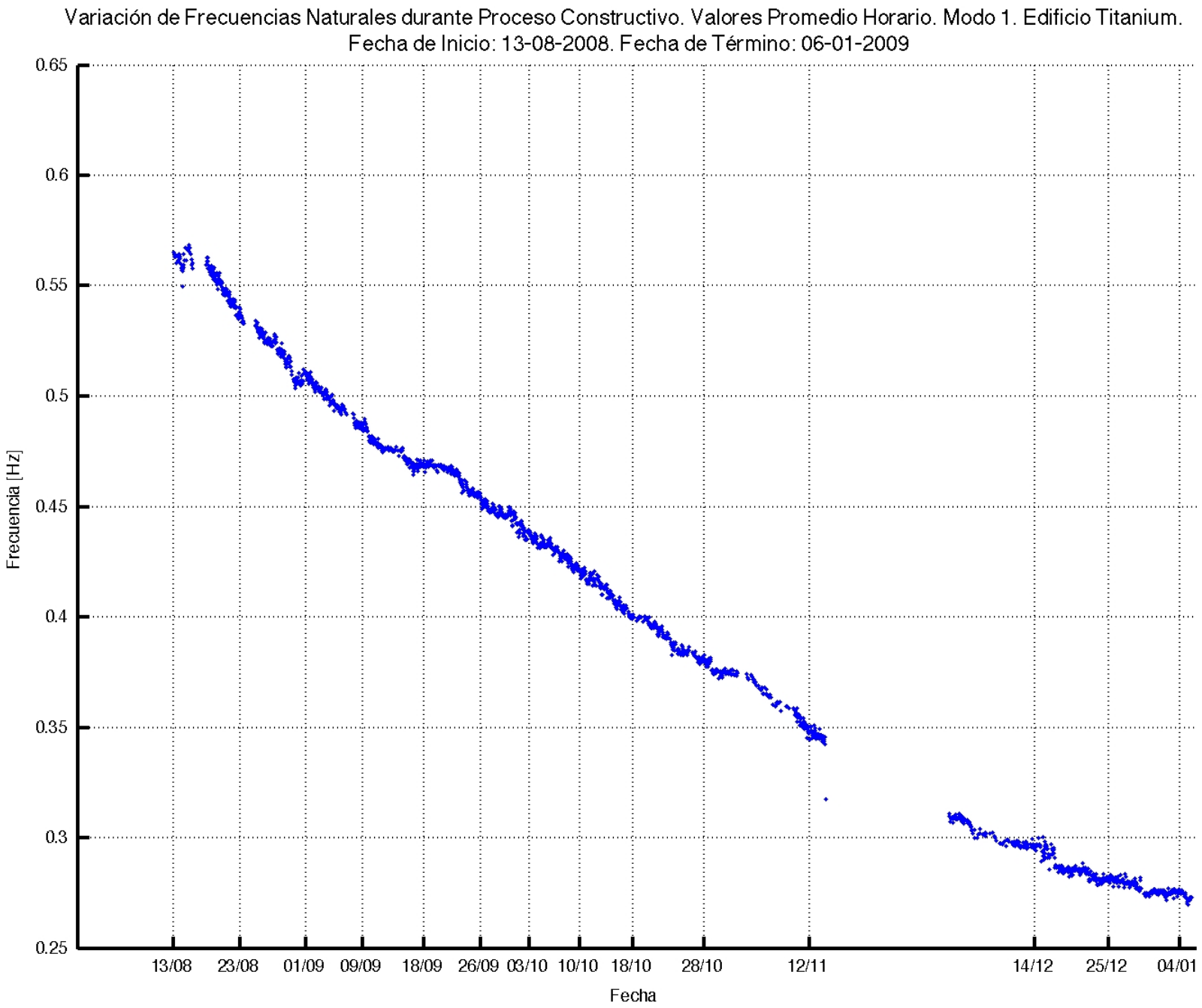

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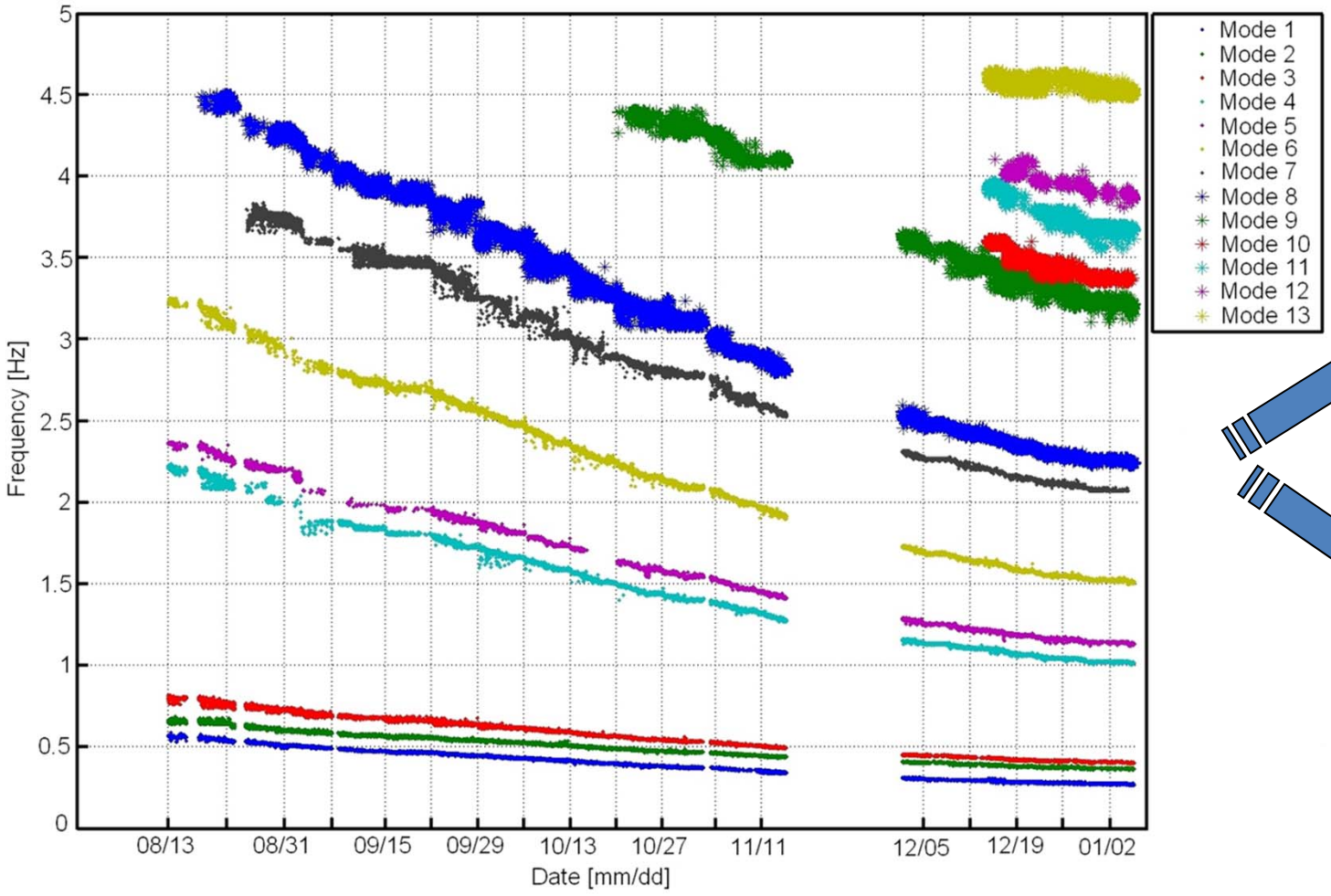
Frequency Variations. SSI.



Construction progress, mass and stiffness (7.4 days)

Daily ambient and usage variations (24 hours).

Filter frequency variation on characteristic pattern

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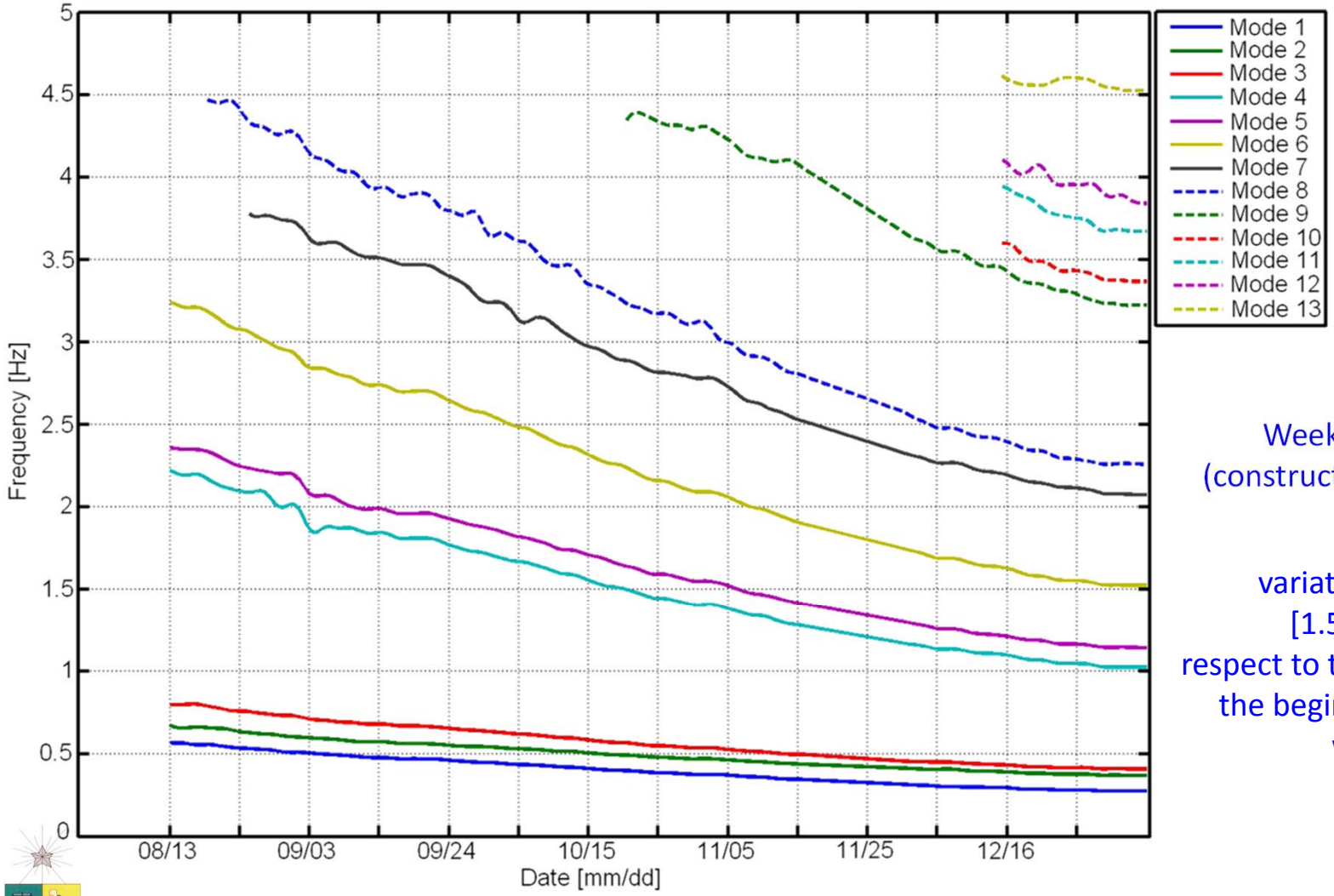
Frequency Variations. SSI.



Weekly pattern
(construction of 1 story)

variations range
[1.5 - 5.5]%
respect to the frequency at
the beginning of each
week

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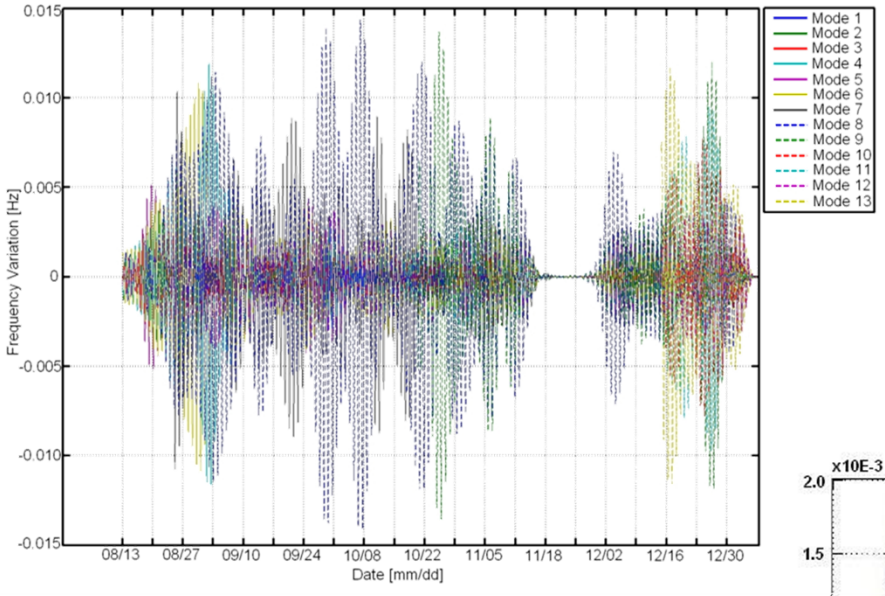
Frequency Variations. SSI.

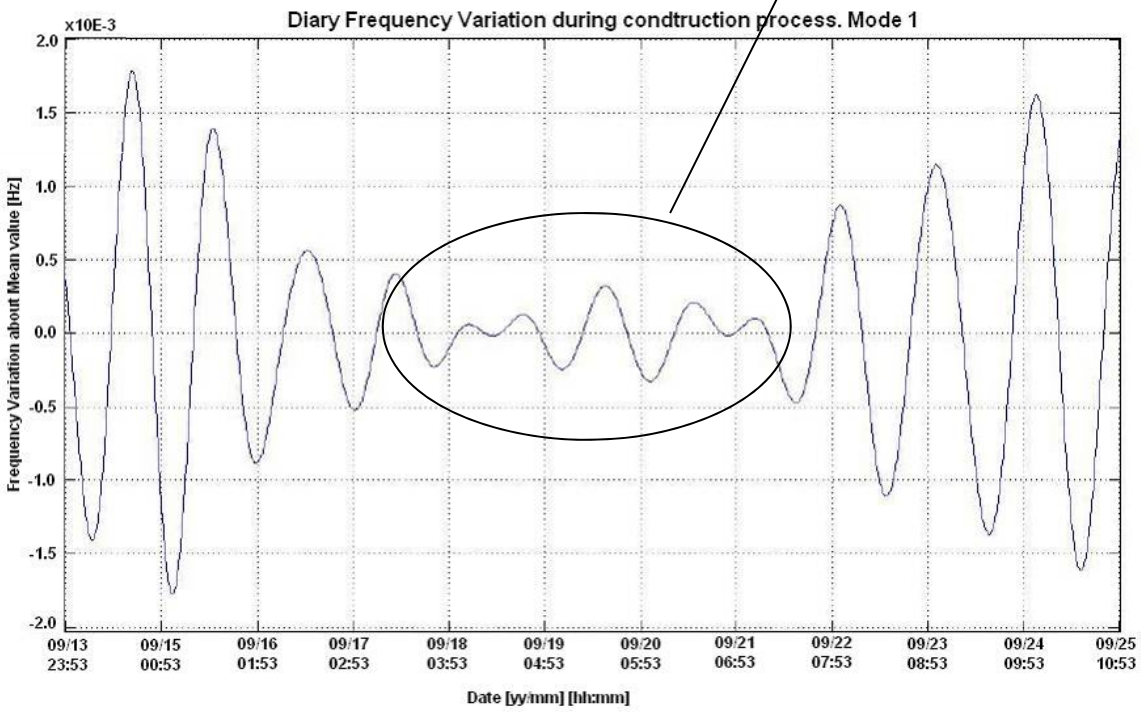


Zoom (Mode 1)

Holyday (Frequency variation reduced)

Daily pattern
(construction of 1 story)

maximum variations (deviation from daily mean value): 1.6%



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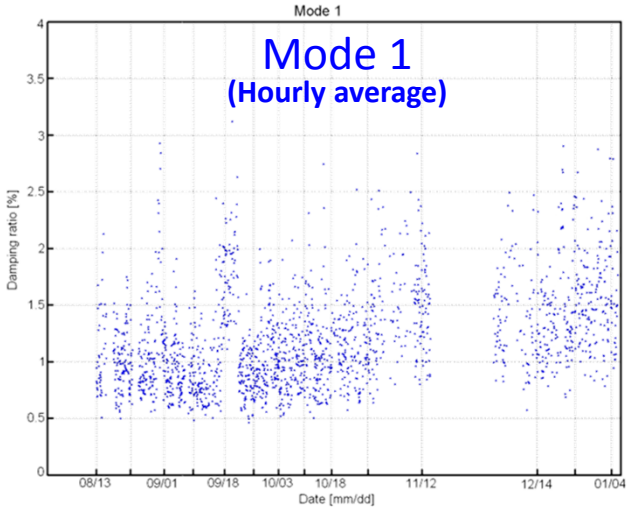
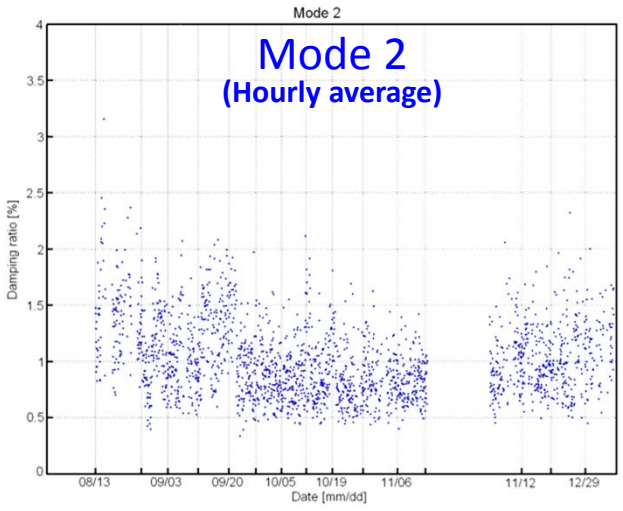
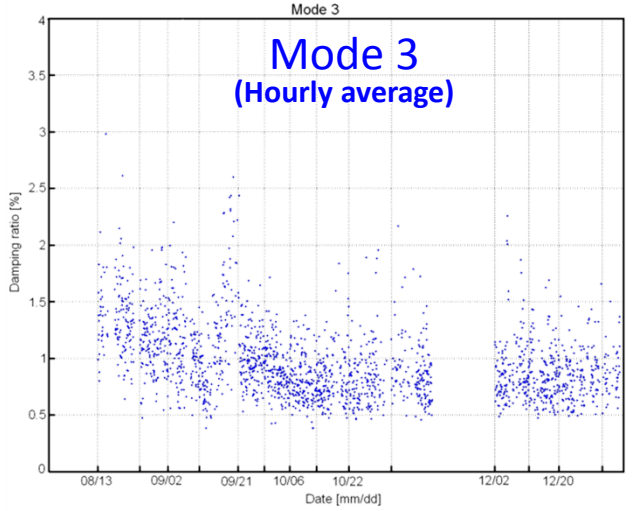
Damping Ratio Variations. SSI



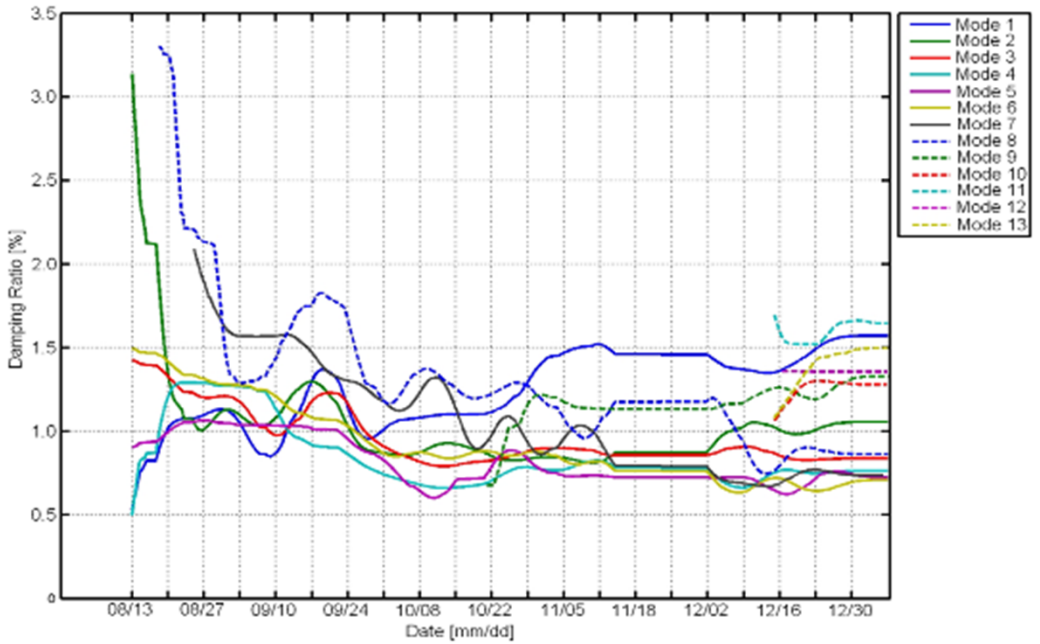




Damping variation pattern spanning around 18.4 days, period required to build about 3 stories.

Damping range

[0.5 – 1.5] %



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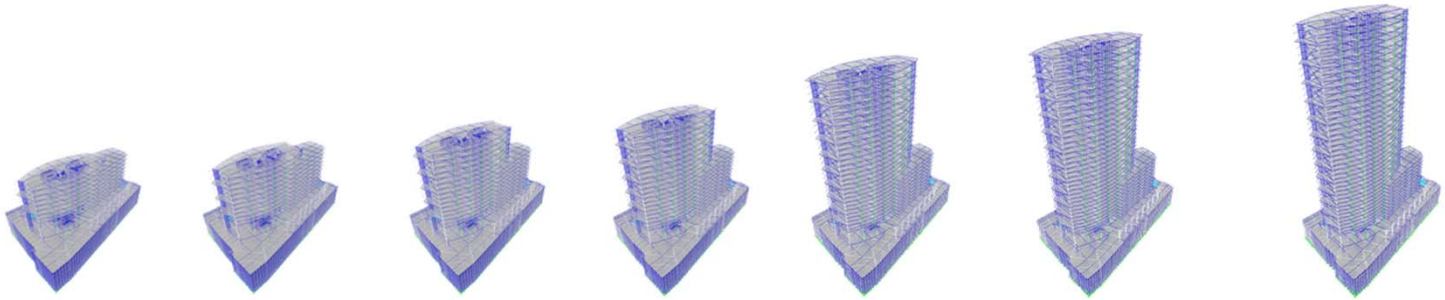
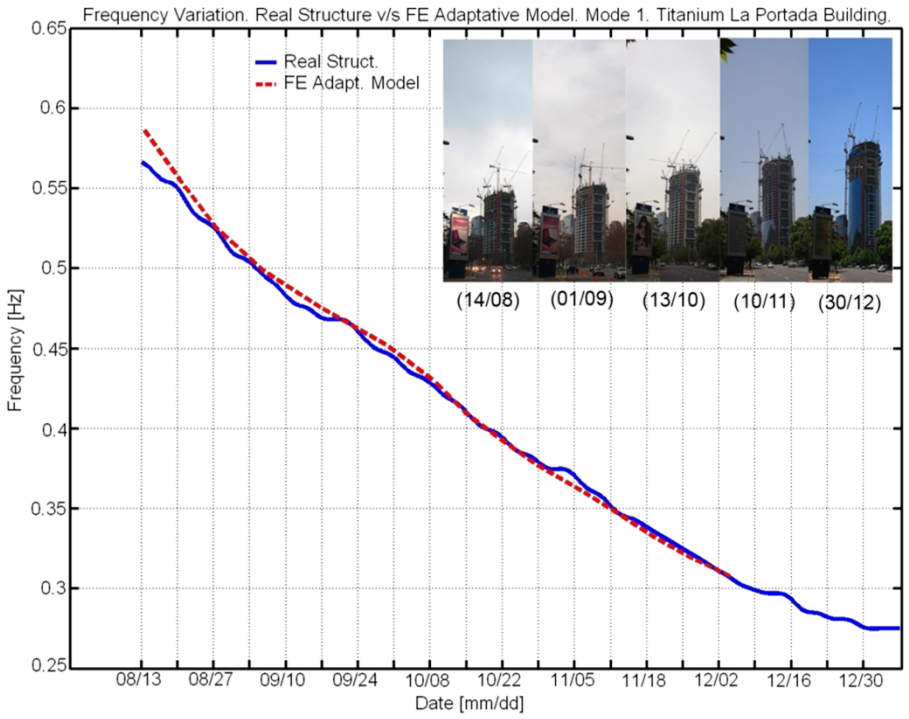
FE Predictive - Adaptative Models.



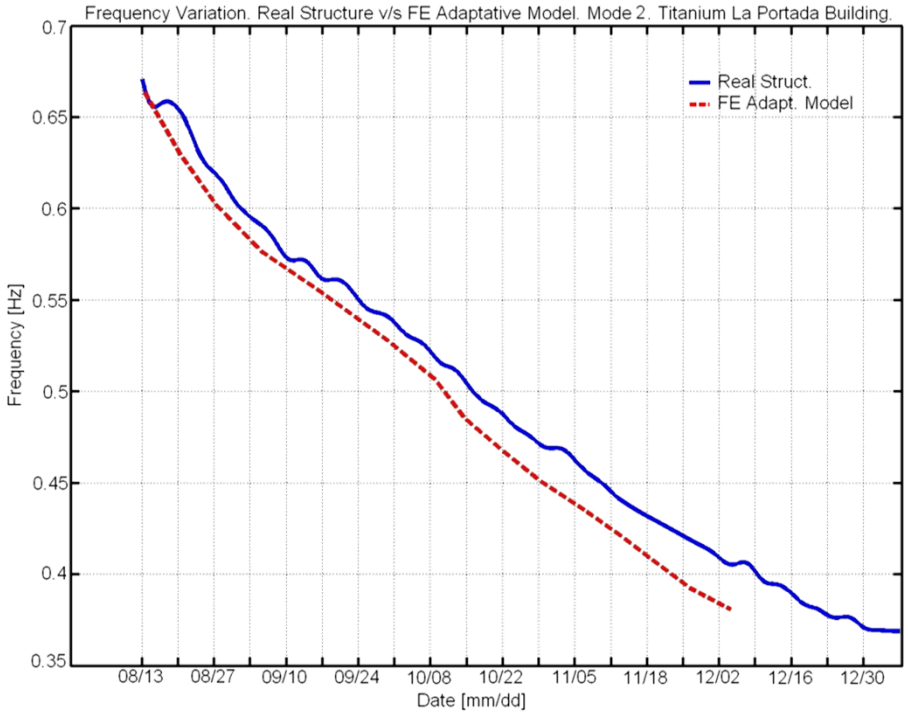
(Live Load not considered)

Monitoring: from story 24 to 42

FE Predictive - Adaptative Models.



Mode 1



Mode 2

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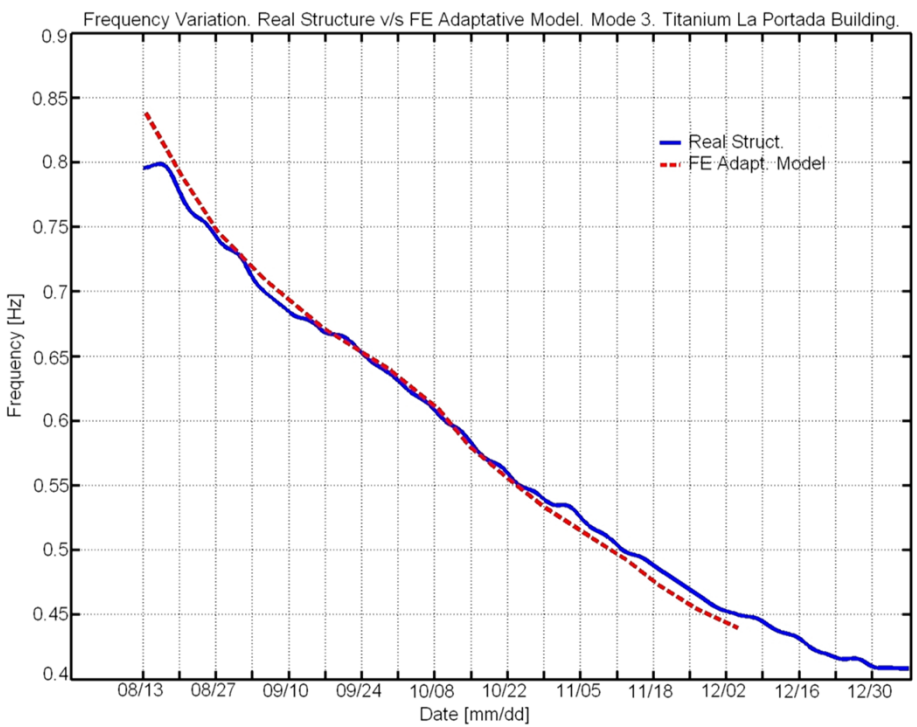
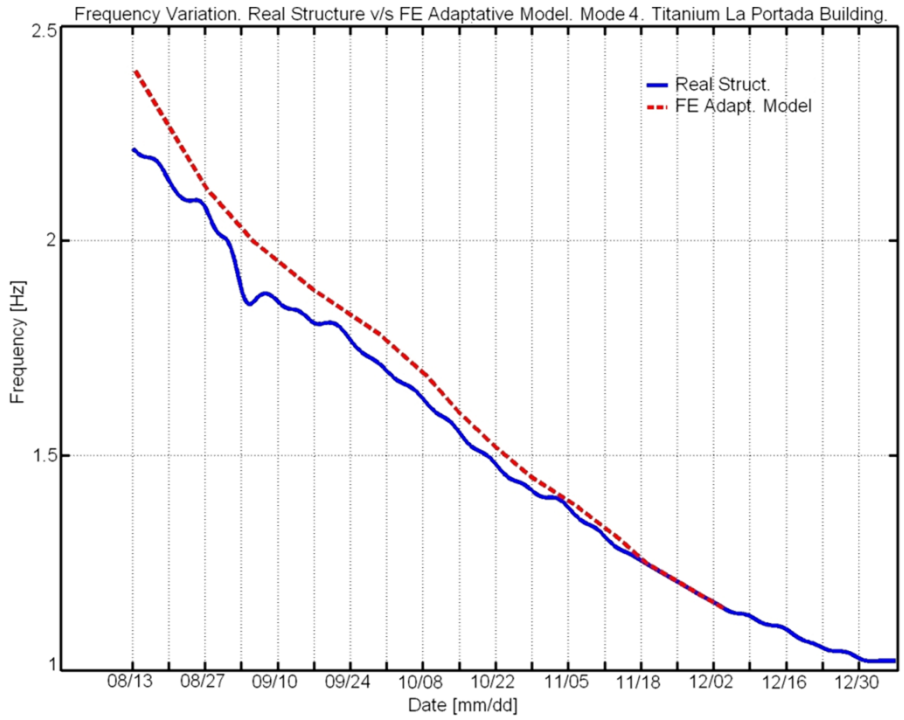
FE Predictive - Adaptative Models. Results



Mode 3



Mode 4

Differences between 2% and 14% for the first 8 modes

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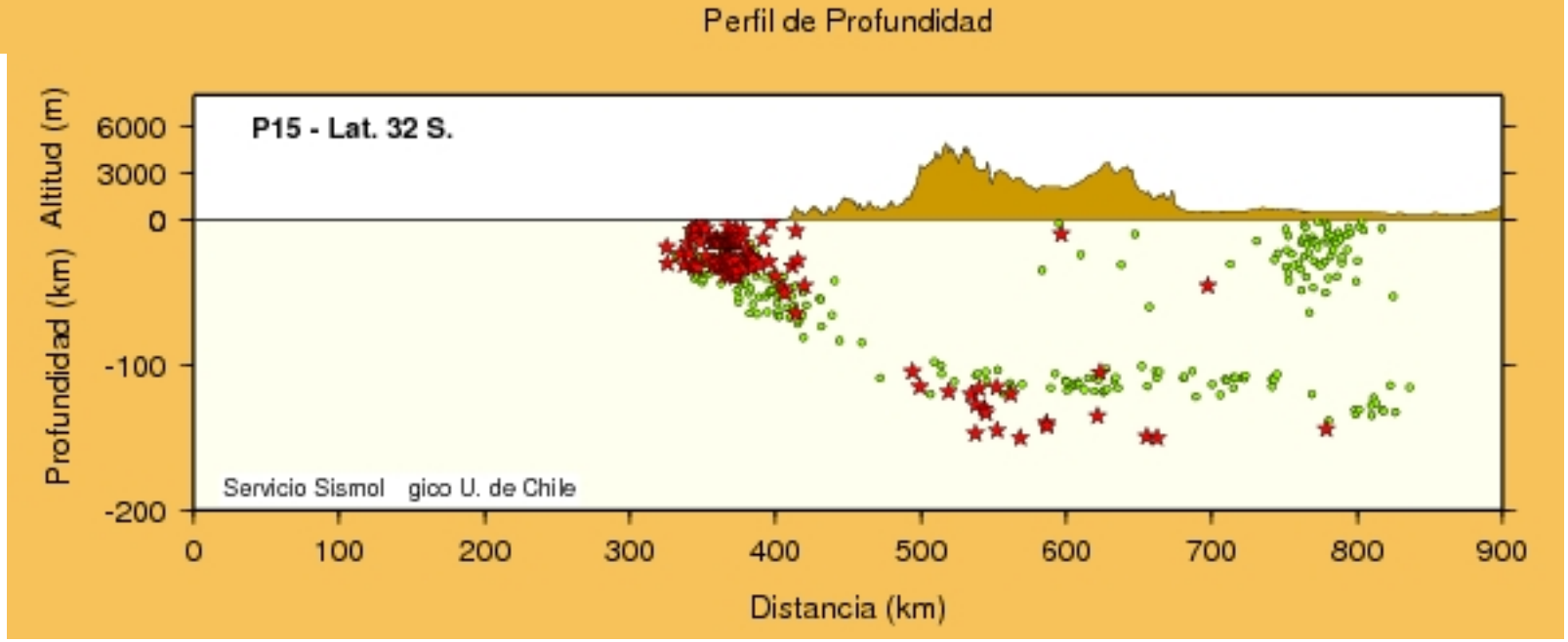
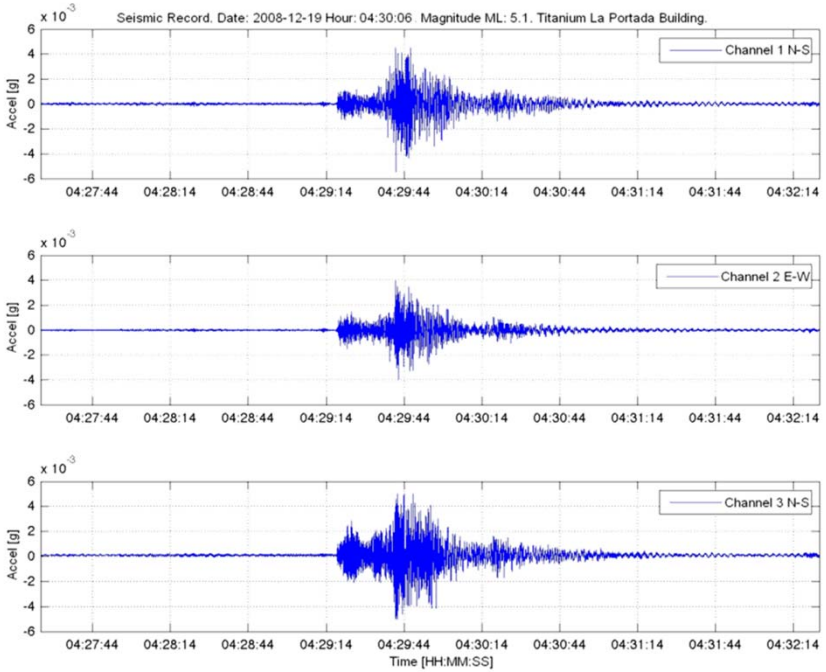
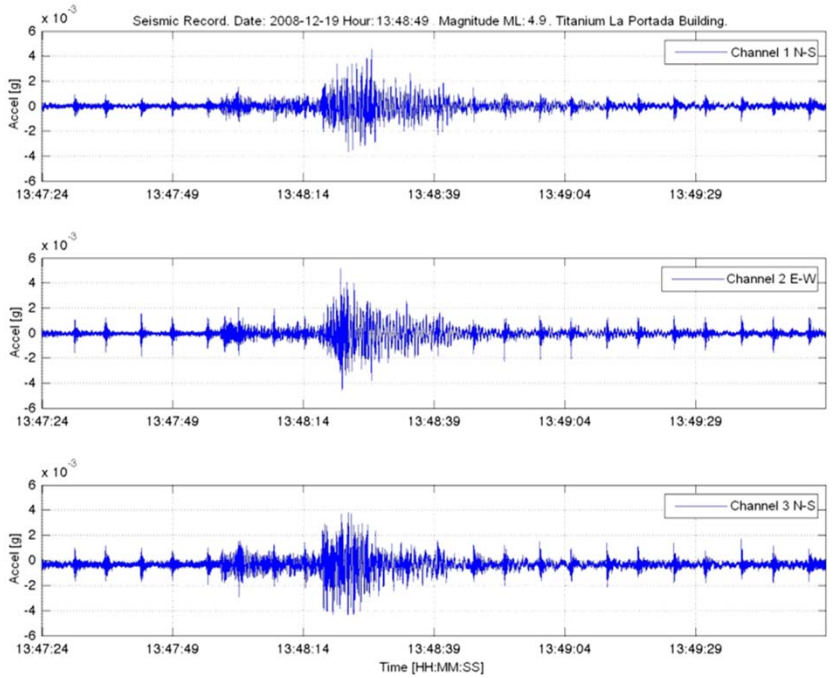
LOW LEVEL
ARTHQUAKE RECORDS
DURING MONITORING



Low Level Earthquake Records during monitoring





N	Fecha	Hora Local	Latitud	Longitud	Profundidad [km]	Magnitud (ML)
1	18-12-2008	18:19:28	-32 28' 33''	-71 54' 00''	24.0	**5.9**
2	18-12-2008	18:25:02	-32 29' 24''	-71 52' 37''	37.7	**4.6**
3	18-12-2008	18:50:28	-32 28' 44''	-72 04' 15''	25.1	**5.5**
4	19-12-2008	0:04:16	-32 29' 27''	-71 54' 50''	26.7	**4.5**
5	19-12-2008	4:30:06	-32 32' 20''	-72 01' 19''	12.0	**5.1**
6	19-12-2008	6:36:04	-32 27' 28''	-71 56' 56''	32.2	**5.8**
7	19-12-2008	10:57:30	-32 35' 02''	-71 51' 07''	13.8	**5.1**
8	19-12-2008	13:48:49	-32 35' 41''	-72 00' 21''	6.0	**4.9**
9	19-12-2008	14:43:26	-32 36' 43''	-71 49' 47''	29.5	**4.2**
10	19-12-2008	16:25:54	-32 34' 30''	-71 48' 21''	14.1	**4.9**
11	19-12-2008	18:33:10	-32 33' 07''	-71 57' 25''	32.0	**4.4**

-Eleven low level earthquakes were recorded

- P.A. 0.5% [g].

-No damage or detention of construction was done.

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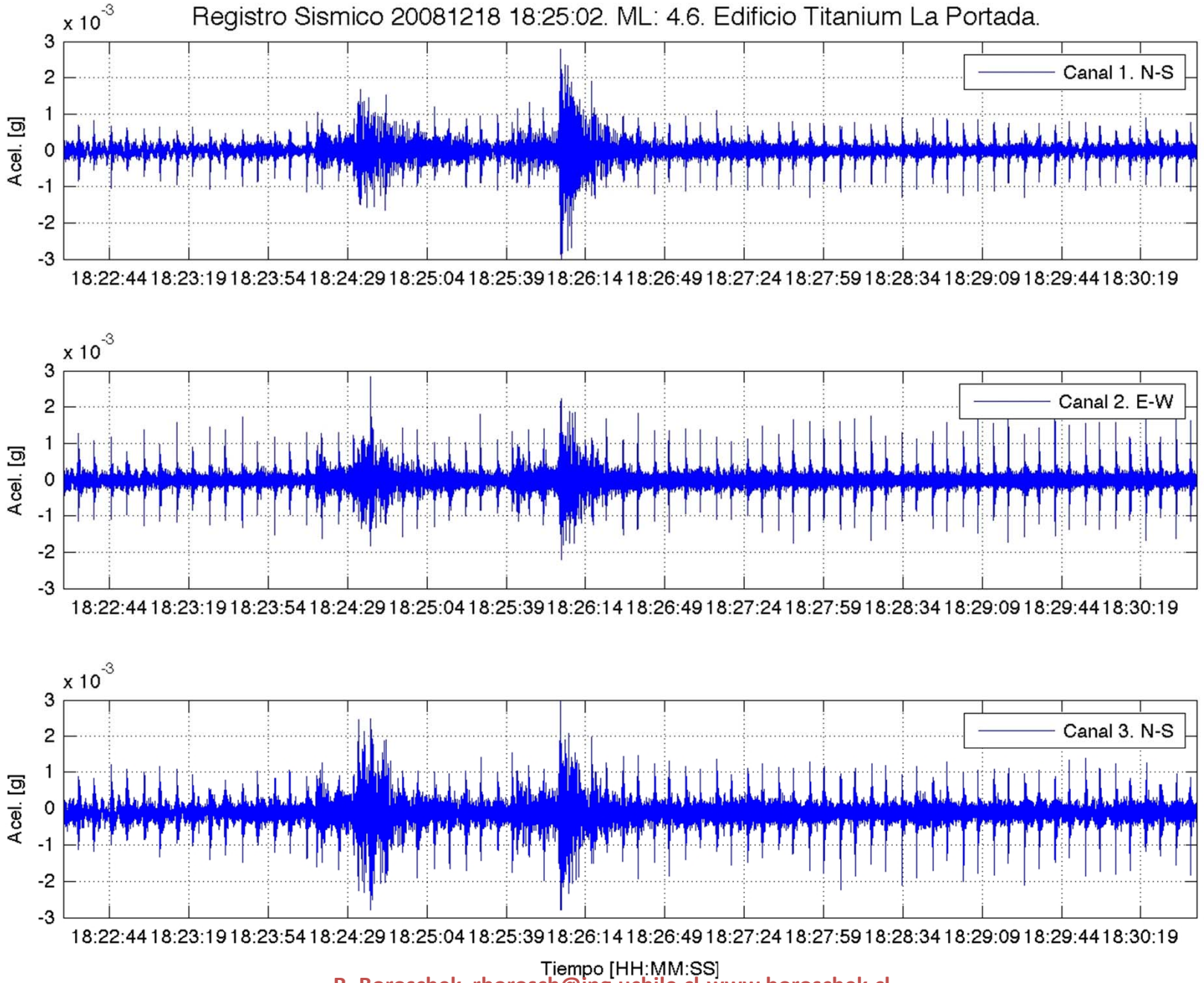

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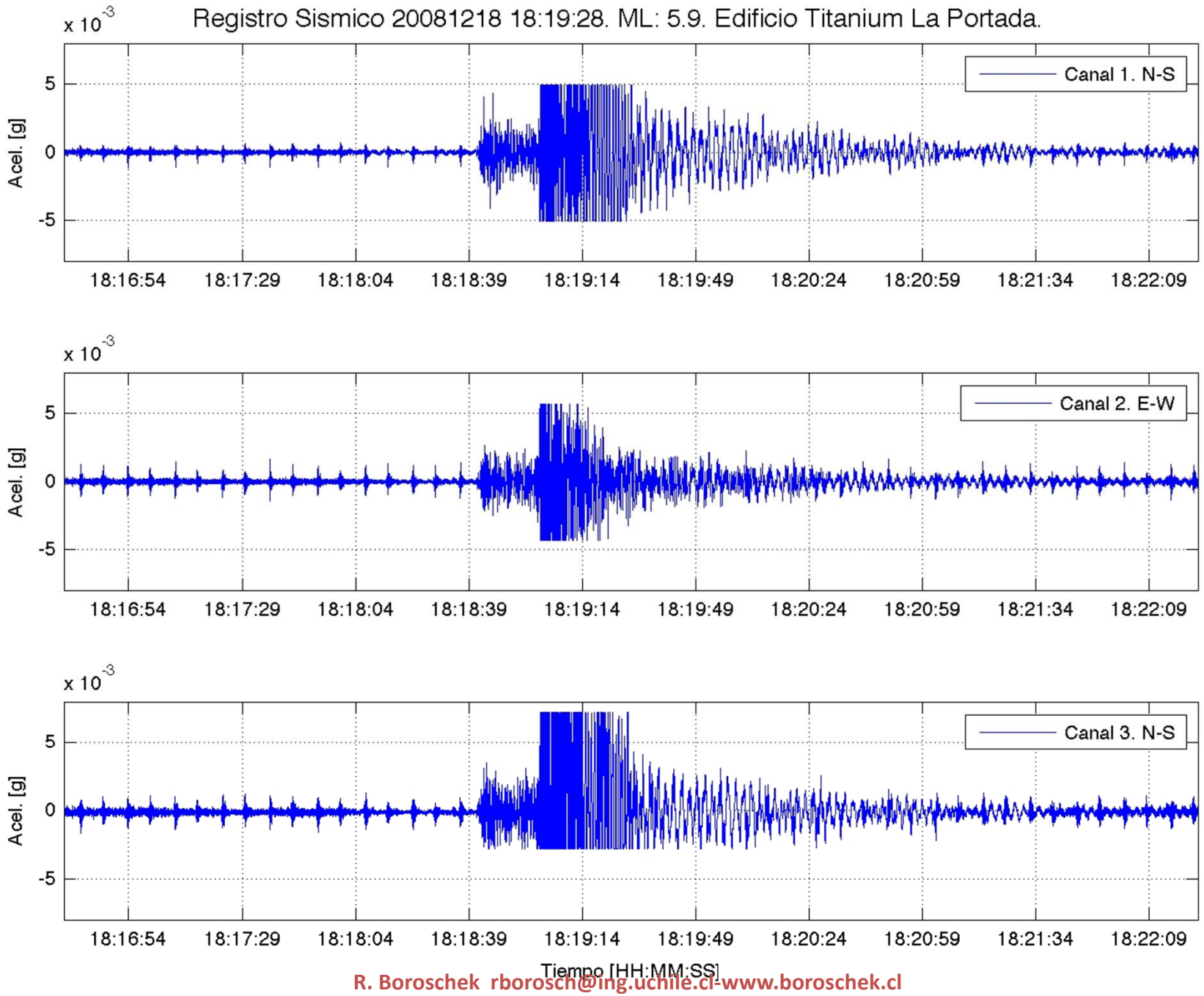

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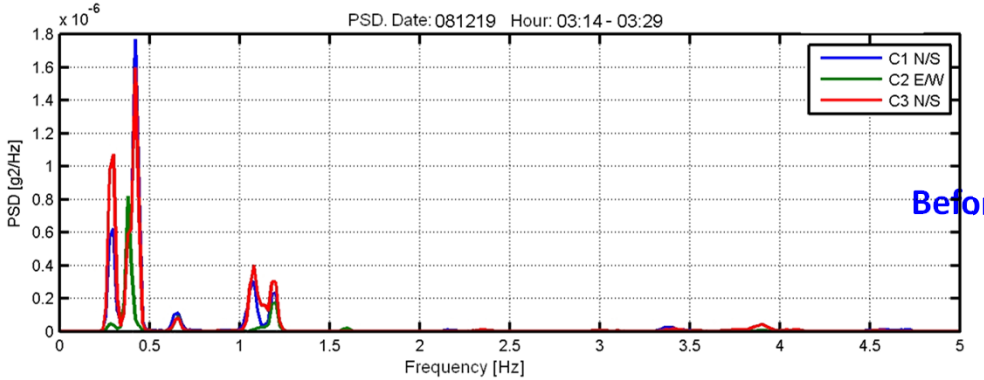
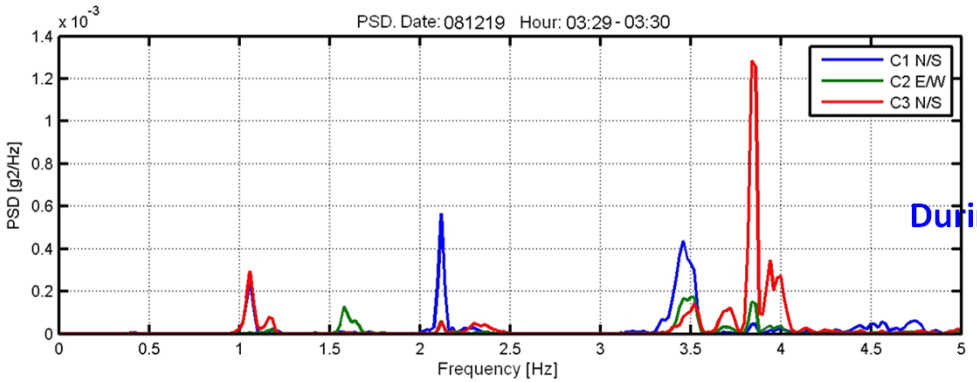
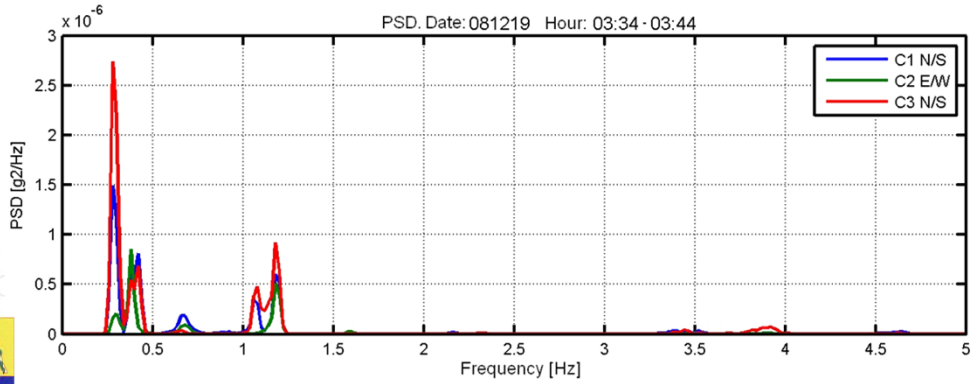
Low Level Earthquake Records during monitoring.



Before EQ



During EQ



After EQ

Higher modes are excited, while modes under 1 Hz are clearly attenuated.

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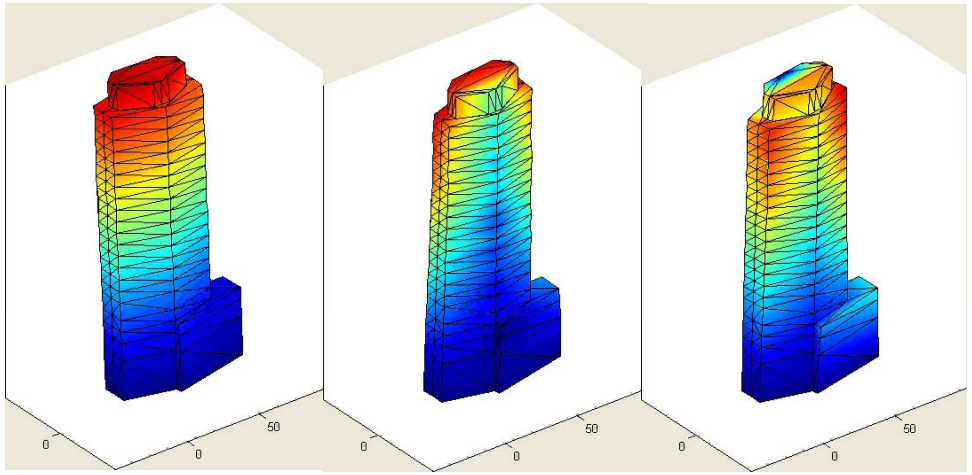
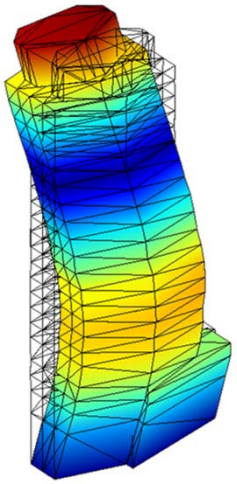
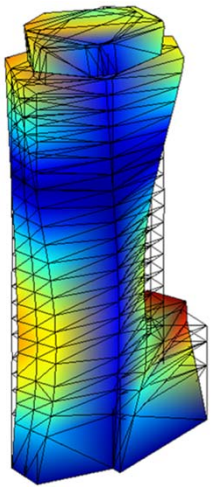
Complete Building.

Source: MACEC 3.0



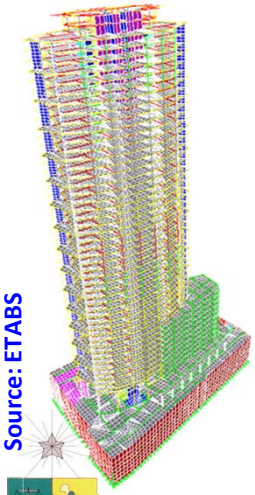


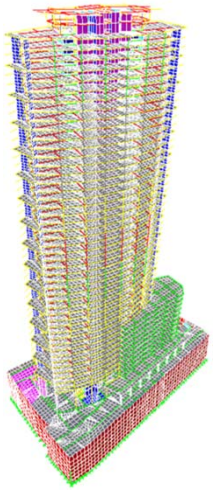


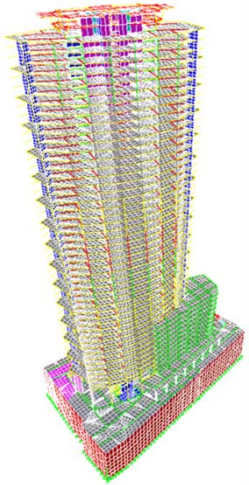
Experimental Model.

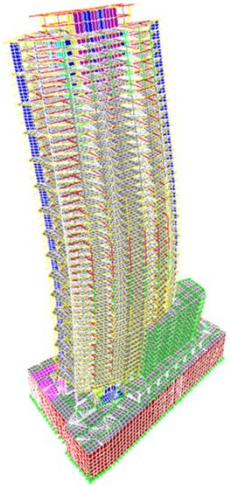
$f_1 = 0.187$ [Hz] $f_2 = 0.256$ [Hz] $f_3 = 0.297$ [Hz] $f_4 = 0.713$ [Hz] $f_5 = 0.864$ [Hz]

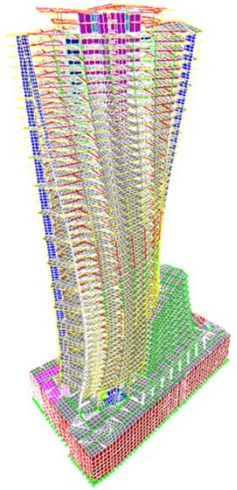
Source: ETABS











Finite Element Model.

$f_1 = 0.187$ [Hz] $f_2 = 0.250$ [Hz] $f_3 = 0.288$ [Hz] $f_4 = 0.700$ [Hz] $f_5 = 0.811$ [Hz]

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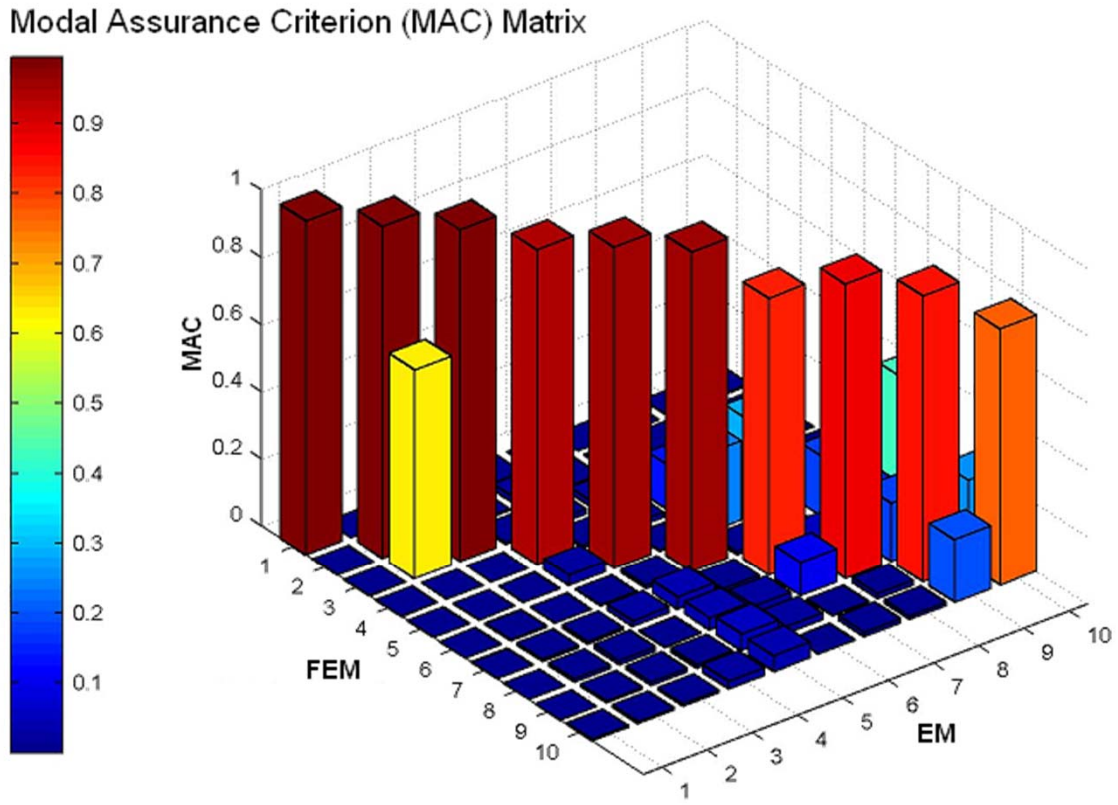
Measured Results. Complete Building.

Mode	f mean [Hz]	β mean [%]
1	0.19	0.6
2	0.27	1.0
3	0.30	0.7
4	0.71	0.5
5	0.86	0.6
6	1.07	0.6
7	1.50	0.6
8	1.61	0.5
9	2.25	0.8
10	2.42	0.7



1	**0.99**	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	**0.99**	0.44	0.00	0.02	0.00	0.00	0.01	0.00	0.00
3	0.00	0.62	**0.99**	0.01	0.01	0.02	0.01	0.01	0.00	0.00
4	0.00	0.00	0.00	**0.94**	0.01	0.01	0.13	0.01	0.00	0.00
5	0.00	0.00	0.00	0.03	**0.96**	0.00	0.24	0.28	0.02	0.01
6	0.00	0.00	0.00	0.00	0.01	**0.95**	0.01	0.00	0.18	0.01
7	0.00	0.01	0.01	0.02	0.04	0.01	**0.83**	0.05	0.14	0.43
8	0.00	0.01	0.01	0.00	0.04	0.02	0.10	**0.88**	0.17	0.18
9	0.00	0.01	0.01	0.01	0.05	0.02	0.00	0.01	**0.85**	0.25
10	0.00	0.01	0.01	0.02	0.05	0.00	0.01	0.01	0.19	**0.76**

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