DYNAMIC TESTING OF A SCALED LABORATORY PHYSICAL MODEL STRUCTURE USING THE UPRM EARTHQUAKE SIMULATOR FACILITY

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AGENDA

SECTION I

- Introduction

Shaking Table

- Calibration of Shaking Table

- Prototype and Model

SECTION II

Model in SAP2000 without dampers

SECTION III

Model in SAP2000 with dampers

SECTION IV

-Conclusions

- Recommendations

INTRODUCTION

In 1960 the experimental earthquake simulation was first introduced to the research world. The first servo valves were built between 1960 and 1970. There are three ways to classify shaking tables:

- small (<10 feet)
- medium (10-30 feet)
- large (> 30 feet)

There are a varying products of shaking tables for structures such as one dimensional, bi dimensional and tridimensional. Tridimensional shaking tables are ideals for modeling scaled earthquakes.
The shaking tables components:

1. Reaction Mass
2. Simulator Rigid Platform
3. Linear Roller Bearings
4. Hydraulic Power Unit
5. Servo valve and Actuator
6. Sevo-Controller
7. Control & Data Acquisition
8. Instrumentation for Measurements

SHAKING TABLES

Rice University

- Small shaking table
- Dimensions 5x5 ft
- Payload Limit 1500 lb

State University of New York at Buffalo

- Medium shaking table
- Dimensions 12x12 ft
- Payload Limit 44000 lb

SHAKING TABLES

E-Defense Japan

- Large shaking table
- Dimensions 50x50 ft
- Payload Limit 1000 kip

CLOSED LOOP CONTROL

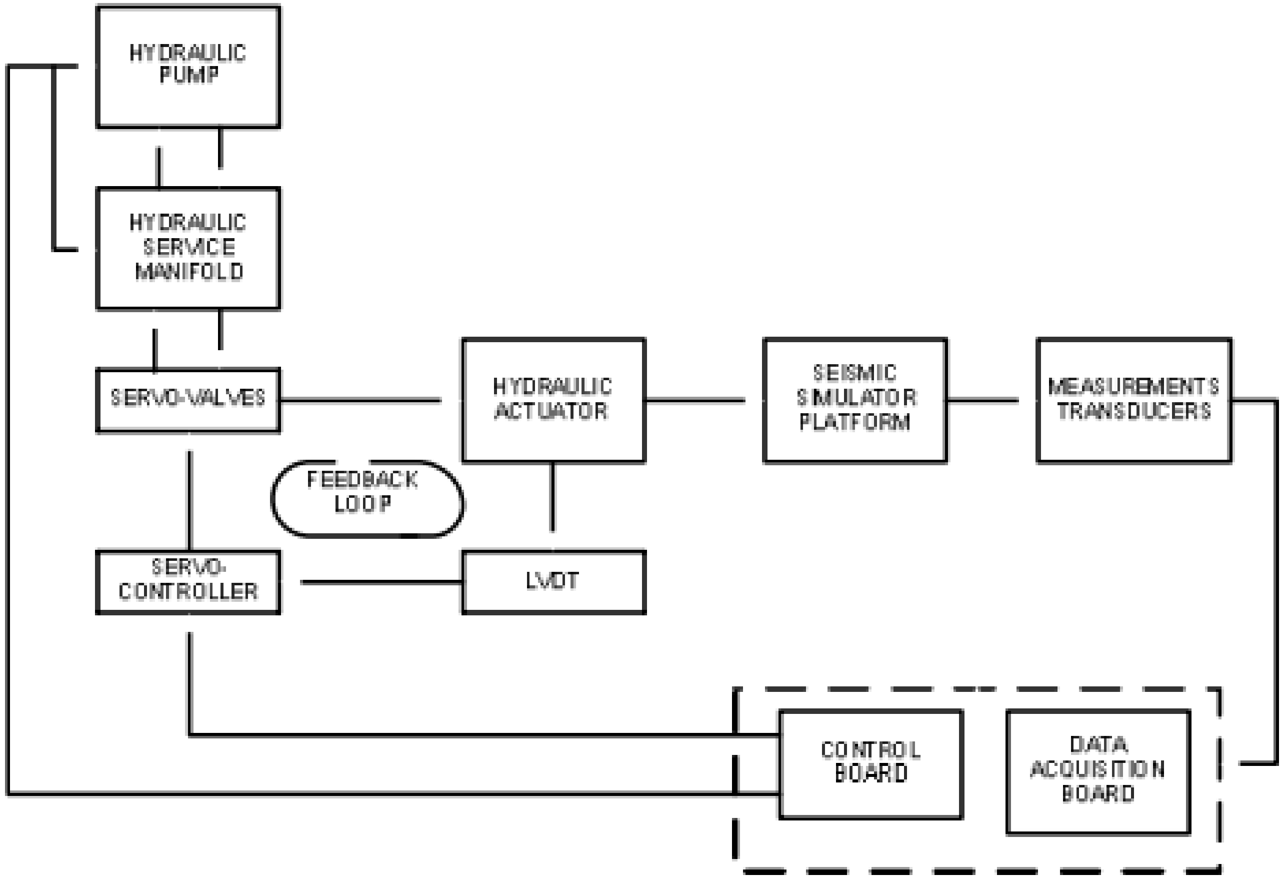
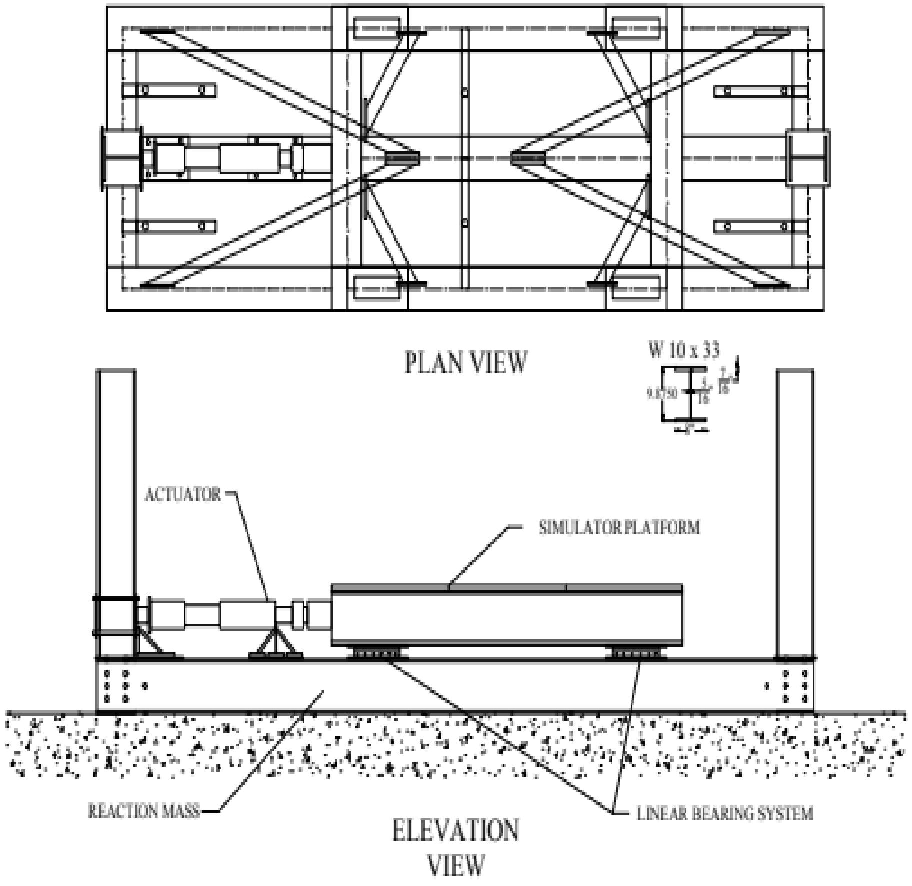


Figure 3.3 Block Diagram of Seismic Simulator [19].

UPRM EARTHQUAKE SIMULATION

- The design concept of the UPRM Earthquake Simulator was the design of a small unidirectional servo-hydraulic shaking table facility.
- The final design consists of a rigid platform sliding over a near frictionless linear bearing system and driven by an actuator attached to a reaction frame.



UPRM EARTHQUAKE SIMULATOR MAIN PROPERTIES

Table size	*4.5ft by 7.5ft*
Payload (Test Structure)	*5300 lb.*
Shaking direction	*Longitudinal (x-dir.)*
Max. Acceleration (max. loading)	*2.0 g (with ¼ test structure)*
Max. Velocity	*29.62 in/sec*
Max. Displacement	*+3.0/-3.0 in*
Operating Frequency	*0.0-20.0 Hz*

REACTION FRAME

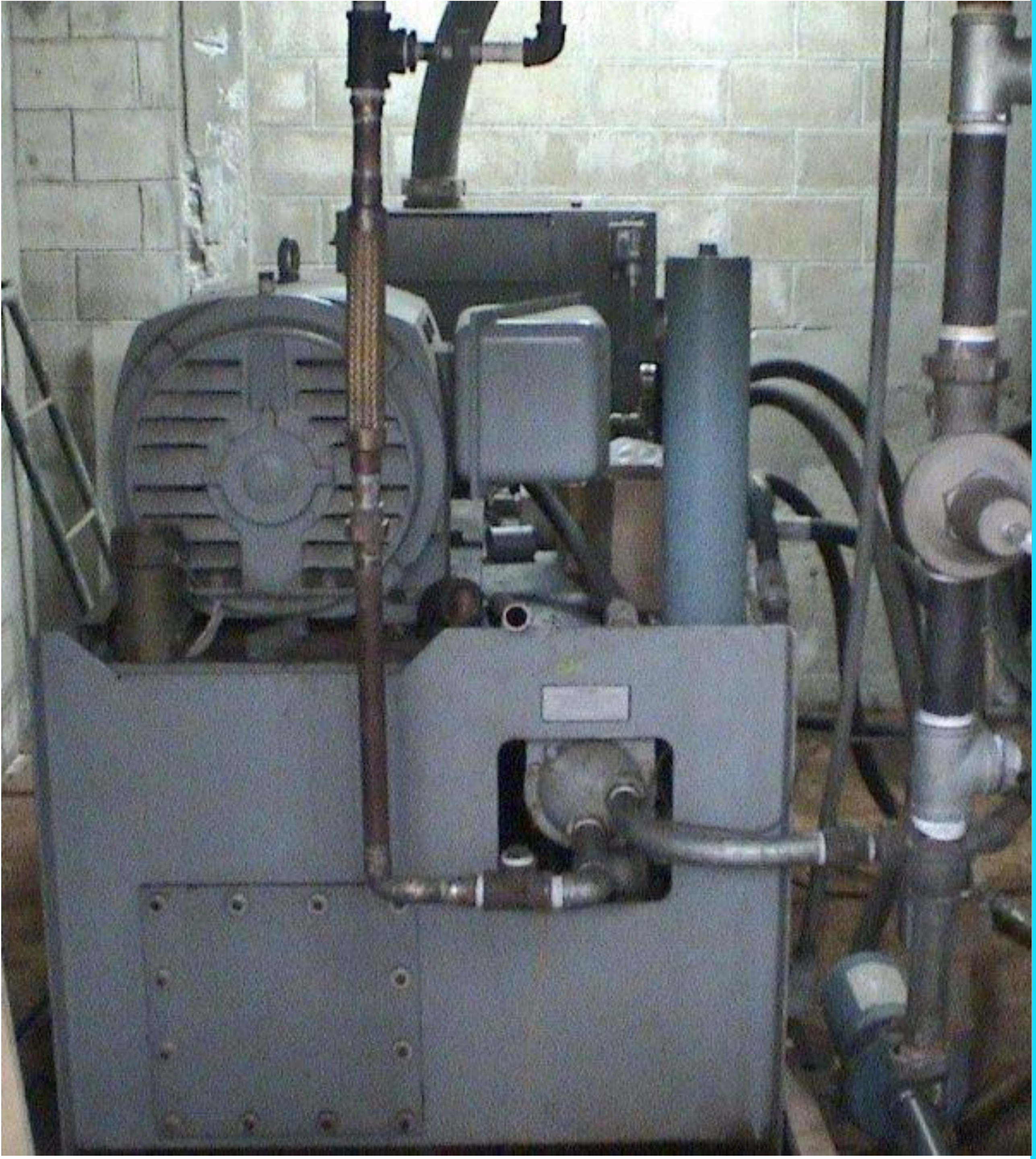
- The reaction frame is connected to the Structural Laboratory floor
- It's important to measure the reaction frame's motion during tests with connections to strong floor

SIMULATOR RIGID PLATFORM

LINEAR ROLLER BEARINGS

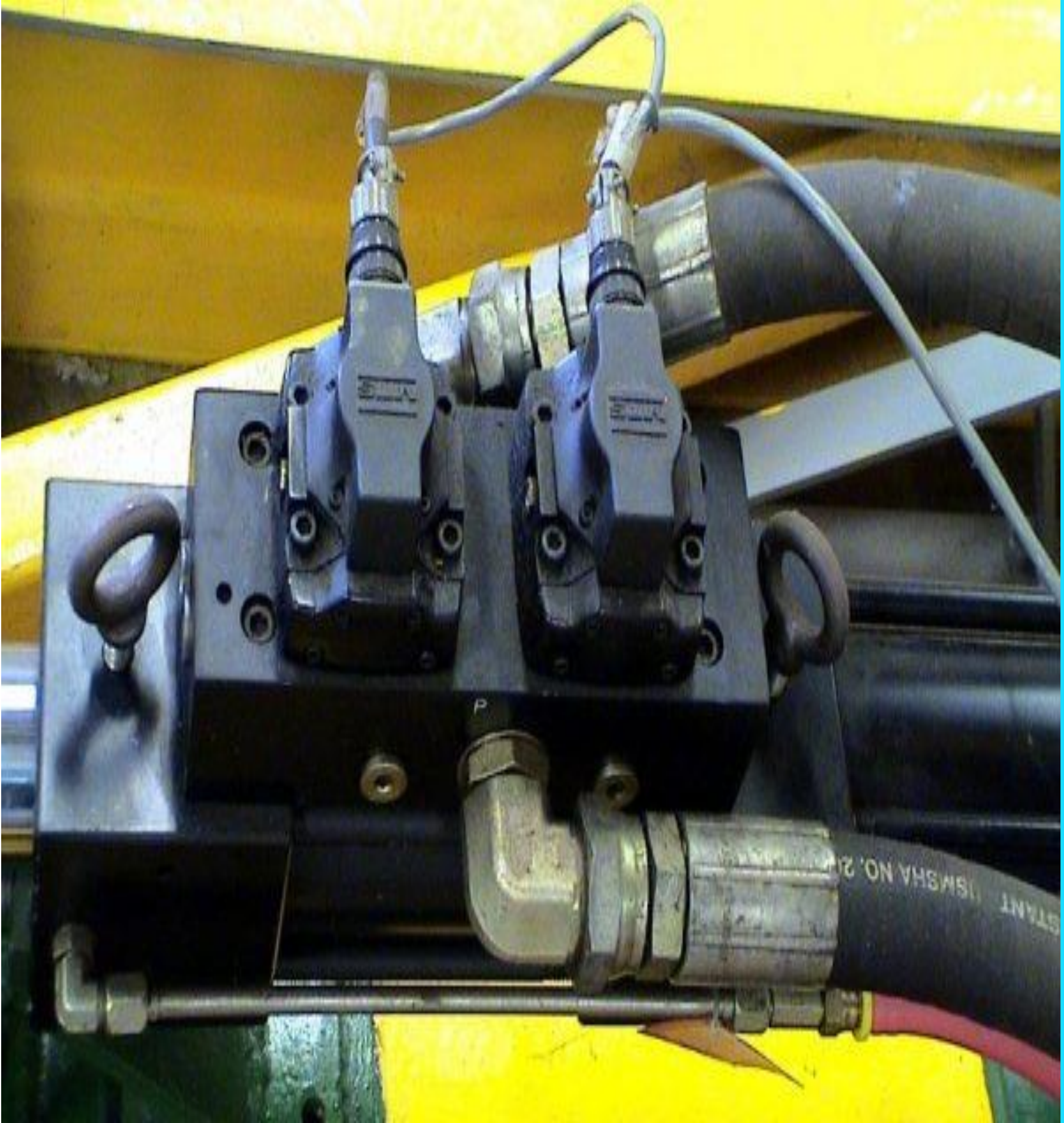
HYDRAULIC POWER UNIT

The Hydraulic Power Supply (pump) installed in the laboratory is a MTS Model 506.61 and is rated at 265.0 l/min (70 gpm) of steady flow [24]. A Hydraulic Service Manifold (HSM) MTS Model 293.11, with a rated capacity of 190.0 l/min (50 gpm), is mounted between the HPS and the servovalves.



HYDRAULIC POWER UNIT

- Hydraulic power systems typically consist of an arrangement of hydraulic power supplies, remote services manifolds, and accesory equipement.
- These components integrate into a hydraulic power distribution network to provide hydraulic fluid power to servo-controlled actuators



SERVO VALVE AND ACTUATOR

- The servovalve ports the fluid, provided by the hydraulic power system, into the appropriate side of the actuator's chambers. This causes the actuator's piston to move the actuator's arm in the desired direction.
- The linear actuator system also consists of a load cell transducer, which measures force.

SERVO-CONTROLLER

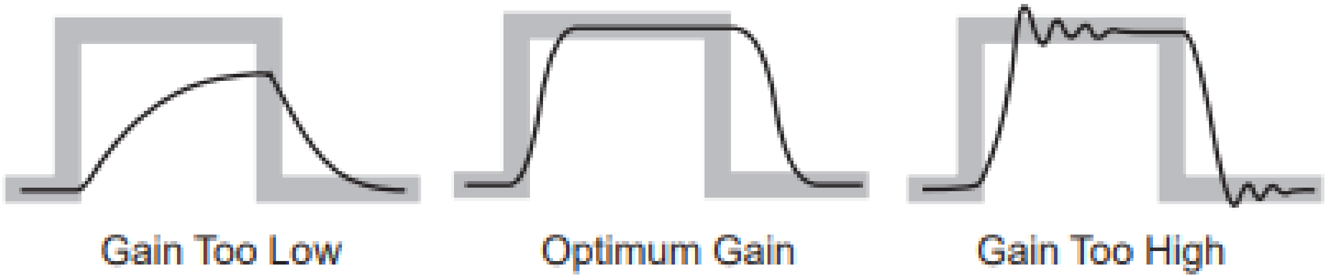
The servo-controller utilizes two levels of control to regulate the displacement of the actuator:

- Inner loop: it regalutes the porting of fluid by the servo-valves. This is the lowest level of control.
- Outer loop: utilizes the displacement signal of the LVDT mounted on the actuator and compares it to the command signal sent by the control computer.

CALIBRATION OF SHAKING TABLE

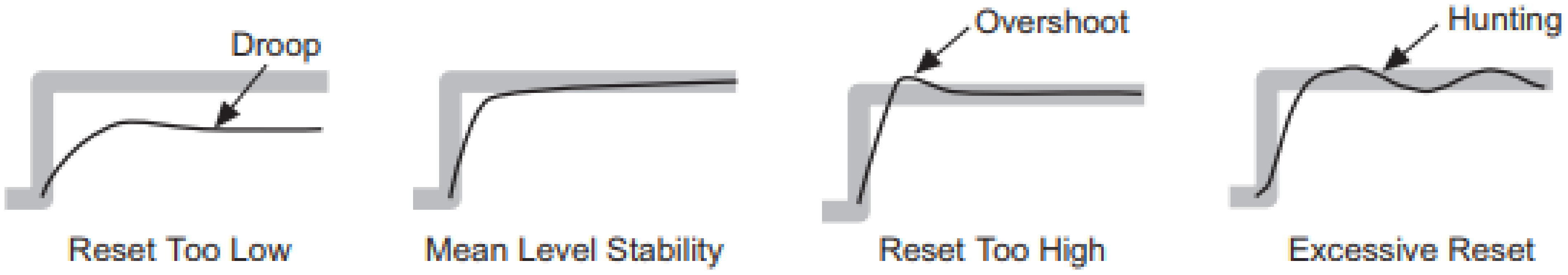
- *“Proportional gain” (P)*
- Proportional gain increases system response by boosting the effect of the error signal on the servovalve. As proportional gain increases, the error decreases and the feedback signal tracks the command signal more closely. Too much proportional gain can cause the system to become unstable. In the other direction, too little proportional gain can cause the system to become sluggish.

The tuning command is shown as a gray square waveform, and the black waveform is the sensor feedback



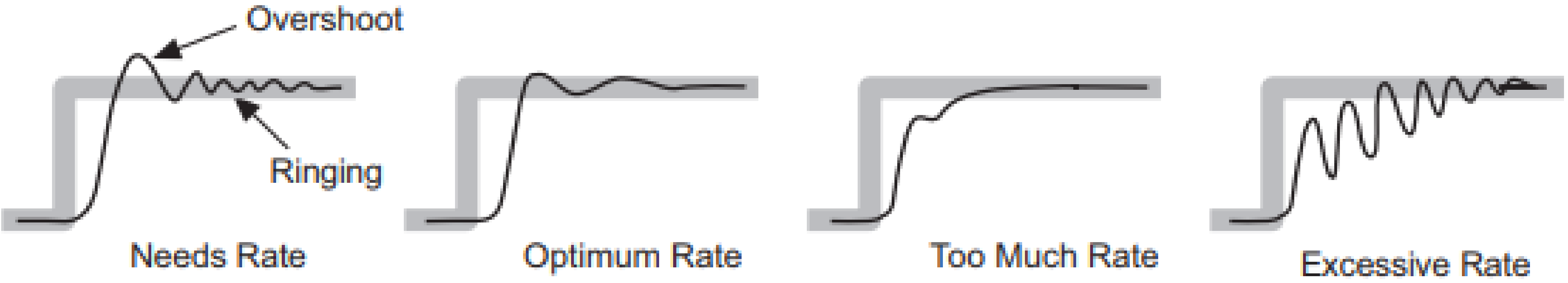
CALIBRATION OF SHAKING TABLE

- *“Integral gain” (I)*
- This value increases the response of the system when a signal with low frequencies or static is considered. In cases of high frequencies, it maintains the average. When a signal is used with low frequencies or static, the signal that returns usually has a "spring" effect due to the selvo-valves. This parameter corrects this behavior.



CALIBRATION OF SHAKING TABLE

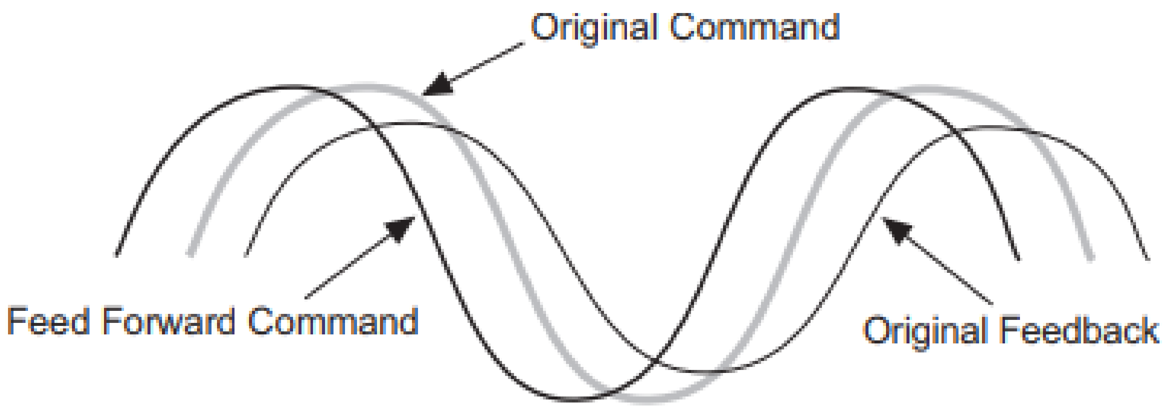
- *“Derivative gain” (D)*
- This parameter is considered when performing dynamic tests. Anticipate the rate of change in the signal received. It also reduces the noise caused by using a high "proportional gain". If this value is greatly increased, it can cause instability at high frequencies. Using a very low value can cause a rumbling sound.



CALIBRATION OF SHAKING TABLE

- *"Feed Forward Gain" (F)*
- This parameter anticipates how much the valve should open to obtain the required response. It is used to minimize the delay of the phase. It helps the servo-control to react correctly when there is an abrupt change in the signal.

Adjusting feed forward causes the command to begin sooner so the feedback may track the original command more closely

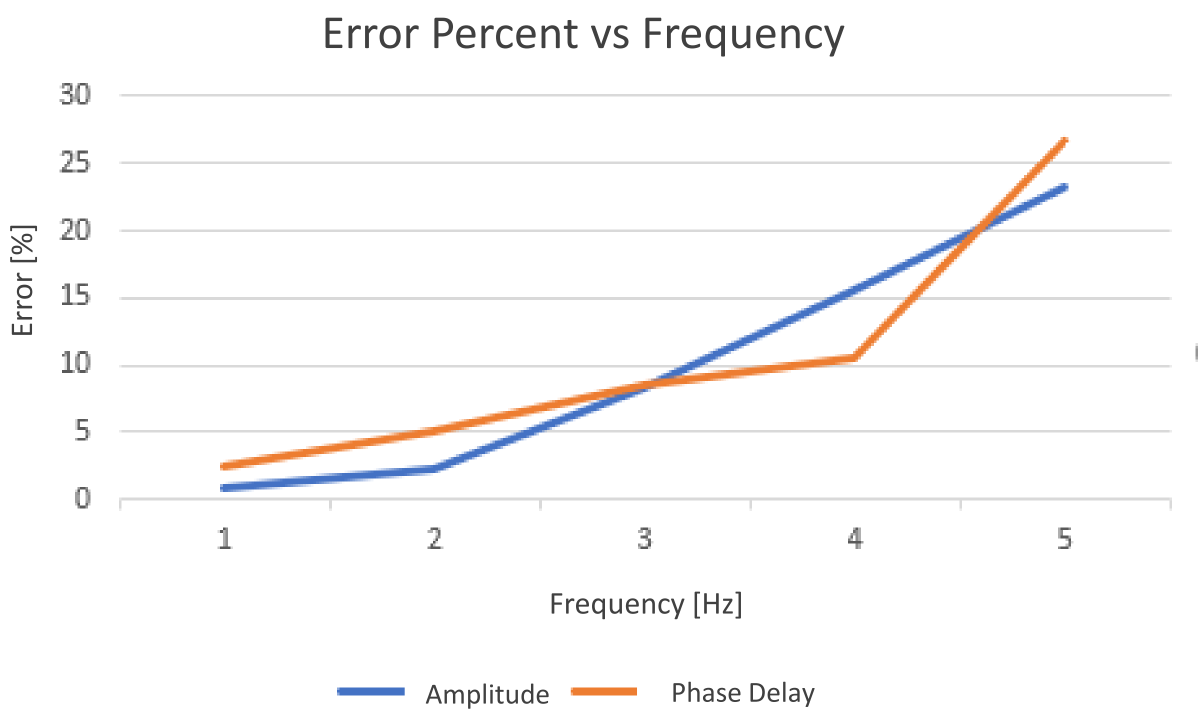


BARE TABLE CALIBRATION GROUP 1

- Group 1

Calibration of Shake Table for Frequencies from 1 Hz- 5 Hz					
Frequecies (Hz)	Command Signal/Amp (inches)	P-gain	I-gain	Response Displacement (inches)	Error (%)
1	0.125	2.4	0.2	0.1261	0.88
2	0.125	2.4	0.2	0.1221	2.32
3	0.125	2.4	0.2	0.1146	8.32
4	0.125	2.4	0.2	0.1054	15.68
5	0.125	2.4	0.2	0.09596	23.23

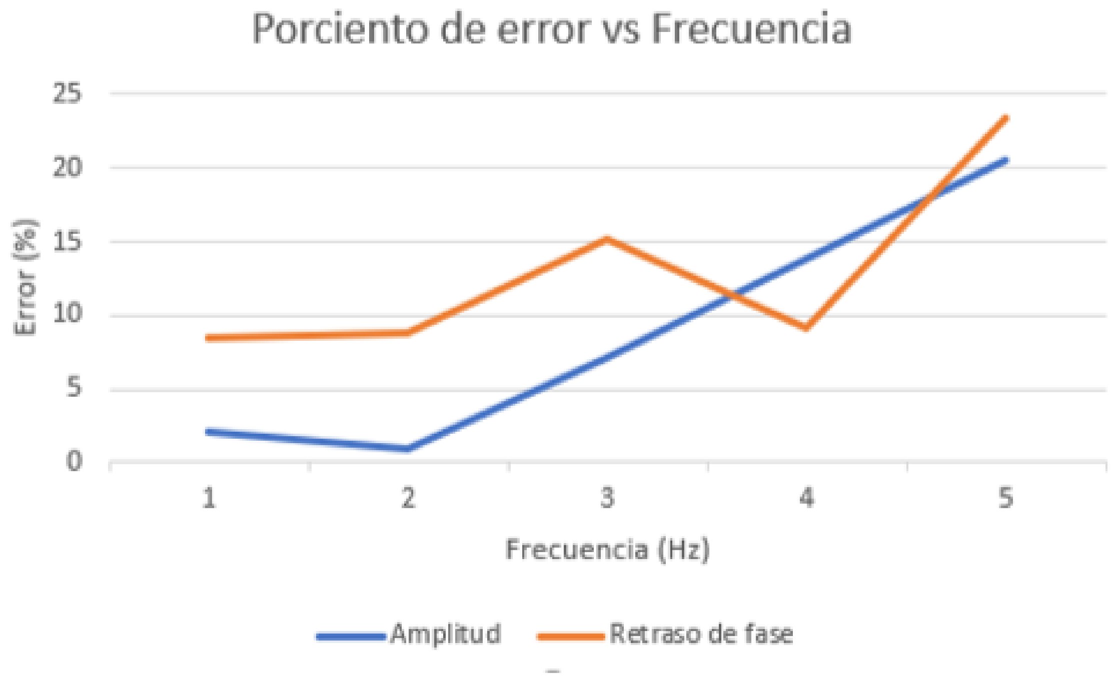
CALIBRATION GROUP 1



LOAD TABLE CALIBRATION GROUP 1

Calibration of Shake Table for Frequencies from 1 Hz- 5 Hz					
Frequecies (Hz)	Command Signal/Amp (inches)	P-gain	I-gain	Response Displacement (inches)	Error (%)
1	0.125	2.4	0.2	0.1275	2
2	0.125	2.4	0.2	0.1238	0.96
3	0.125	2.4	0.2	0.1162	7.04
4	0.125	2.4	0.2	0.1078	13.76
5	0.125	2.4	0.2	0.09939	20.49

CALIBRATION GROUP 1



BARE TABLE CALIBRATION GROUP #2

- Frequencies: 5 Hz-10Hz

Calibration of Shake Table for Frequencies from 5 Hz- 10 Hz					
Frequecies (Hz)	Command Signal/Amp (inches)	P-gain	I-gain	Response Displaceme nt (inches)	Error (%)
5	0.125	2.4	0.2	0.09687	22
6	0.125	2.4	0.2	0.0883	29
7	0.125	2.4	0.2	0.08202	34
8	0.125	2.4	0.2	0.07533	39
9	0.125	2.4	0.2	0.06878	45
10	0.125	2.4	0.2	0.0639	48

FLEXIBLE STRUCTURE CALIBRATION

Calibration of Shake Table for Frequencies from 1 Hz- 5 Hz					
Frequecies (Hz)	Command Signal/Amp (inches)	P-gain	I-gain	Response Displacement (inches)	Error (%)
1	0.25	2.0	0.15	0.2531	1.2
0.5	0.5	2.0	0.15	0.5032	0.64
1	0.5	2.0	0.15	0.4984	0.32

LOAD TABLE CALIBRATION GROUP #3

- Frequencies: 11 Hz-15Hz

Frequencies (Hz)	Command Signal/Amp (inches)	P-gain	I-gain	Response Displacement (inches)	Error (%)
11	0.125	3	0.2	0.07376	40.9
12	0.125	3	0.2	0.07243	41.8
13	0.125	3	0.2	0.07135	42.9
14	0.125	3	0.2	0.07115	43
15	0.125	3	0.2	0.07067	43.4

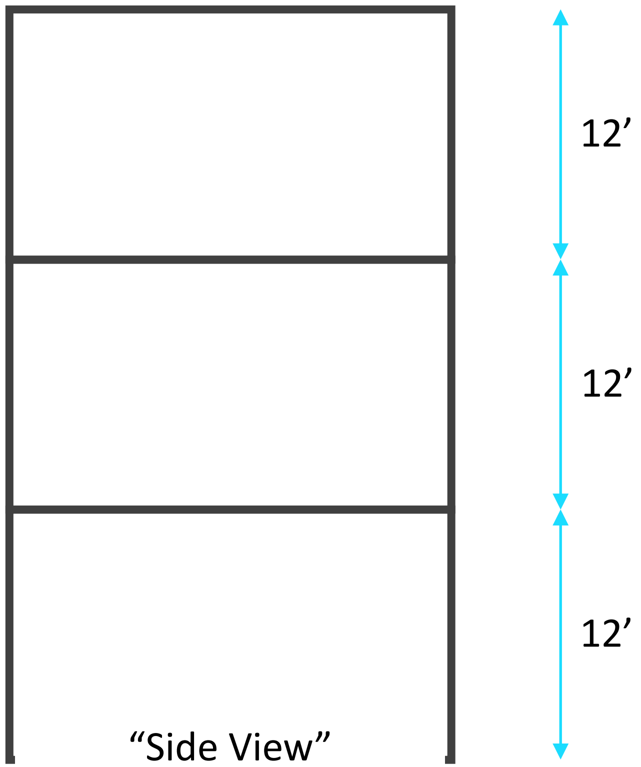
BARE TABLE CALIBRATION GROUP #3

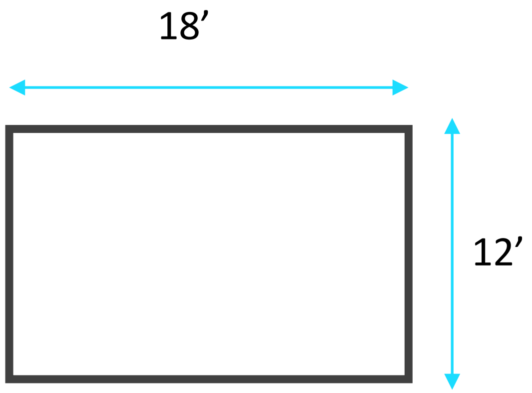
- Frequencies: 11 Hz-15Hz

Frequencies (Hz)	Command Signal/Amp (inches)	P-gain	I-gain	Response Displacement (inches)	Error (%)
11	0.125	3	0.2	0.07376	35.3
12	0.125	3	0.2	0.07243	38.2
13	0.125	3	0.2	0.07135	38.2
14	0.125	3	0.2	0.07115	35.6
15	0.125	3	0.2	0.07067	37.8

STRUCTURE

- Prototype





“Top View”

Columns: W12x53
Beams: W10x30

STRUCTURE

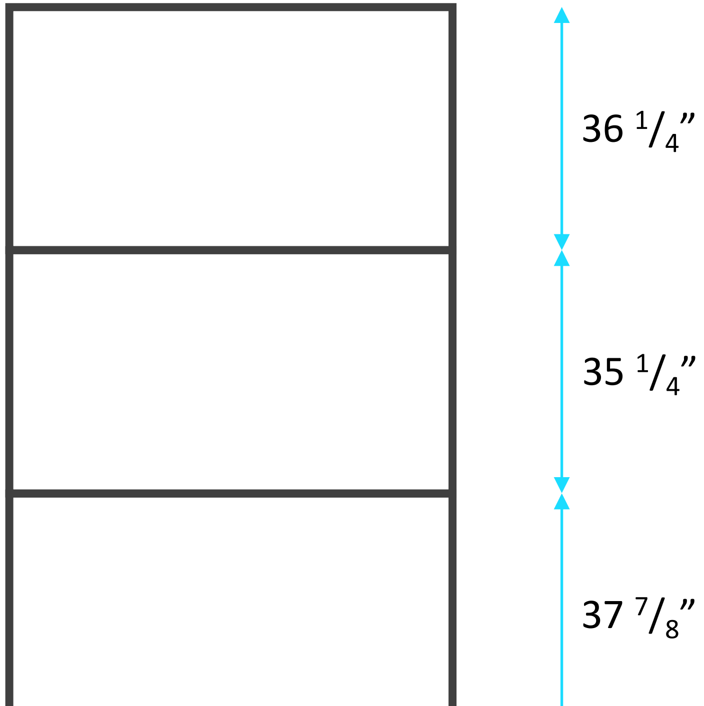
- Similitude Relationships for Artificial Mass Simulation Method.
  - Same material in the model test structure as in the prototype structure
  - $\lambda_g = \lambda_E = 1$
  - $\lambda_L = 4$

Parameter	Units[2]	Any Material	Same Material as Prototype
Length	L	λ_L	λ_L
Time	T	$\lambda_L^{1/2}$	$\lambda_L^{1/2}$
Frequency	$\frac{1}{T}$	$\lambda_L^{-1/2}$	$\lambda_L^{-1/2}$
Velocity	$\frac{L}{T}$	$\lambda_L^{1/2}$	$\lambda_L^{1/2}$
Displacement	L	λ_L	λ_L
Gravitational Acceleration	$\frac{L}{T^2}$	1	1
Acceleration	$\frac{L}{T^2}$	1	1
Force	F	$\lambda_E \lambda_L^2$	λ_L^2
Mass	$\frac{F \cdot T^2}{L}$	$\lambda_E \lambda_L^2$	λ_L^2
Specific Stiffness	L	λ_L	λ_L
Strain	$\frac{L}{L}$	1	1
Stress	$\frac{F}{L^2}$	λ_E	1
Modulus of Elasticity	$\frac{F}{L^2}$	λ_E	1
Energy	FL	$\lambda_E \lambda_L^3$	λ_L^3

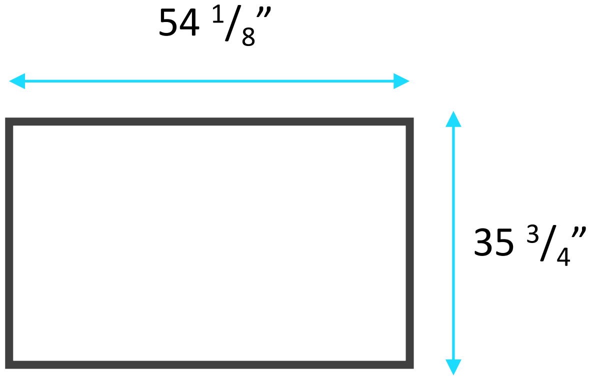
Notes:
1. From [19].
2. L = Length, T =Time, F = Force and E = Modulus of Elasticity.

STRUCTURE

- Model



“Side View”



“Top View”

Columns: S3x5.7
Beams: S3x5.7

STRUCTURE (ARTIFICIAL MASS SIMULATION)

LABORATORY PHYSICAL MODEL
GENERAL GEOMETRY (in Inches)

Length between Columns (c. to c.) :	51.1875	Long Side
Length between Columns (c. to c.) :	33.5	Short Side

Height between base and First Level :	36.375	Base Plate to Center
Height between First and Second Level :	35.25	Center to Center
Height between Second and Roof Level :	36.25	Center to Center

All frame members are S3X5.7

STRUCTURE (ARTIFICIAL MASS SIMULATION)

SELFWEIGHTS (in Pounds)

Base Level:

Weight of Base Plates :	45.94	
Weight of Columns (S3X5.7) :	35.98	Base Plate to Half Height
	81.92	

First Level:

Weight of Beams (S3X5.7) :	80.46	
Weight of Columns (S3X5.7) :	69.47	Half Height down to Half Height Up
Weight of Grating plus Holding Angles:	109.00	
Weight of Beam to Column Angles :	2.56	
Weight of Column Splices :	40.80	
	302.29	

Second Level:

Weight of Beams (S3X5.7) :	80.46	
Weight of Columns (S3X5.7) :	67.93	Half Height down to Half Height Up
Weight of Grating plus Holding Angles:	109.00	
Weight of Beam to Column Angles :	2.56	
Weight of Column Splices :	40.80	
	300.74	

Roof Level:

Weight of Beams (S3X5.7) :	80.46	
Weight of Columns (S3X5.7) :	34.44	Half Height down
Weight of Grating plus Holding Angles:	109.00	
Weight of Beam to Column Angles :	2.56	
Weight of Column Splices :	40.80	
	267.25	

FrameWeight Only:	449.18
Total Weight:	**952.20**

STRUCTURE (ARTIFICIAL MASS SIMULATION)

Artificial Mass Simulation (Theoretical)

FULL SCALE WEIGHTS (in Kips)

Roof:	11.584
Second Level:	12.858
First Level:	12.858
Total:	**37.30**

REQUIRED LAB MODEL WEIGHTS (in Kips) (0.0625 x PROTOTYPE WEIGHTS)

Roof:	0.7240
Second Level:	0.8036
First Level:	0.8036
Total:	**2.3313**

WEIGHT OF FRAME ONLY - S3X5.7's (Self Mass in SAP) (in Kips)

Roof:	0.1149
Second Level:	0.1484
First Level:	0.1499
Base:	0.0360
Total:	0.4492

REST-OF-SELFWEIGHT (RSW) (in Kips)

Roof:	0.1524
Second Level:	0.1524
First Level:	0.1524
Base:	0.0459
Total:	0.5030

THEORETICAL ADDITIONAL WEIGHTS (FOR A.M.S.) (in Kips)

Roof:	0.4567
Second Level:	0.5029
First Level:	0.4194
Base:	0.0000
Total:	1.3791

RSW + AMS (for Additional Mass in SAP) (in Kips)

Roof:	0.6091
Second Level:	0.6552
First Level:	0.5718
Base:	0.0459
Total:	1.8821

A.M.S. = Artificial Mass Simulation

STRUCTURE (ARTIFICIAL MASS SIMULATION)

Artificial Mass Simulation (Actual)

FULL SCALE WEIGHTS (in Kips)

Roof:	11.584
Second Level:	12.858
First Level:	12.858
Total:	**37.30**

REQUIRED LAB MODEL WEIGHTS (in Kips) (0.0625 x PROTOTYPE WEIGHTS)

Roof:	0.7240
Second Level:	0.8036
First Level:	0.8036
Total:	**2.3313**

WEIGHT OF FRAME ONLY - S3X5.7's (Self Mass in SAP) (in Kips)

Roof:	0.1149
Second Level:	0.1484
First Level:	0.1499
Base:	0.0360
Total:	0.4492

REST-OF-SELFWEIGHT (RSW) (in Kips)

Roof:	0.1524
Second Level:	0.1524
First Level:	0.1524
Base:	0.0459
Total:	0.5030

ACTUAL ADDITIONAL WEIGHTS (FOR A.M.S.) (in Kips)

Roof:	0.4860	(*)
Second Level:	0.4860	(*)
First Level:	0.4860	(*)
Base:	0.0000	
Total:	1.4580	

A.M.S. = Artificial Mass Simulation
(*) Three 24"x24"x1" thick plates.

RSW + AMS (for Additional Mass in SAP) (in Kips)

Roof:	0.6384
Second Level:	0.6384
First Level:	0.6384
Base:	0.0459
Total:	1.9610

STRUCTURE (ARTIFICIAL MASS SIMULATION)

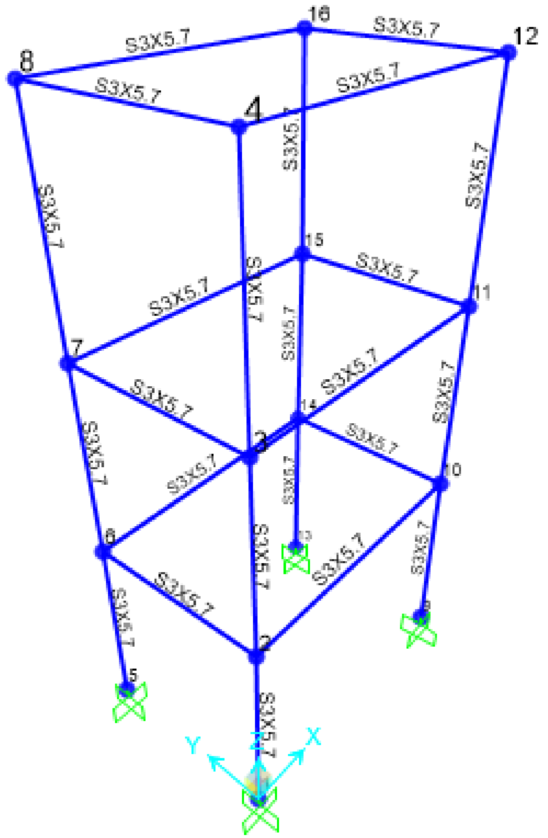
TABLE: Assembled Joint Masses - MASS CHECK

Joint	MassSource	U1	U2	U3	R1	R2	R3	CenterX	CenterY	CenterZ			Kips
Text	Text	Kip-s2/in	Kip-s2/in	Kip-s2/in	Kip-in-s2	Kip-in-s2	Kip-in-s2	in	in	in			
1	Self+AddMass	2.217E-05	2.217E-05	2.217E-05	0	0	0	0	0	0	Base	Node 1:	0.0086
2	Self+AddMass	0.0005087	0.0005087	0.0005087	0	0	0	0	0	36.375	First	Node 2:	0.1966
3	Self+AddMass	0.0005086	0.0005086	0.0005086	0	0	0	0	0	71.625	Second	Node 3:	0.1965
4	Self+AddMass	0.0004871	0.0004871	0.0004871	0	0	0	0	0	107.875	Roof	Node 4:	0.1882
5	Self+AddMass	2.217E-05	2.217E-05	2.217E-05	0	0	0	0	33.5	0	Base	Node 5:	0.0086
6	Self+AddMass	0.0005087	0.0005087	0.0005087	0	0	0	0	33.5	36.375	First	Node 6:	0.1966
7	Self+AddMass	0.0005086	0.0005086	0.0005086	0	0	0	0	33.5	71.625	Second	Node 7:	0.1965
8	Self+AddMass	0.0004871	0.0004871	0.0004871	0	0	0	0	33.5	107.875	Roof	Node 8:	0.1882
9	Self+AddMass	2.217E-05	2.217E-05	2.217E-05	0	0	0	51.188	0	0	Base	Node 9:	0.0086
10	Self+AddMass	0.0005087	0.0005087	0.0005087	0	0	0	51.188	0	36.375	First	Node 10:	0.1966
11	Self+AddMass	0.0005086	0.0005086	0.0005086	0	0	0	51.188	0	71.625	Second	Node 11:	0.1965
12	Self+AddMass	0.0004871	0.0004871	0.0004871	0	0	0	51.188	0	107.875	Roof	Node 12:	0.1882
13	Self+AddMass	2.217E-05	2.217E-05	2.217E-05	0	0	0	51.188	33.5	0	Base	Node 13:	0.0086
14	Self+AddMass	0.0005087	0.0005087	0.0005087	0	0	0	51.188	33.5	36.375	First	Node 14:	0.1966
15	Self+AddMass	0.0005086	0.0005086	0.0005086	0	0	0	51.188	33.5	71.625	Second	Node 15:	0.1965
16	Self+AddMass	0.0004871	0.0004871	0.0004871	0	0	0	51.188	33.5	107.875	Roof	Node 16:	0.1882
SumAccelUX	Self+AddMass	0.0061	0	0	0	0	0	25.594	16.75	70.406			
SumAccelUY	Self+AddMass	0	0.0061	0	0	0	0	25.594	16.75	70.406			
SumAccelUZ	Self+AddMass	0	0	0.0061	0	0	0	25.594	16.75	70.406			

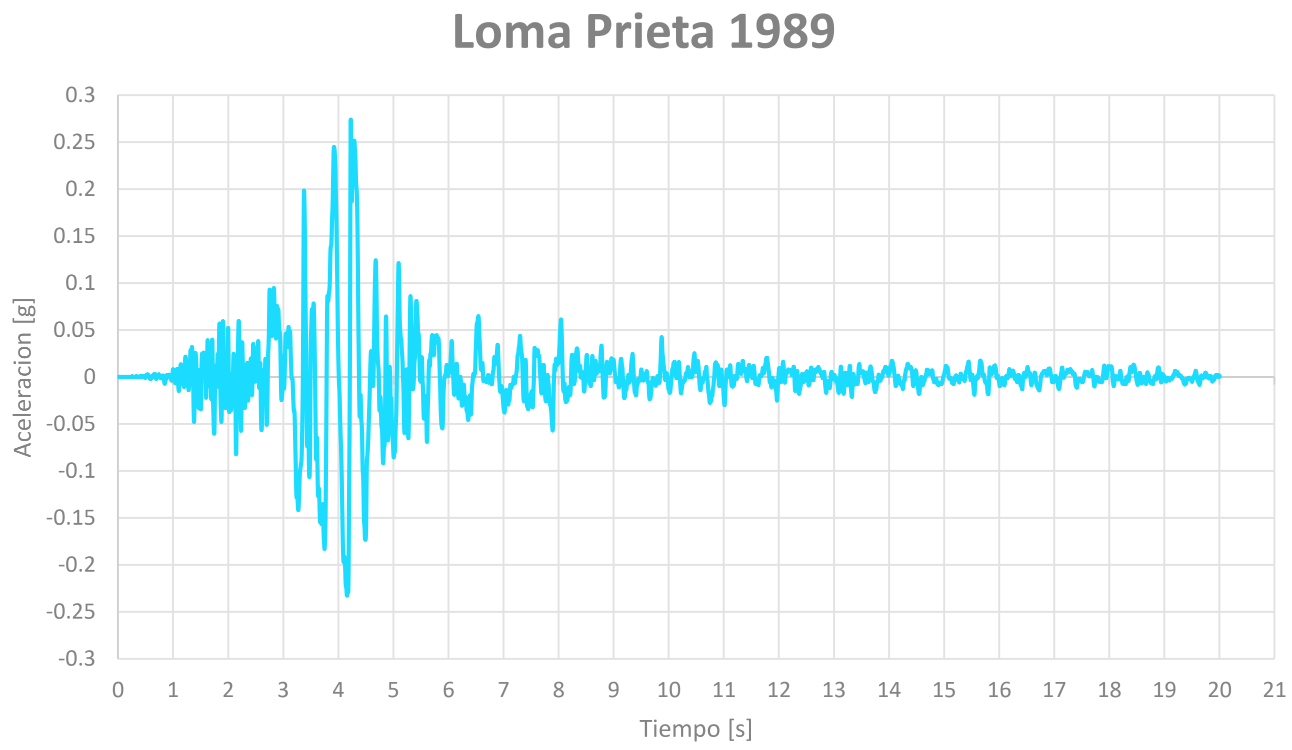
	TOTALS	
	SAP2000	Calculated
Base Level:	0.0343	0.0819
First Level:	0.7862	0.7883
Second Level:	0.7861	0.7868
Roof Level:	0.7529	0.7533
	2.3595	**2.4103**
	2.11% difference	

SAP2000 MODEL PROPERTIES

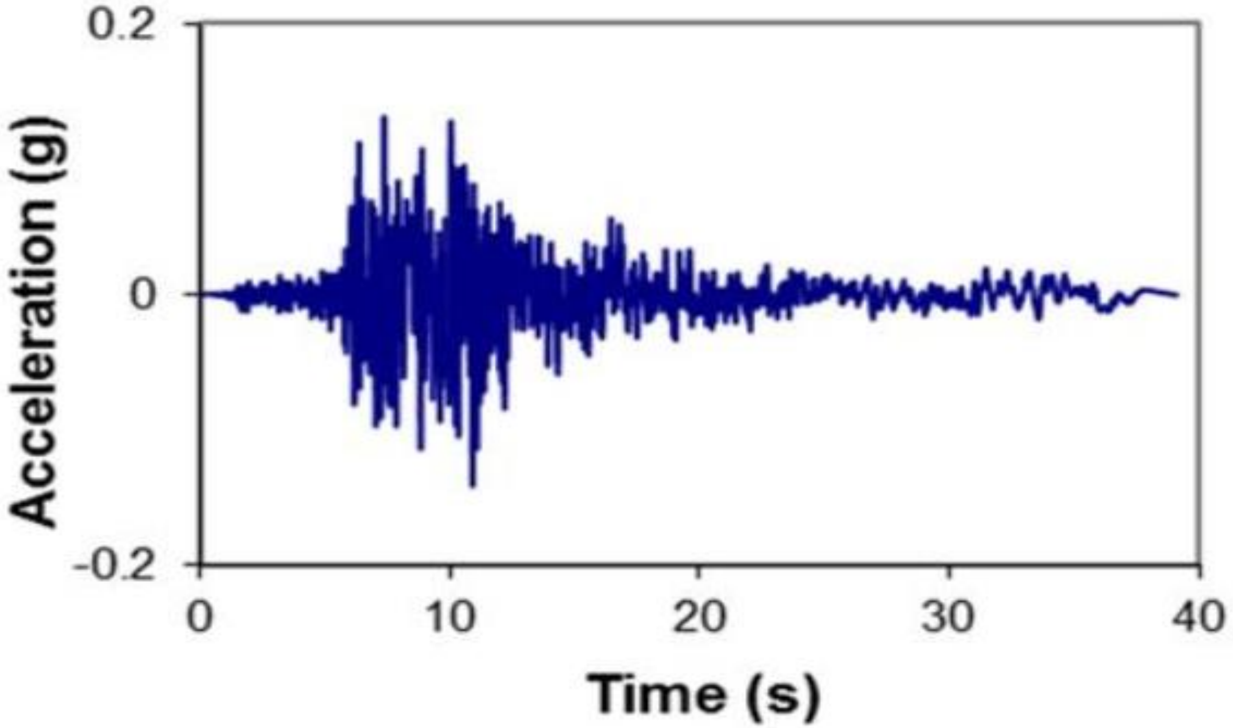
- Linear 3D Model
- 3 Story Building
- Natural Frequency: 8.28209 Hz
- Period of Structure: 0.12074 s



LOMA PRIETA 1989 EARTHQUAKE



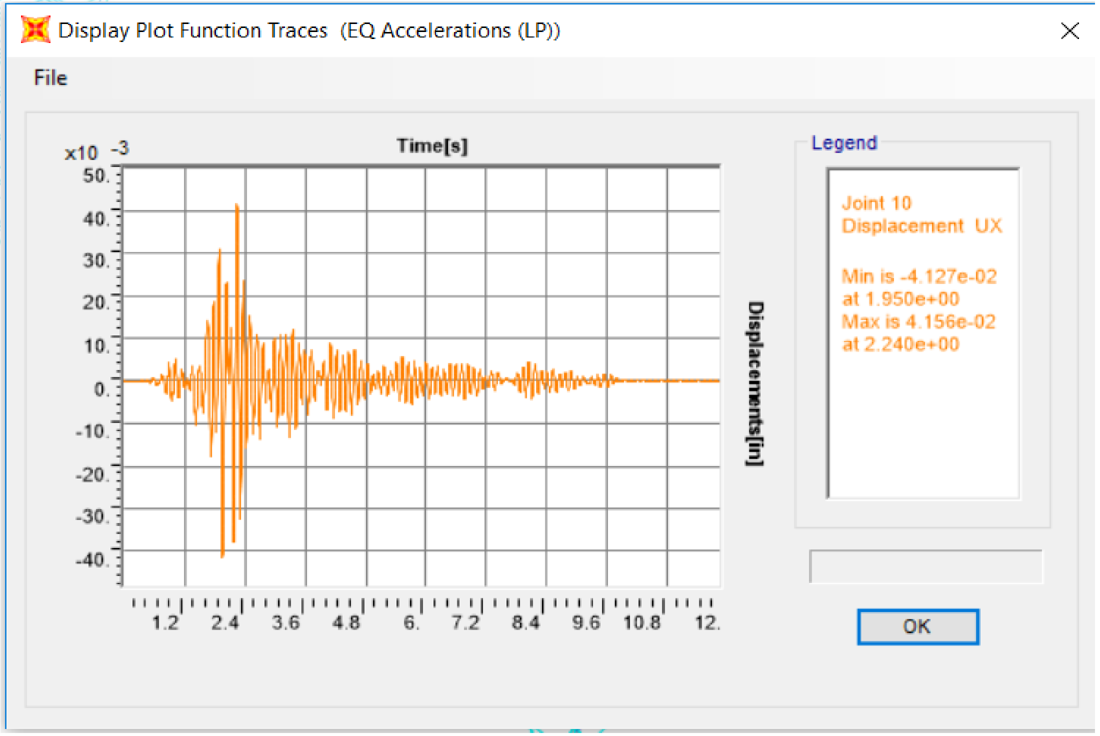
IMPERIAL VALLEY(EL CENTRO) EARTHQUAKE



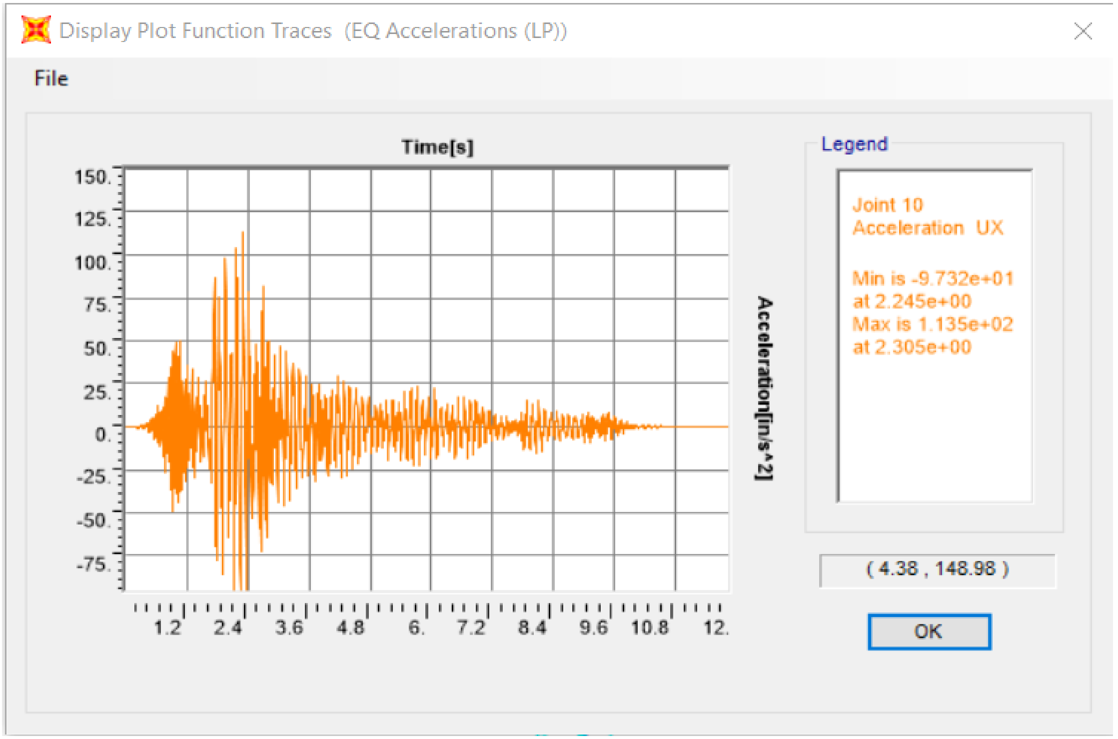
ATH of Imperial Valley 1979, as actual ATH (accessed from http://ngawest2.berkeley.edu/,27 July 2015).

SAP2000 – WITHOUT DAMPERS DISPLACEMENT AND ACCELERATION FIRST FLOOR (LOMA PRIETA)

- Displacement [in]

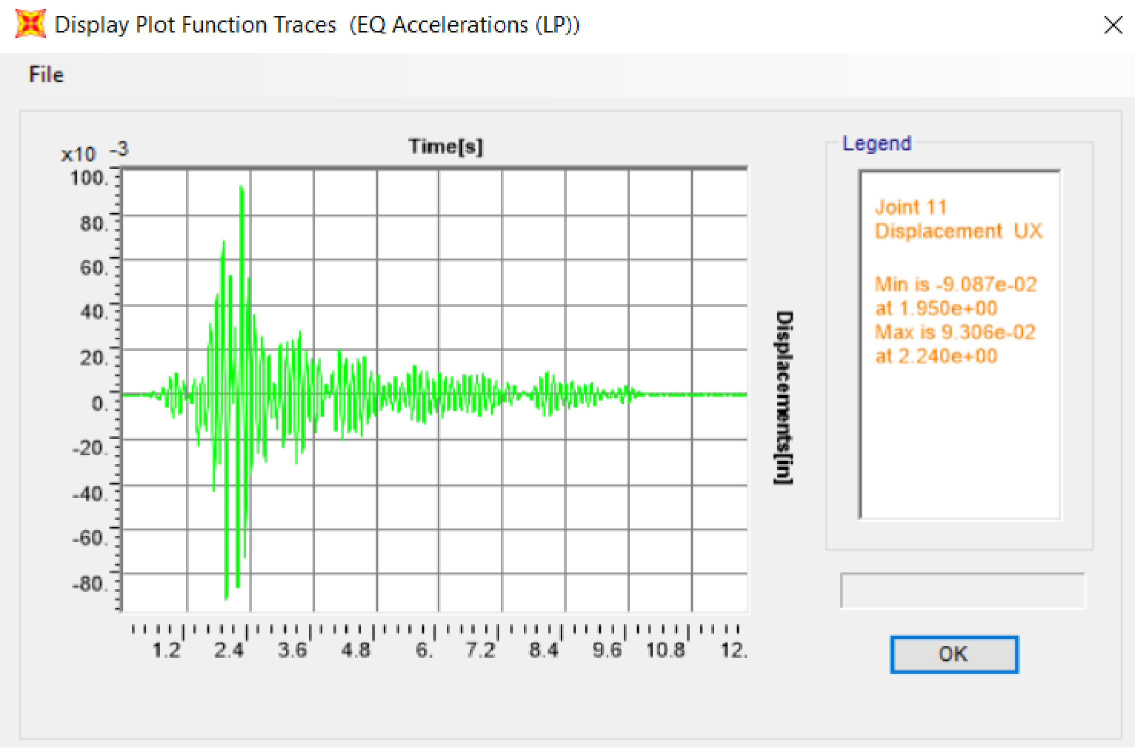


- Acceleration [in/s^2]

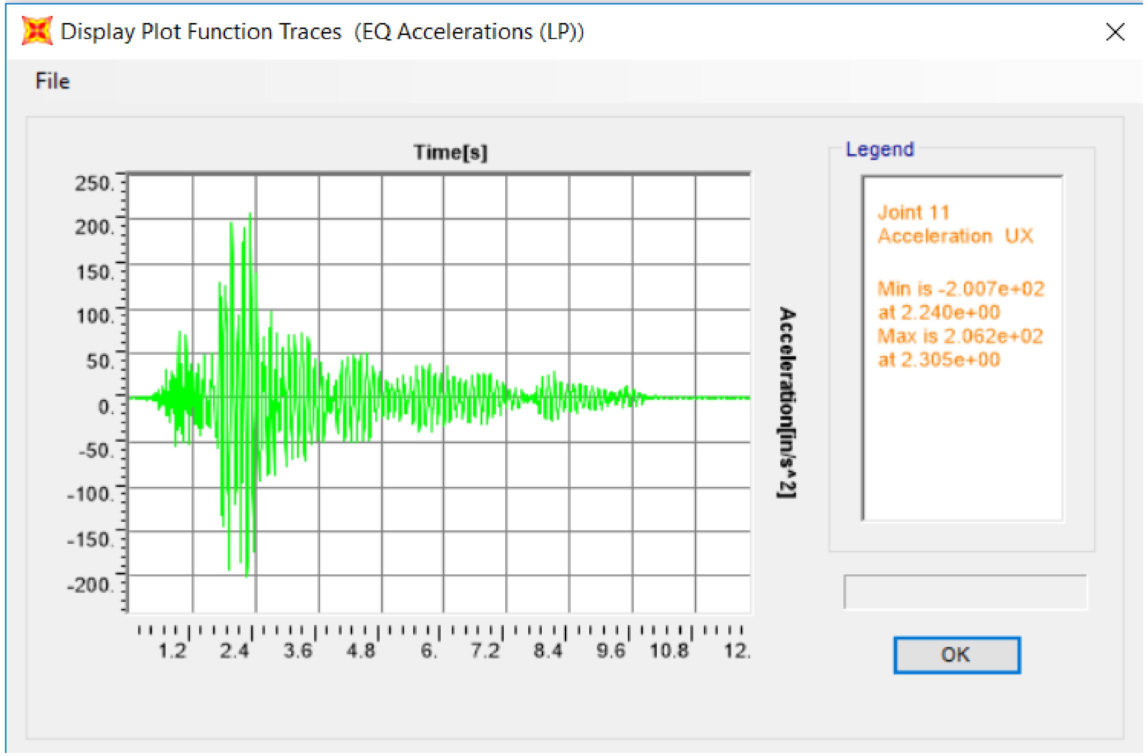


SAP2000 – WITHOUT DAMPERS DISPLACEMENT AND ACCELERATION SECOND FLOOR

- Displacement [in]

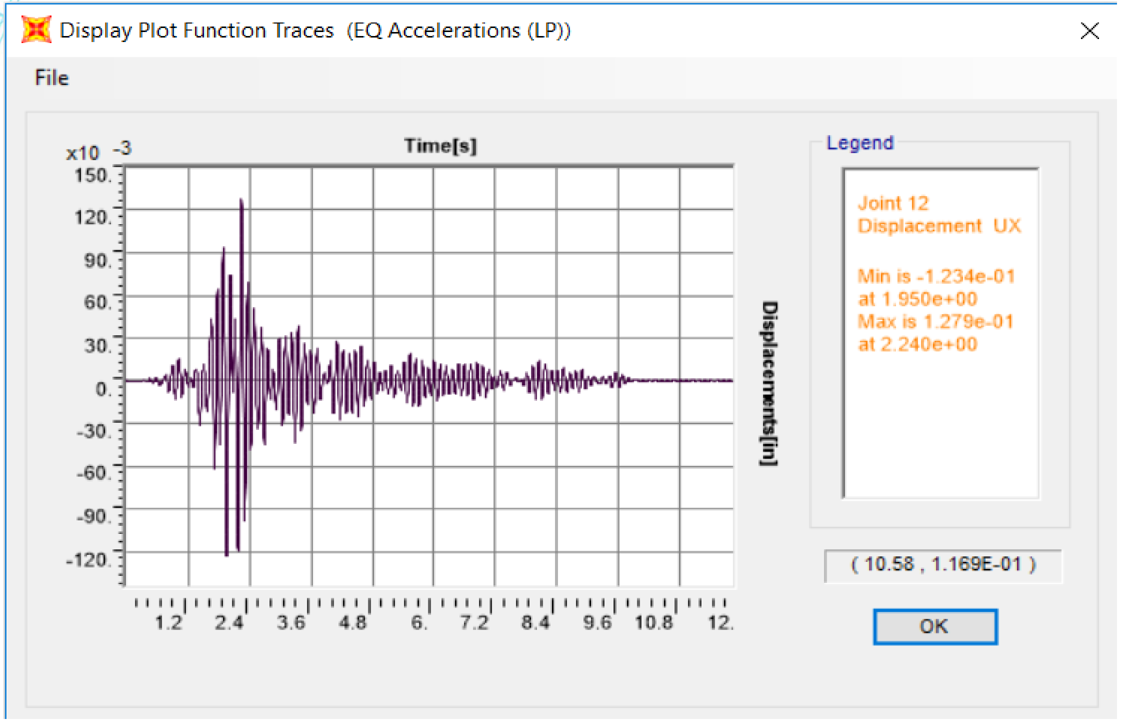


- Acceleration [in/s^2]

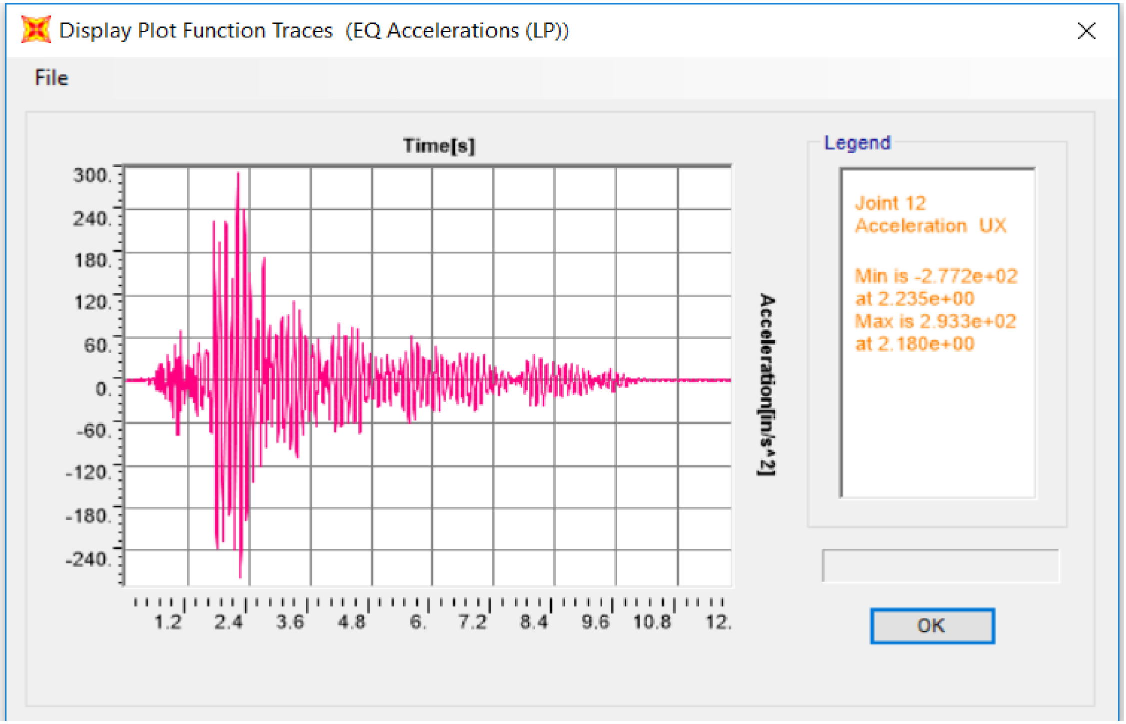


SAP2000 – WITHOUT DAMPERS DISPLACEMENT AND ACCELERATION THIRD FLOOR

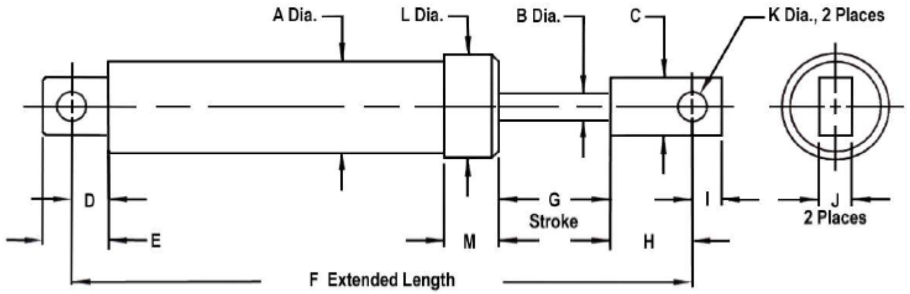
- Displacement [in]



- Acceleration [in/s^2]



DAMPERS CONFIGURATIONS



Model	Damping Force	A	B	C	D	E	F	G	H	I	J	K	L	M
1 x 2 D	450 lbs. max	1.00	.28	.75	.38	.63	8.25	2	.62	.38	.44	.25	1.10	.35
1 x 4 D	450 lbs. max	1.00	.28	.75	.38	.63	12.50	4	.62	.38	.44	.25	1.10	.35
1 x 6 D	450 lbs. max	1.00	.28	.75	.38	.63	16.75	6	.62	.38	.44	.25	1.10	.35
1.5 x 2 D	2000 lbs. max	1.50	.44	1.00	.62	1.12	9.75	2	1.40	.50	.56	.50	1.73	.93
1.5 x 4 D	2000 lbs. max	1.50	.44	1.00	.62	1.12	14.80	4	1.40	.50	.56	.50	1.73	.93
1.5 x 6 D	2000 lbs. max	1.50	.44	1.00	.62	1.12	19.85	6	1.40	.50	.56	.50	1.73	.93
1.5 x 8 D	2000 lbs. max	1.50	.44	1.00	.62	1.12	24.90	8	1.40	.50	.56	.50	1.73	.93

1. A modern, monotube hydraulic damper with internal construction similar to the M-Series Fluidicshoks.
2. A true linear damping system using a fluidic amplifier that applies a damping force in direct proportion to velocity input.
3. Output is continuously compensated for temperature ranges of -40 degrees F to +160 degrees F.
4. Damping force does not vary with stroke position.
5. Solid stainless steel piston rod, corrosion protected steel cylinder.
6. Ideal for high speed machinery and robotic applications.
7. Choice of damping directions:

   ALL MODELS:

   C = Compression damping, free extension
   T = Tension damping, free compression
   TC = Double acting damping

   VELOCITY RANGE:

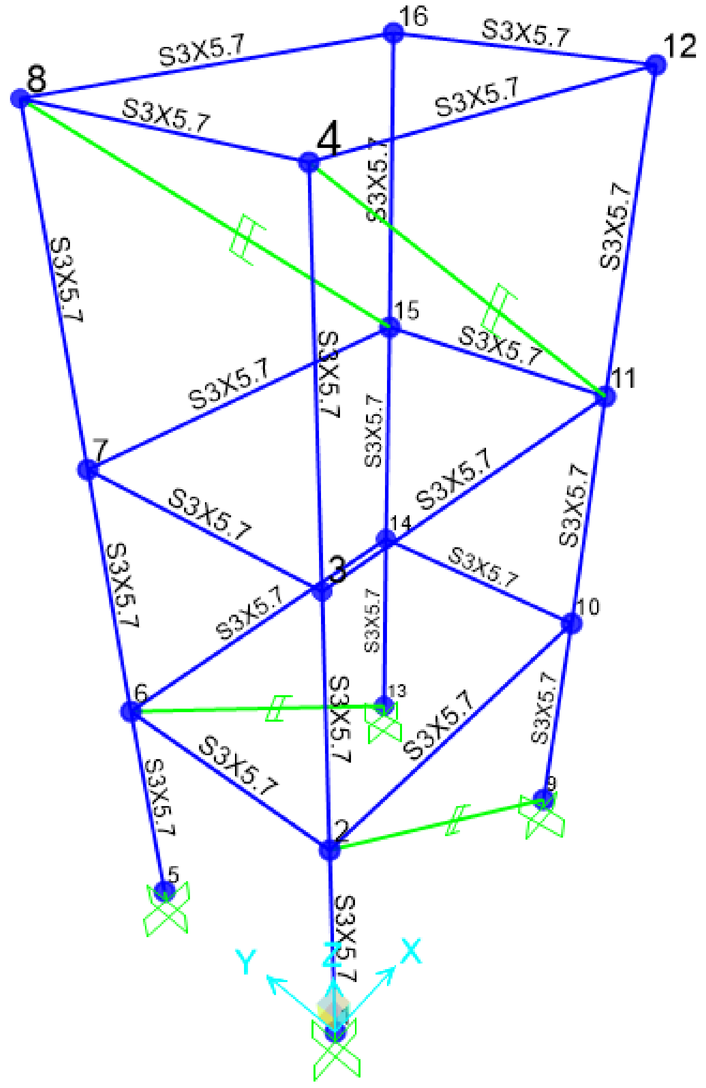
   Any desired damping force up to the maximum listed can be set at any specified velocity between 1 in/sec. and 200 in/sec.

8. ORDERING NOTES:

   Specify: Model, damping type letter code, maximum damping force at maximum damping velocity.
   Example: Model 1 x 2 D, damping code C, 250 lb. at 30 in/sec.

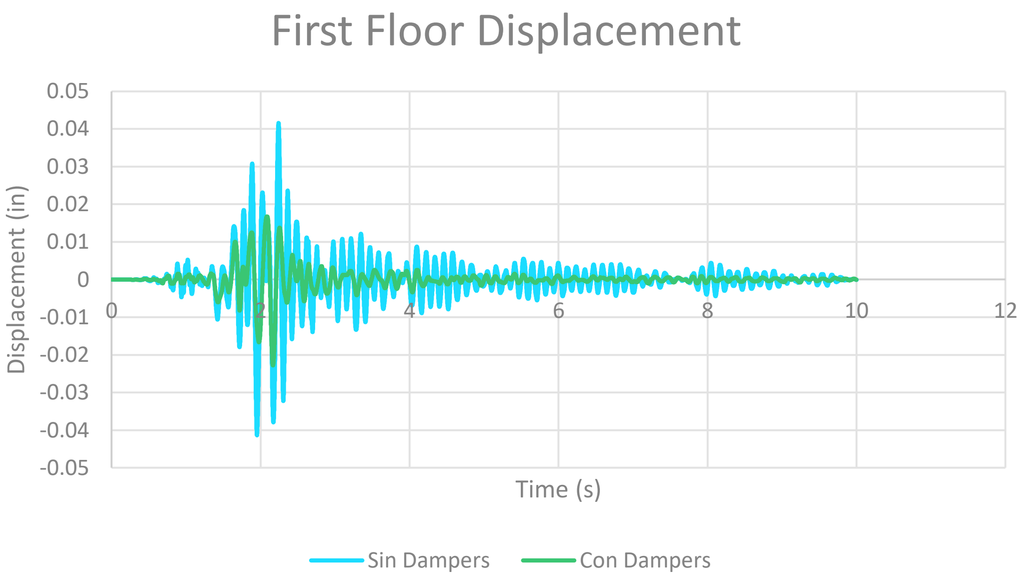
SAP2000 RESULTS FOR CONFIGURATION #1

- Damping of dampers: 0.45 kip*s/in
- Natural frequency of Structure: 8.28209 Hz
- Period of Structure: 0.12 s



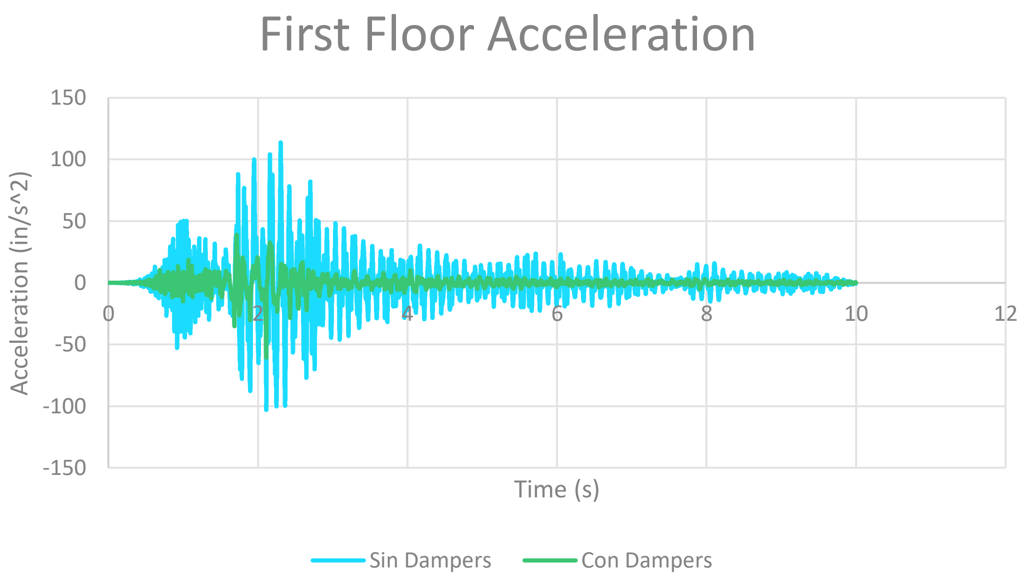
SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION FIRST FLOOR

- Displacement [in]



Without dampers: 0.04158 in
With dampers: 0.01677 in
Difference: 59.67%

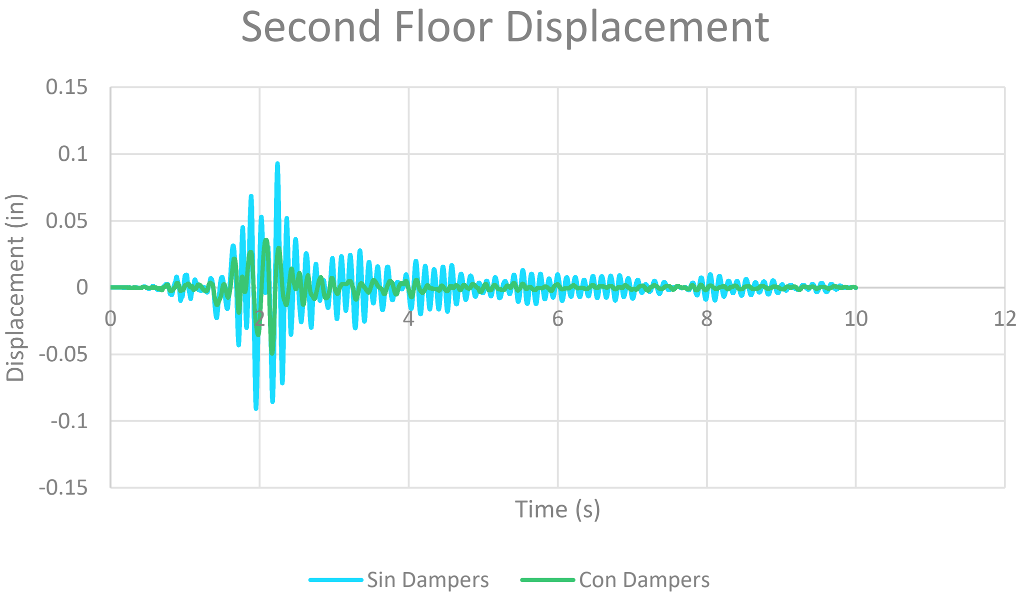
- Acceleration [in/s^2]



Without dampers: 113.85 in/s^2
With dampers: 39.01 in/s^2
Difference: 65.73%

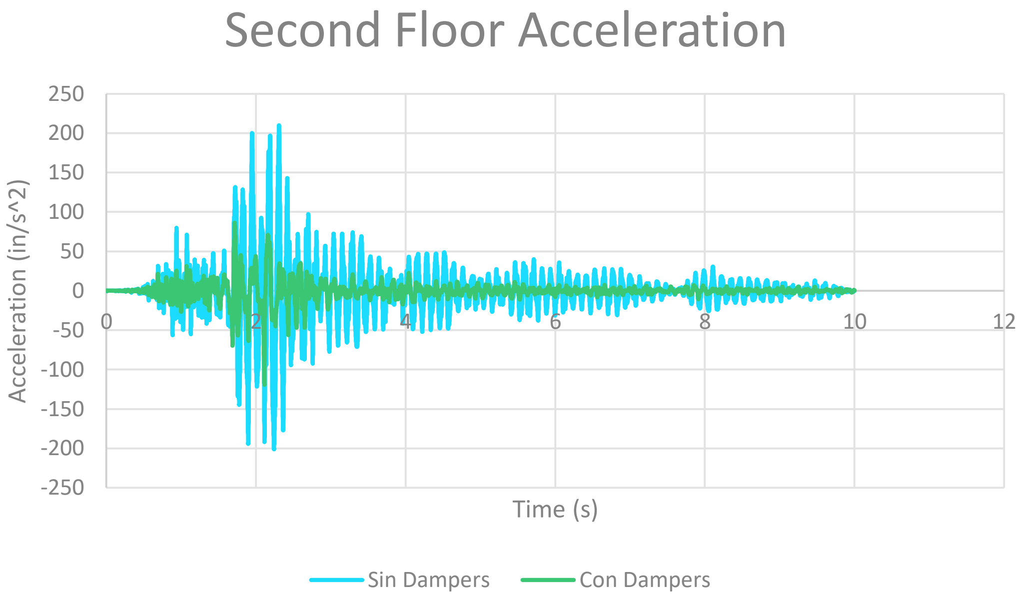
SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION SECOND FLOOR

- Displacement [in]



Without dampers: 0.09307 in
With dampers: 0.03579 in
Difference: 61.55%

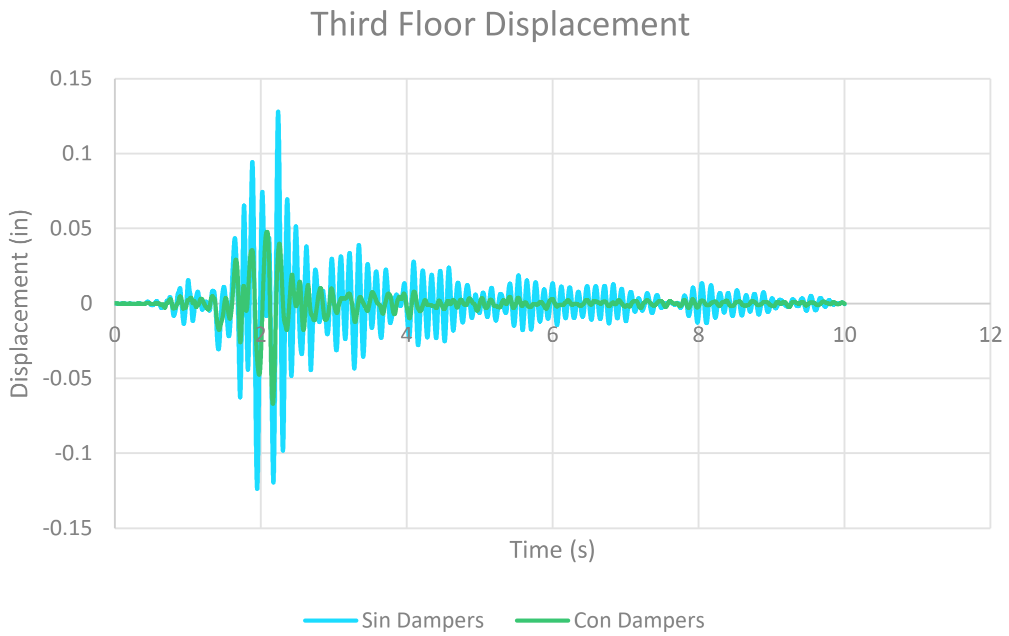
- Acceleration [in/s^2]



Without dampers: 210.05 in/s^2
With dampers: 86.21 in/s^2
Difference: 58.96%

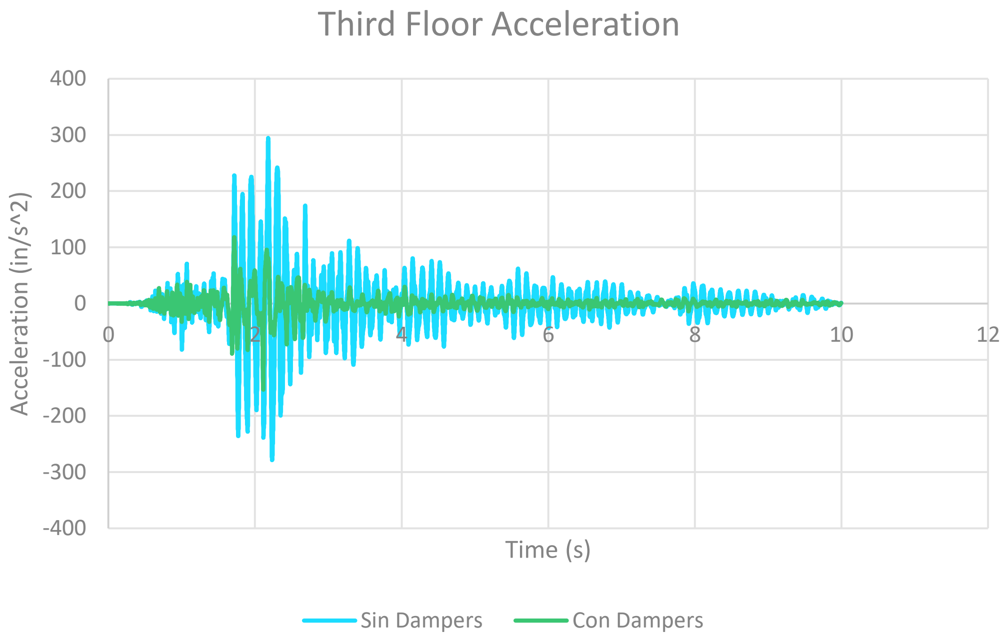
SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION THIRD FLOOR

- Displacement [in]



Without dampers: 0.12804 in
With dampers: 0.04794 in
Difference: 62.56%

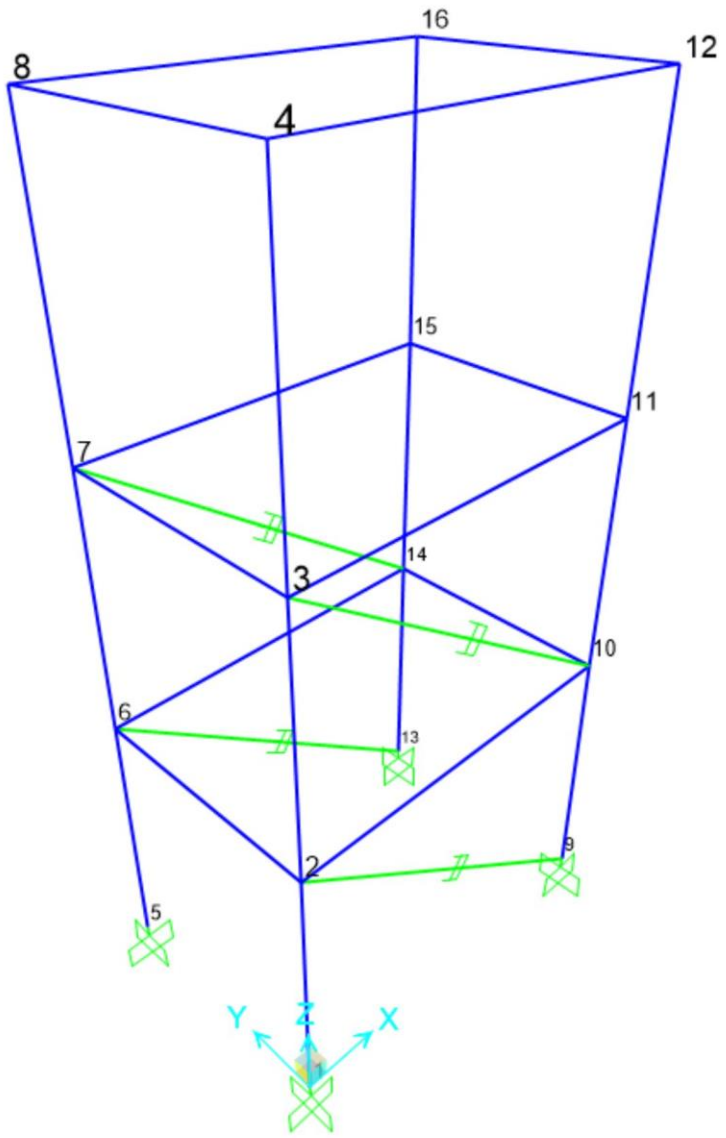
- Acceleration [in/s^2]



Without dampers: 294.09 in/s^2
With dampers: 117.74 in/s^2
Difference: 59.96%

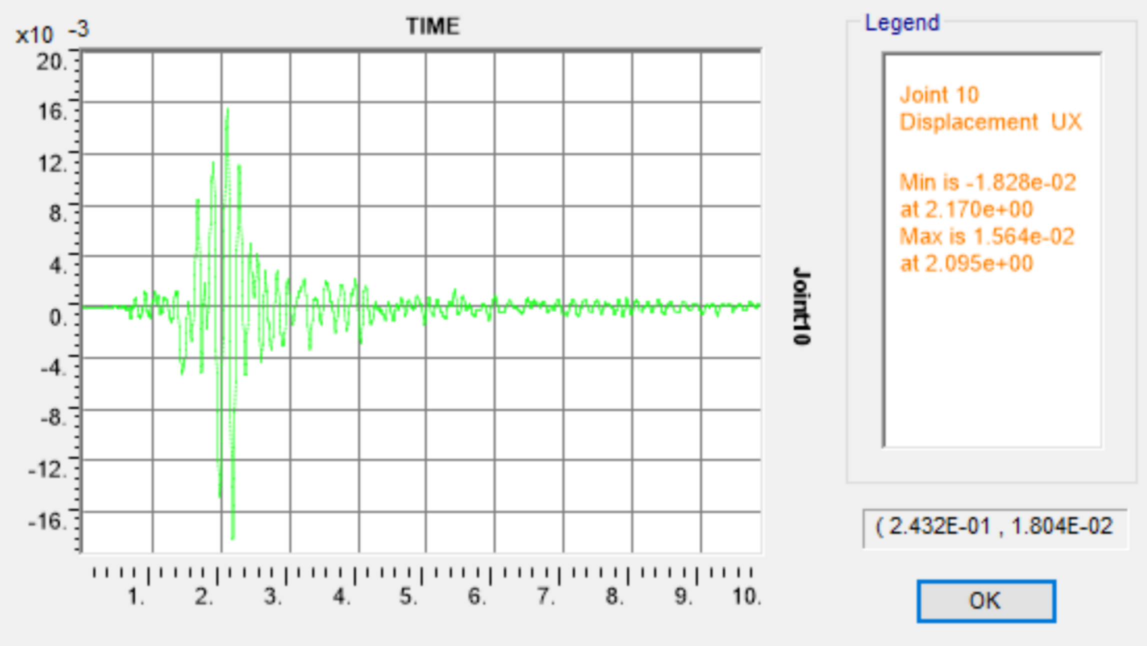
SAP2000 RESULTS FOR CONFIGURATION #2

- Effective damping of each dampers: 0.45 kip*s/in
- Natural frequency of Structure: 8.28209 Hz
- Period of Structure: 0.12 s

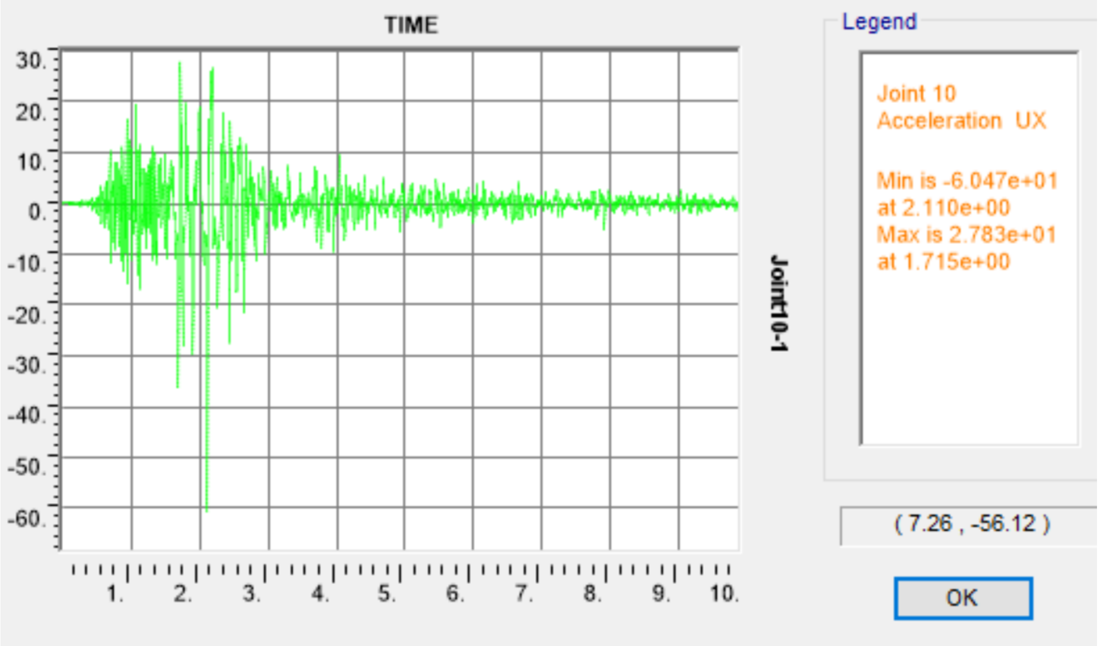


SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION FIRST FLOOR

- Displacement [in]

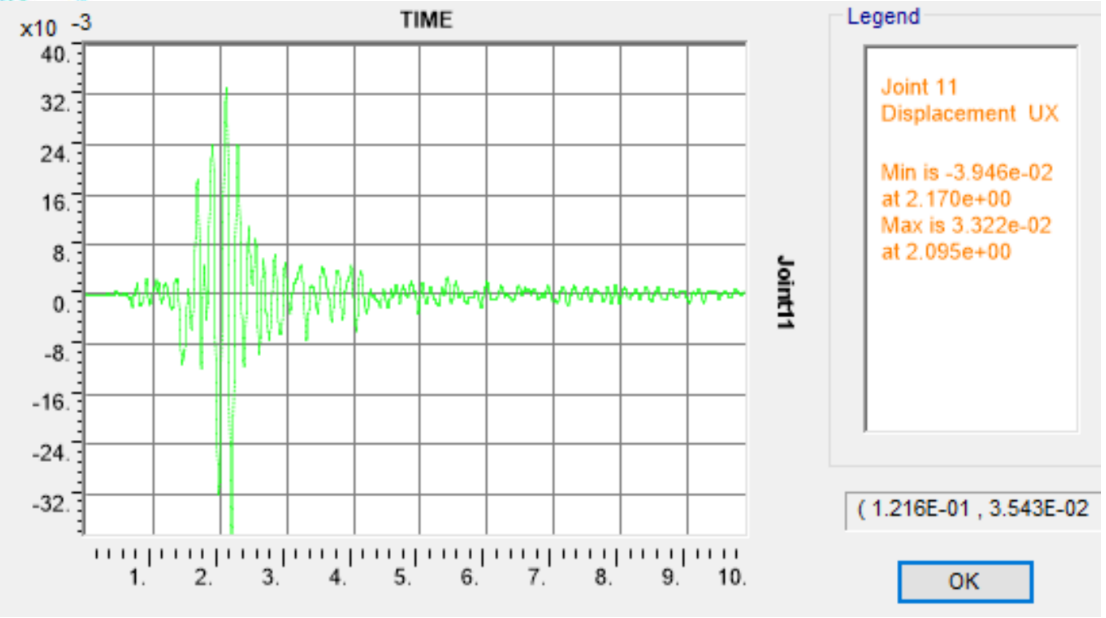


- Acceleration [in/s^2]

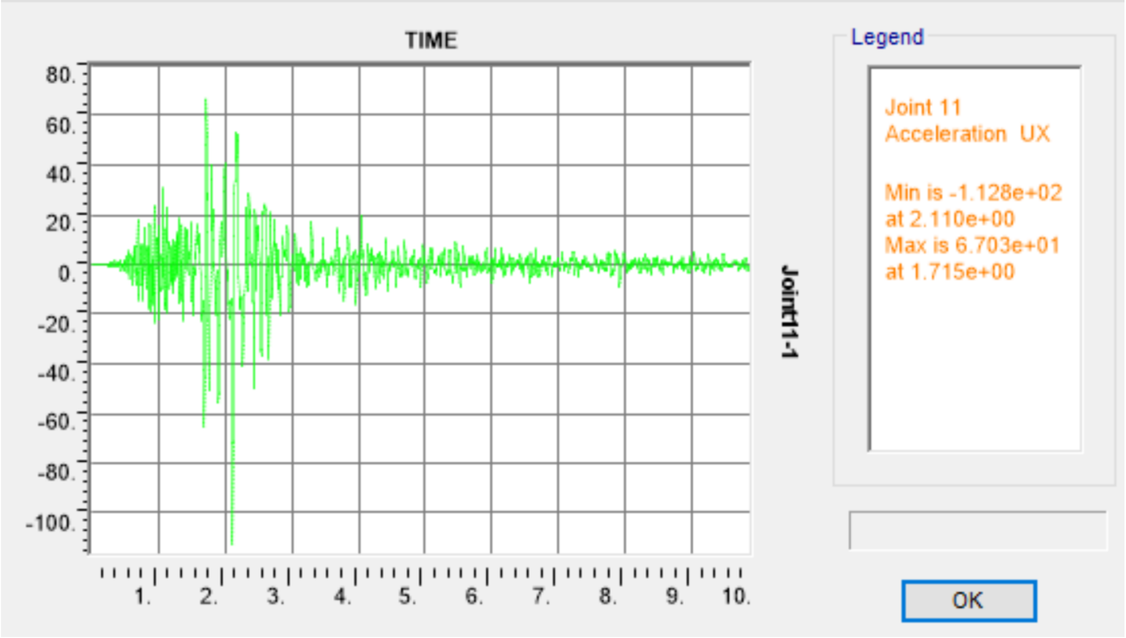


SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION SECOND FLOOR

- Displacement [in]

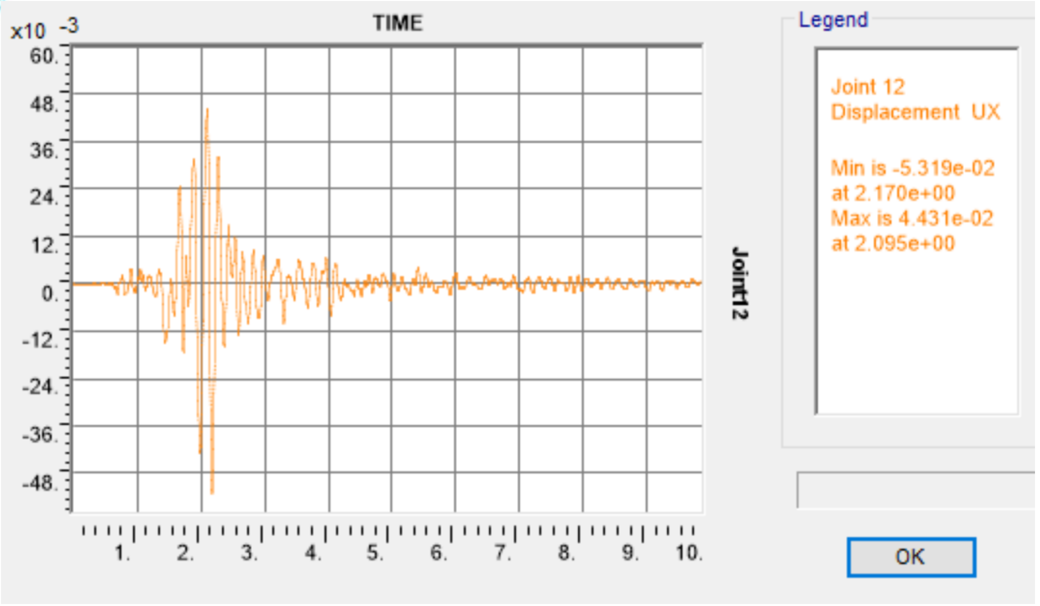


- Acceleration [in/s^2]

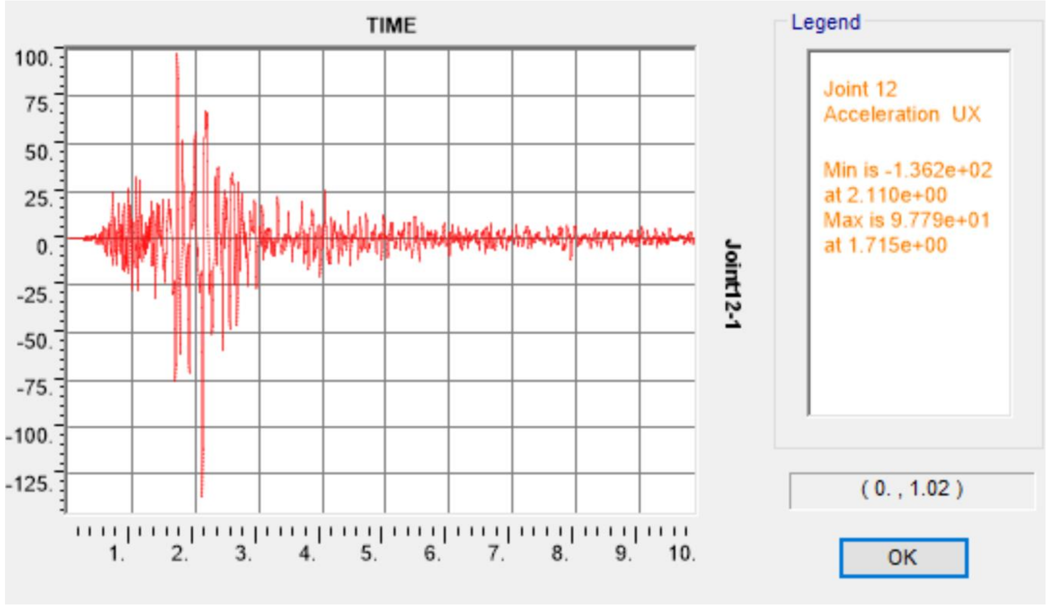


SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION THIRD FLOOR

- Displacement [in]



- Acceleration [in/s^2]

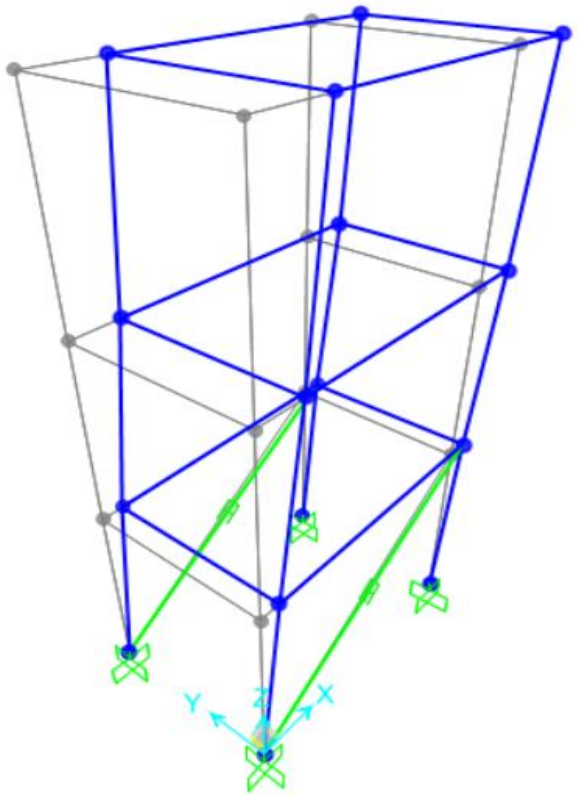


SUMMARY OF RESULTS

	SAP2000 Results Modal Loma Prieta									
	Displacement 1st Level (in)	Displacement 2nd Level (in)	Displacement 3rd Level (in)	Acceleration 1st Level (in/s^2)	Acceleration 1st Level (g)	Acceleration 2nd Level (in/s^2)	Acceleration 2nd Level (g)	Acceleration 3rd Level (in/s^2)	Acceleration 3rd Level (g)	**Max Acceleration (g)**
Without Dampers	0.042	0.093	0.128	113.500	0.294	206.200	0.534	293.300	0.759	0.759
With Dampers	0.018	0.039	0.053	60.470	0.156	67.030	0.173	97.790	0.253	0.253
%Reduction	56.02	57.60	58.41	46.72	46.72	67.49	67.49	66.66	66.66	66.66

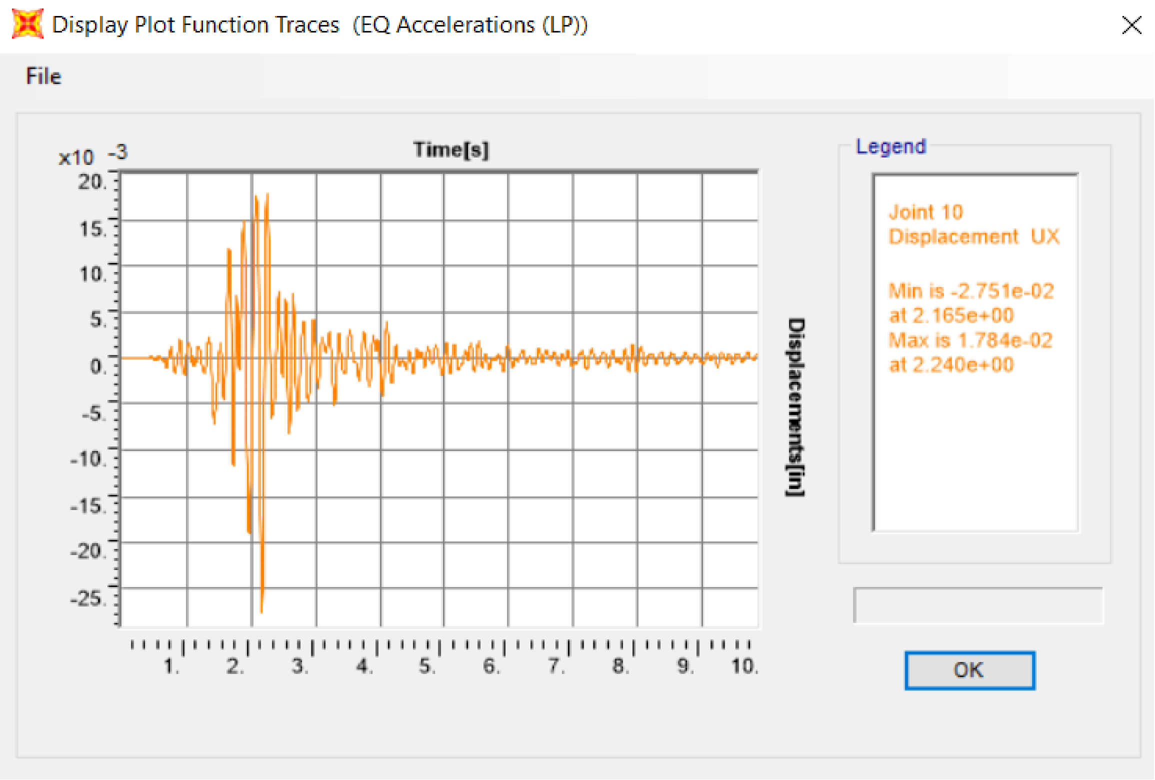
SAP2000 RESULTS FOR CONFIGURATION #3

- Damping of dampers: 0.45 kip*s/in
- Natural frequency of Structure: 8.28209 Hz
- Period of Structure: 0.12 s

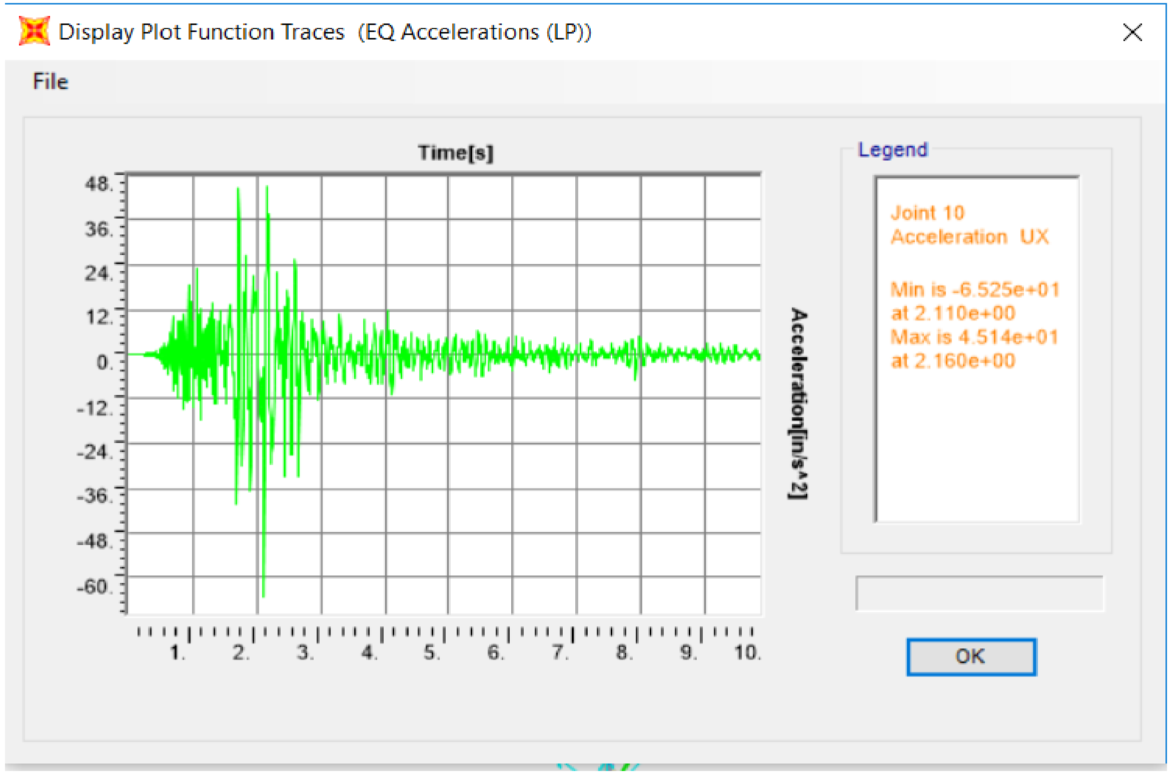


SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION FIRST FLOOR

- Displacement [in]

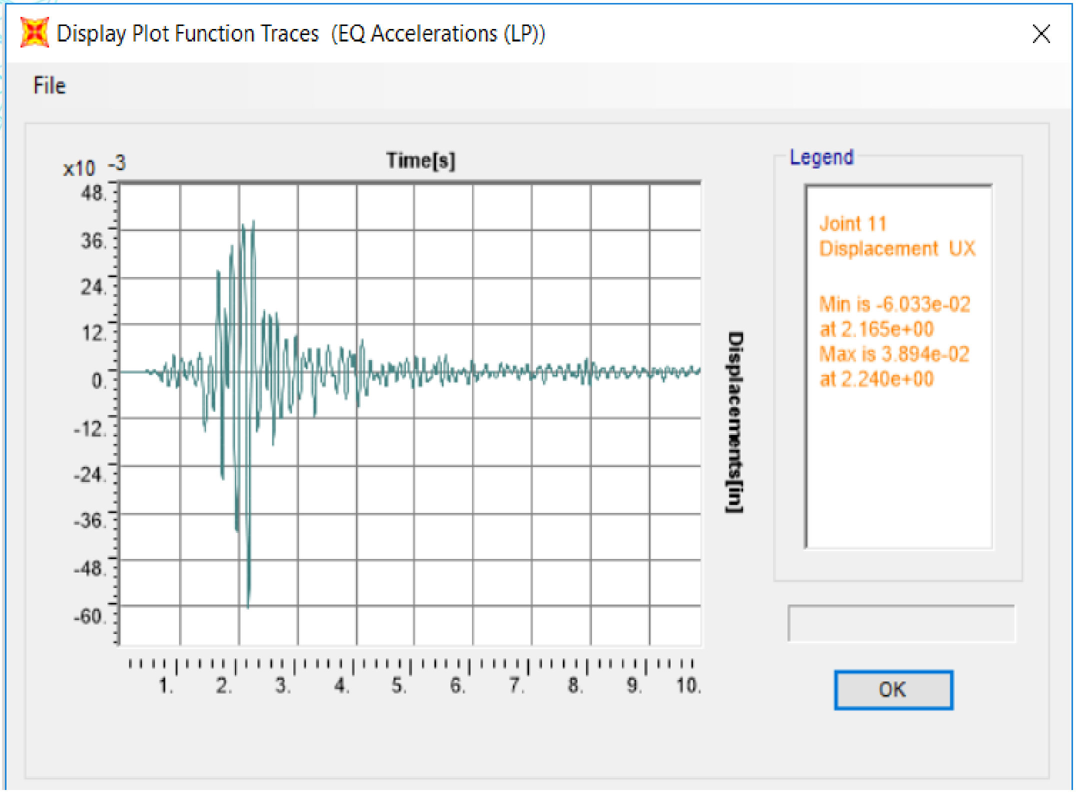


- Acceleration [in/s^2]

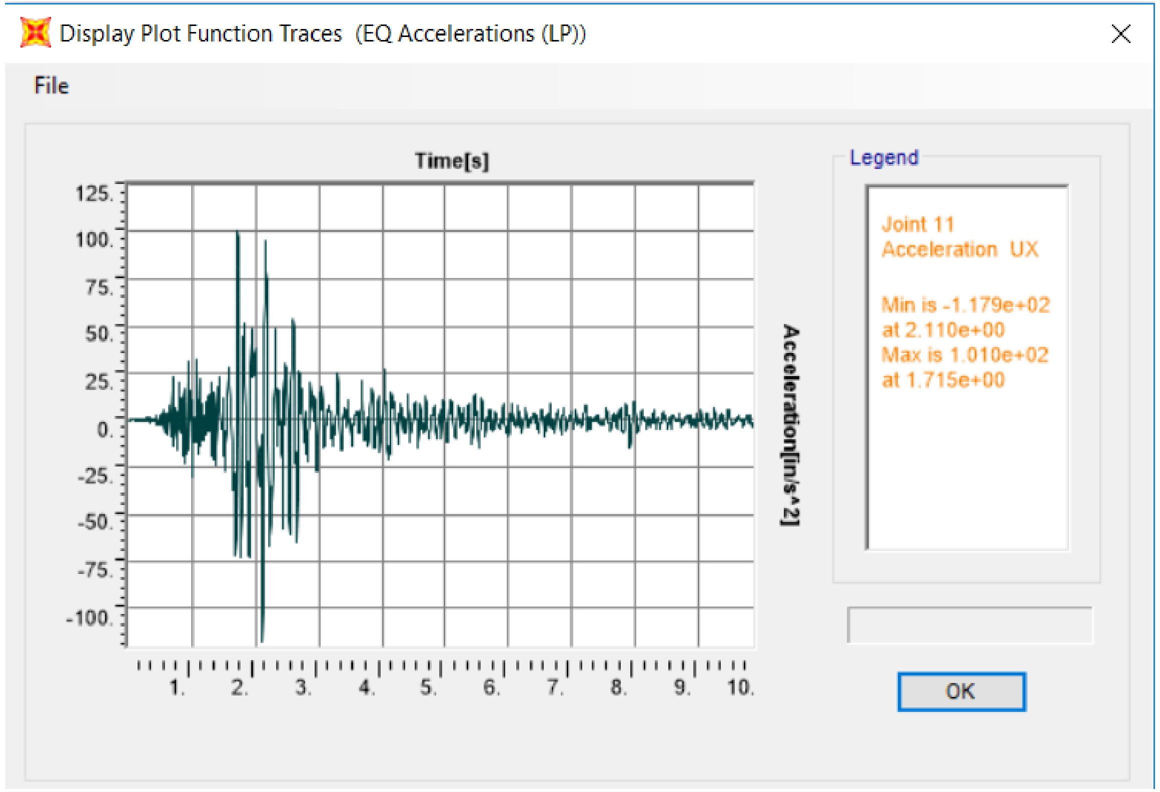


SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION SECOND FLOOR

- Displacement [in]

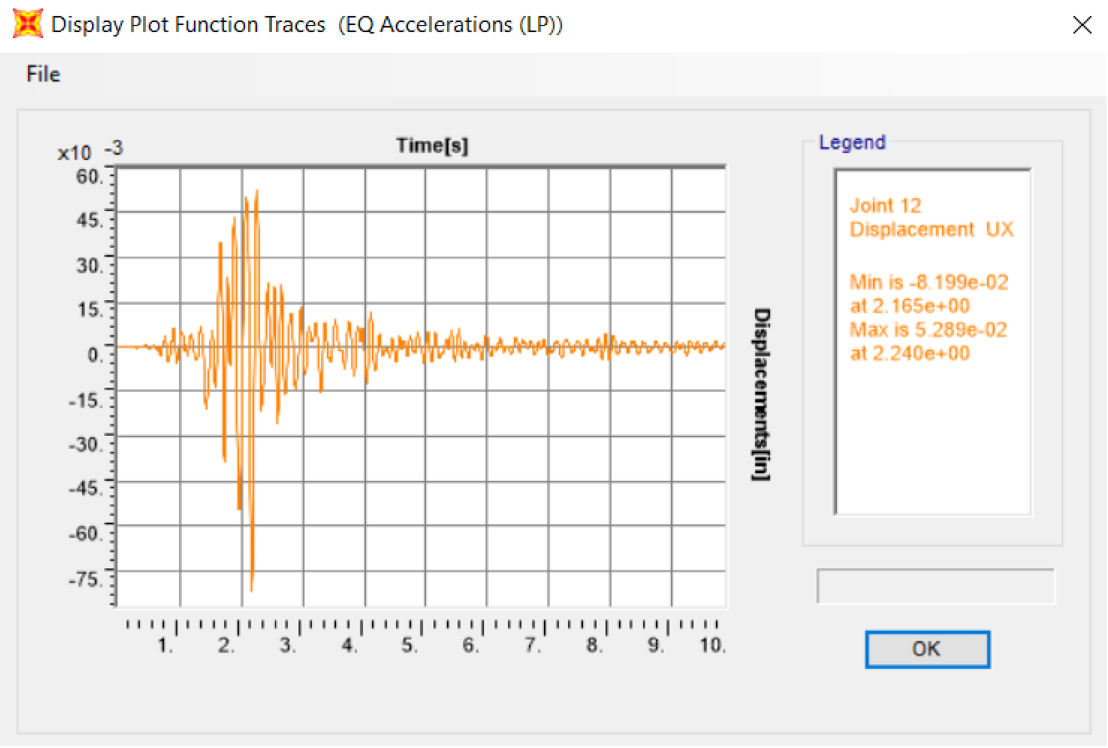


- Acceleration [in/s^2]

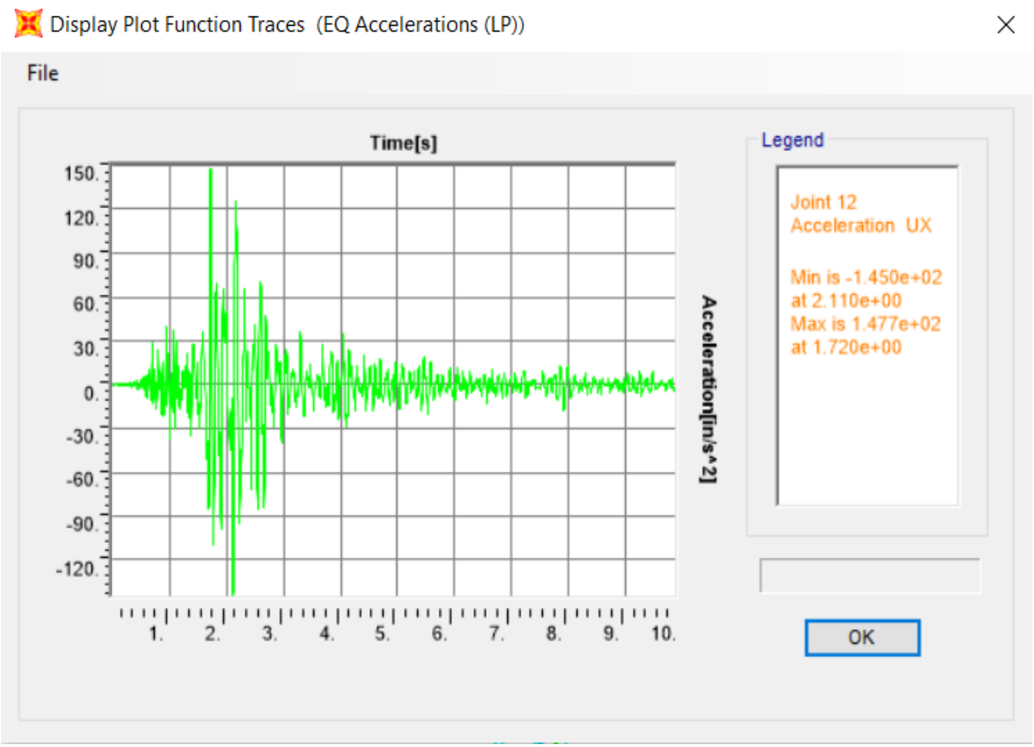


SAP2000 – WITH DAMPERS DISPLACEMENT AND ACCELERATION THIRD FLOOR

- Displacement [in]



- Acceleration [in/s^2]



SUMMARY OF RESULTS

	SAP2000 Results Model Loma Prieta						
	Displacement 1st level(in)	Displacement 2nd level(in)	Displacement 3rd level(in)	Acceleration 1st level(in/s^2)	Acceleration 2nd level(in/s^2)	Acceleration 3rd level(in/s^2)	Max Acc(g)
Without Dampers	0.04156	0.09306	0.1279	113.5	206.2	293.3	0.759058
With Dampers	0.02751	0.0633	0.08199	65.25	117.9	147.7	
%Reduction	34%	32%	36%	43%	43%	50%	
	SAP2000 Results Prototype Loma Prieta						
Without Dampers	0.7448	1.943	2.873	202.7	453.1	599.2	

	SAP2000 Results Model El Centro						
	Displacement 1st level(in)	Displacement 2nd level(in)	Displacement 3rd level(in)	Acceleration 1st level(in/s^2)	Acceleration 2nd level(in/s^2)	Acceleration 3rd level(in/s^2)	Max Acc(g)
Without Dampers	0.06589	0.1511	0.2105	210.5	415.8	564	1.4596273
With Dampers	0.02308	0.05035	0.06878	74.97	183.2	218.1	
%Reduction	65%	67%	67%	64%	56%	61%	
	SAP2000 Results Prototype El Centro						
Without Dampers	0.8238	2.032	3.061	401.4	570.5	761	

PERFORMANCE BASED DESIGN – NONSTRUCTURAL COMPONENTS

Figure 1. Test fixture mounted on the simulator at the University at Buffalo.

PERFORMANCE BASED DESIGN – NONSTRUCTURAL COMPONENTS

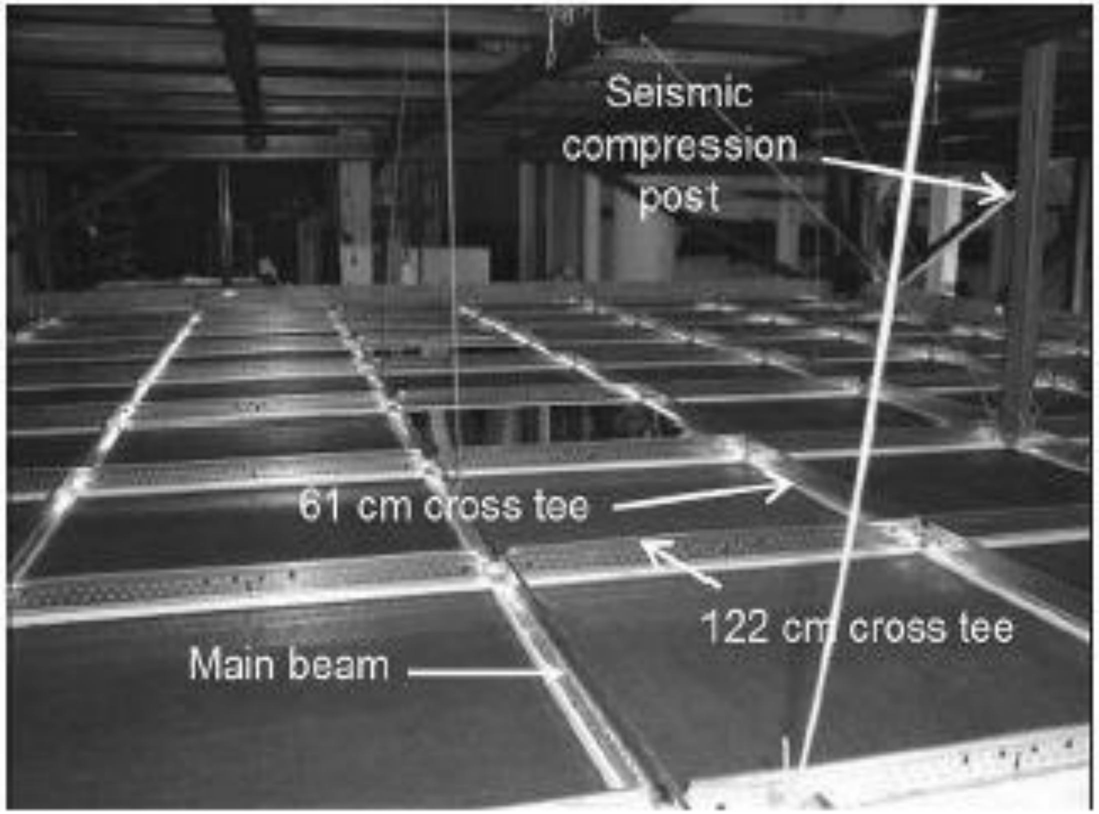


Figure 2. Suspension grid components.

PERFORMANCE BASED DESIGN – NONSTRUCTURAL COMPONENTS

SIMULATOR TESTING OF SUSPENDED CEILING SYSTEMS

Four variables that affect the seismic performance of suspended ceiling systems were investigated herein: size and weight of tiles, use of retainer clips, installation of compression posts, and physical condition of grid components. Six ceiling system configurations were tested:

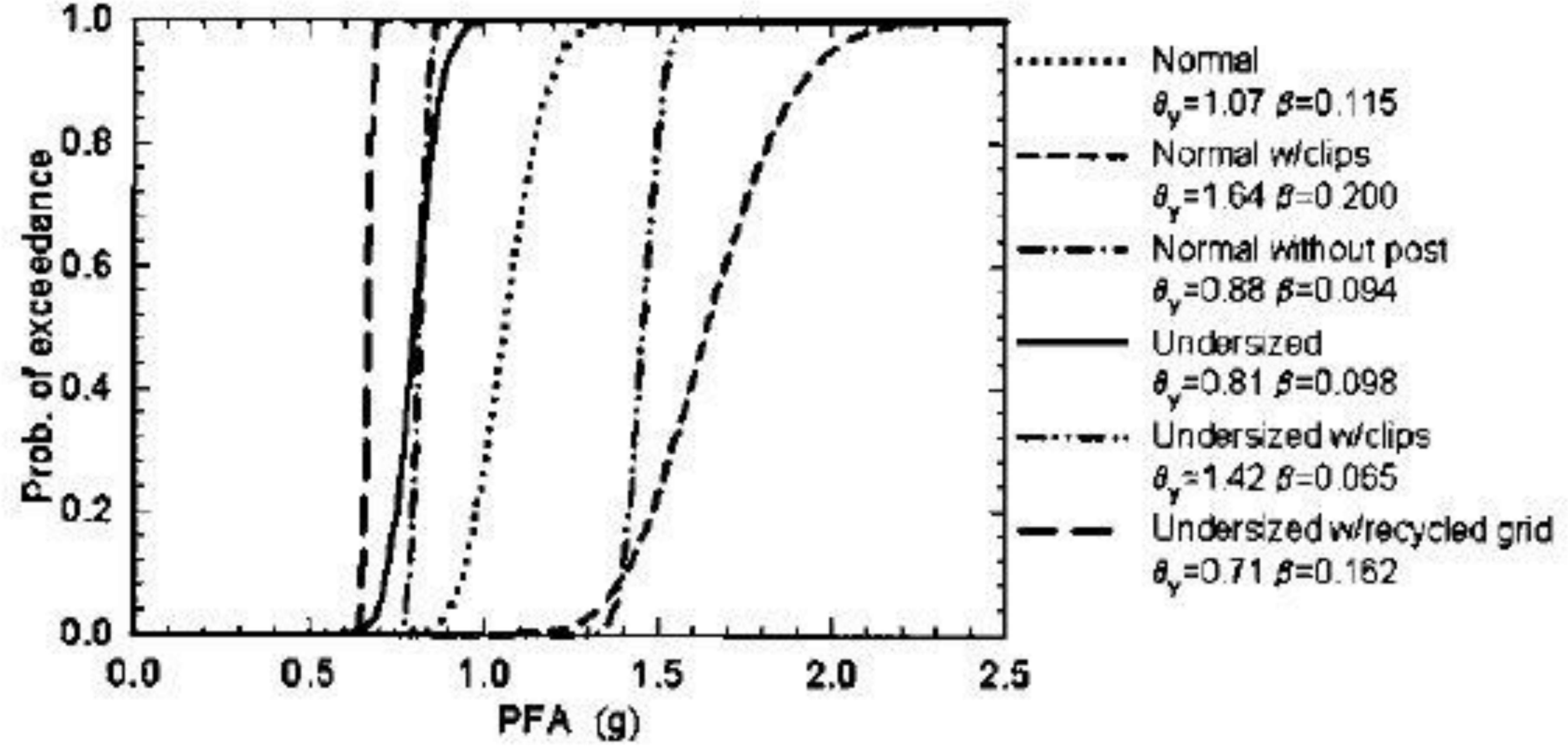
1. undersized tiles (4 systems)
2. undersized tiles with retainer clips (3 systems)
3. undersized tiles with recycled grid components (3 systems)
4. normal-sized tiles (6 systems)
5. normal-sized tiles with retainer clips (4 systems)
6. normal-sized tiles without the compression post (6 systems)

All tiles, connections, anchors, hanging wires, and splay wires were examined after each test. All damaged ceiling components (e.g., broken latches of cross tees, chipped tiles, etc.) were replaced prior to the following test. After each test cycle, the ceiling system (tiles and grid) was disassembled and then reassembled to return the ceiling system to a newly installed condition.

PERFORMANCE BASED DESIGN – NONSTRUCTURAL COMPONENTS

Figure 9. Failure of grid and tiles in configuration 5.

PERFORMANCE BASED DESIGN – NONSTRUCTURAL COMPONENTS



(a) Fragility curves for peak floor acceleration

PERFORMANCE BASED DESIGN – NONSTRUCTURAL COMPONENTS

Table 4. Observed threshold peak floor accelerations[1] for damage in ceiling systems

		Threshold peak floor acceleration (g)			
Ceiling system	Configuration	Minor damage	Moderate damage	Major damage	Grid failure
Undersized tiles	1	0.70	0.90	1.05	1.25
Undersized tiles with clips	2	1.25	NR[2]	NR[2]	1.10
Normal-sized tiles	4	0.85	1.05	1.60	1.25
Normal-sized tiles with clips	5	1.0	1.60	1.60	1.05
Normal-sized tiles w/out compression post	6	0.60	1.00	1.35	1.00

[1] Values rounded down to nearest 0.05 g

[2] Damage state not reached in testing program; >1.25 g

INPUT PARAMETERS FOR RESPONSE EVALUATION USING MATLAB EXTENDED MODAL ANALISIS– NO DAMPER CONFIGURATION

Configuration #2			
Items	Story 1	Story 2	Story 3
Gravity (in/s^2)	386.4	386.4	386.4
Weight (kip)	0.7883	0.7868	0.7533
K (stiffness, kip/in)	36.153	39.726	36.528
Height (in)	36.375	35.25	36.25
Length (in)	51.1875	51.1875	51.1875
Z (damping)	0.02	0.02	0.02
C (damping coefficient)	0	0	0
Degrees of Freedom	3	3	3
Time Step (scaled, s)	0.001	0.001	0.001

RESPONSE USING MATLAB (EXTENDED MODAL ANALISIS) NO DAMPER CONFIGURATION

Configuration #1 Results for 1st, 2nd, and 3rd Story			
Items	Story 1	Story 2	Story 3
PGA (g)	0.27	0.27	0.27
Natural Frequencies (rad/s)	60.981	168.72	247.37
Natural Period (s)	0.10303	0.037241	0.0254
Damping Ratio	0.0020	0.0020	0.0020
Max. Relative Displacement to Base (in)	0.038777	0.065466	0.080356
Max Relative Displacement	0.031609	0.021762	0.012231
Max Damping Force	0	0	0

INPUT PARAMETERS FOR RESPONSE EVALUATION IN MATLAB CONFIGURATION #1

Configuration #3			
Items	Story 1	Story 2	Story 3
Gravity (in/s^2)	386.4	386.4	386.4
Weight (kip)	0.7883	0.7868	0.7533
K (stiffness, kip/in)	36.153	39.726	36.528
Height (in)	36.375	35.25	36.25
Length (in)	51.1875	51.1875	51.1875
Z (damping)	0.02	0.02	0.02
C (damping coefficient)	0.9	0	0.9
Degrees of Freedom	3	3	3
Time Step (scaled,s)	0.001	0.001	0.001

RESPONSE FOR MATLAB (EXTENDED MODAL ANALISIS) CONFIGURATION #1

Configuration #1 Results for 1st, 2nd, and 3rd Story			
Items	Story 1	Story 2	Story 3
PGA (g)	0.27	0.27	0.27
Natural Frequencies (rad/s)	60.981	168.72	247.37
Natural Period (s)	0.10303	0.037241	0.0254
Damping Ratio	1.0000	1.0000	1.0000
Max. Relative Displacement to Base (in)	0.021365	0.036392	0.043783
Max Relative Displacement	0.80909	0.96074	0.33335
Max Damping Force	0.72818	0	0.30001

INPUT PARAMETERS FOR RESPONSE EVALUATION IN MATLAB CONFIGURATION #2

Configuration #2			
Items	Story 1	Story 2	Story 3
Gravity (in/s^2)	386.4	386.4	386.4
Weight (kip)	0.7883	0.7868	0.7533
K (stiffness, kip/in)	36.153	39.726	36.528
Height (in)	36.375	35.25	36.25
Length (in)	51.1875	51.1875	51.1875
Z (damping)	0.02	0.02	0.02
C (damping coefficient)	0.9	0.9	0
Degrees of Freedom	3	3	3
Time Step (scaled,s)	0.001	0.001	0.001

RESPONSE MATLAB (EXTENDED MODAL ANALISIS) CONFIGURATION #2

Configuration #2 Results for 1st, 2nd, and 3rd Story			
Items	Story 1	Story 2	Story 3
PGA (g)	0.27	0.27	0.27
Natural Frequencies (rad/s)	60.981	168.72	247.37
Natural Period (s)	0.10303	0.037241	0.0254
Damping Ratio	0.4811	0.4811	0.4811
Max. Relative Displacement to Base (in)	0.019194	0.031627	0.038542
Max Relative Displacement (in)	0.015646	0.01014	0.0074249
Max Damping Force (kip)	0.63209	0.46243	0

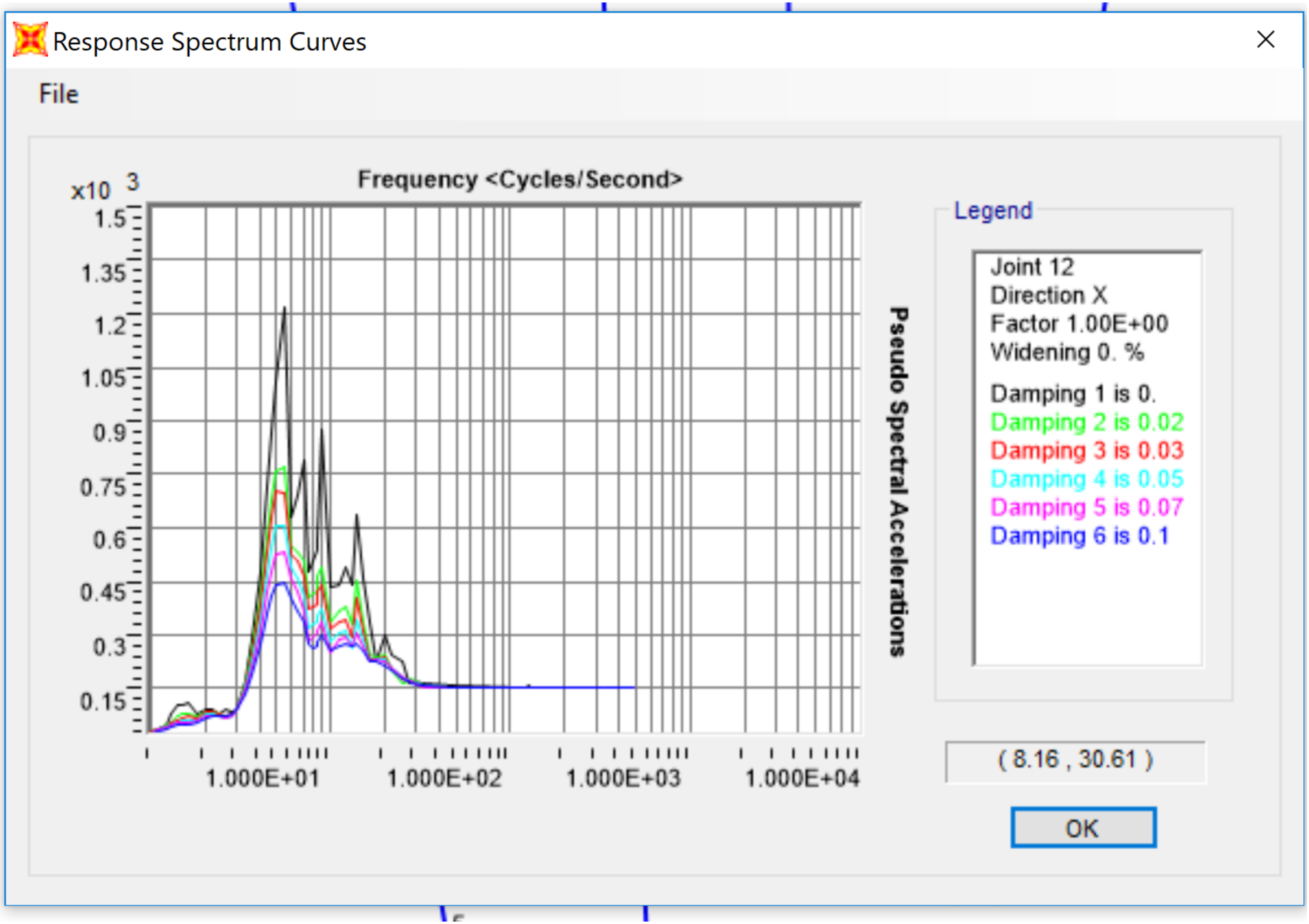
INPUT PARAMETERS FOR RESPONSE EVALUATION FOR MATLAB CONFIGURATION #3

Configuration #2			
Items	Story 1	Story 2	Story 3
Gravity (in/s^2)	386.4	386.4	386.4
Weight (kip)	0.7883	0.7883	0.7883
K (stiffness, kip/in)	36.153	39.726	36.528
Height (in)	36.375	35.25	36.25
Length (in)	51.1875	51.1875	51.1875
Z (damping)	0.02	0.02	0.02
C (damping coefficient)	0.9	0	0
Degrees of Freedom	3	3	3
Time Step (scaled, s)	0.001	0.001	0.001

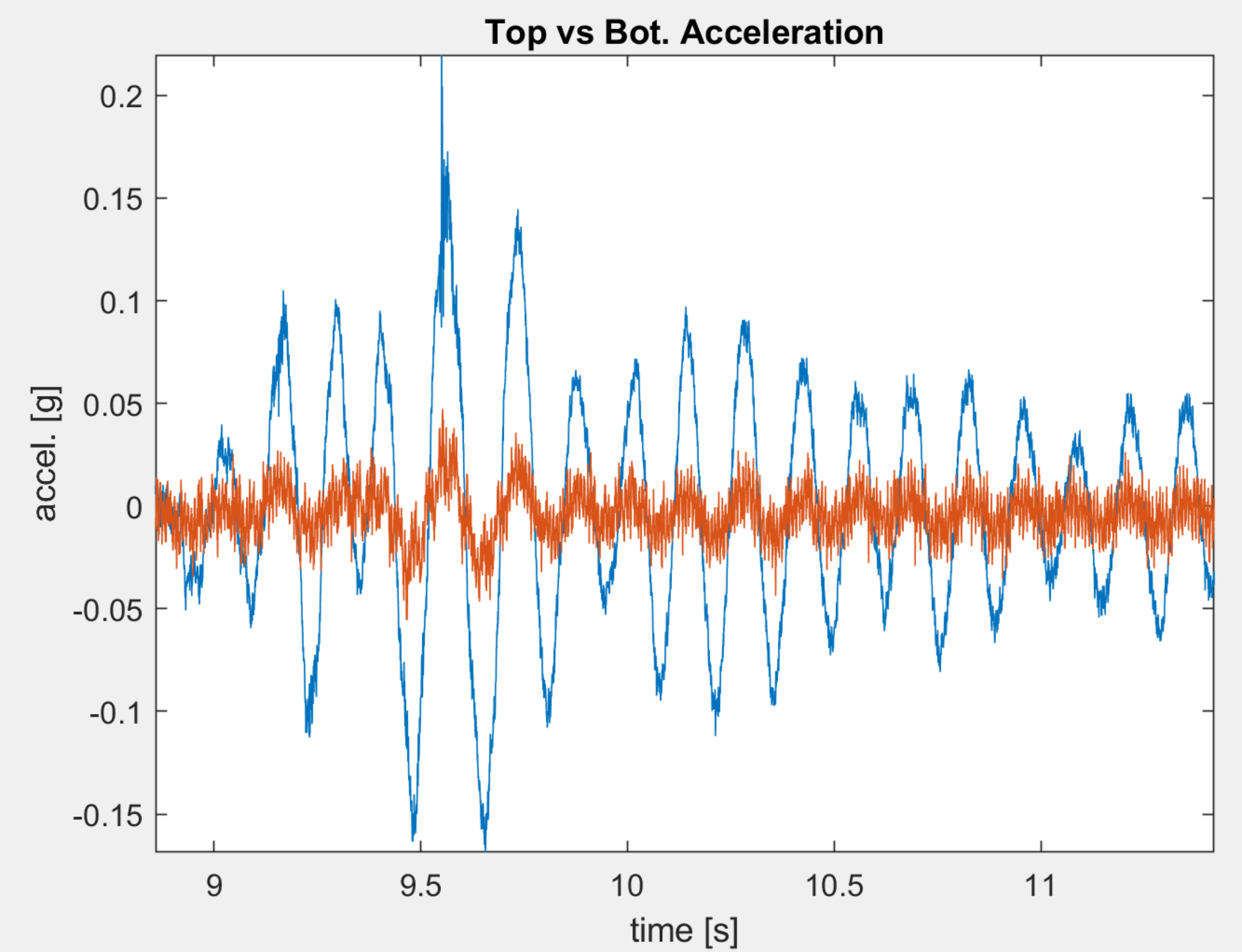
RESPONSE FOR MATLAB (EXTENDED MODAL ANALISIS) CONFIGURATION #3

Configuration #1 Results for 1st, 2nd, and 3rd Story			
Items	Story 1	Story 2	Story 3
PGA (g)	0.27	0.27	0.27
Natural Frequencies (rad/s)	60.981	168.72	247.37
Natural Period (s)	0.10303	0.037241	0.0254
Damping Ratio	0.2554	0.2554	0.2554
Max. Relative Displacement to Base (in)	0.022988	0.039868	0.049721
Max Relative Displacement	0.76984	0.88445	0.67351
Max Damping Force	0.69285	0	0

SAP RESPONSE SPECTRUM CURVES



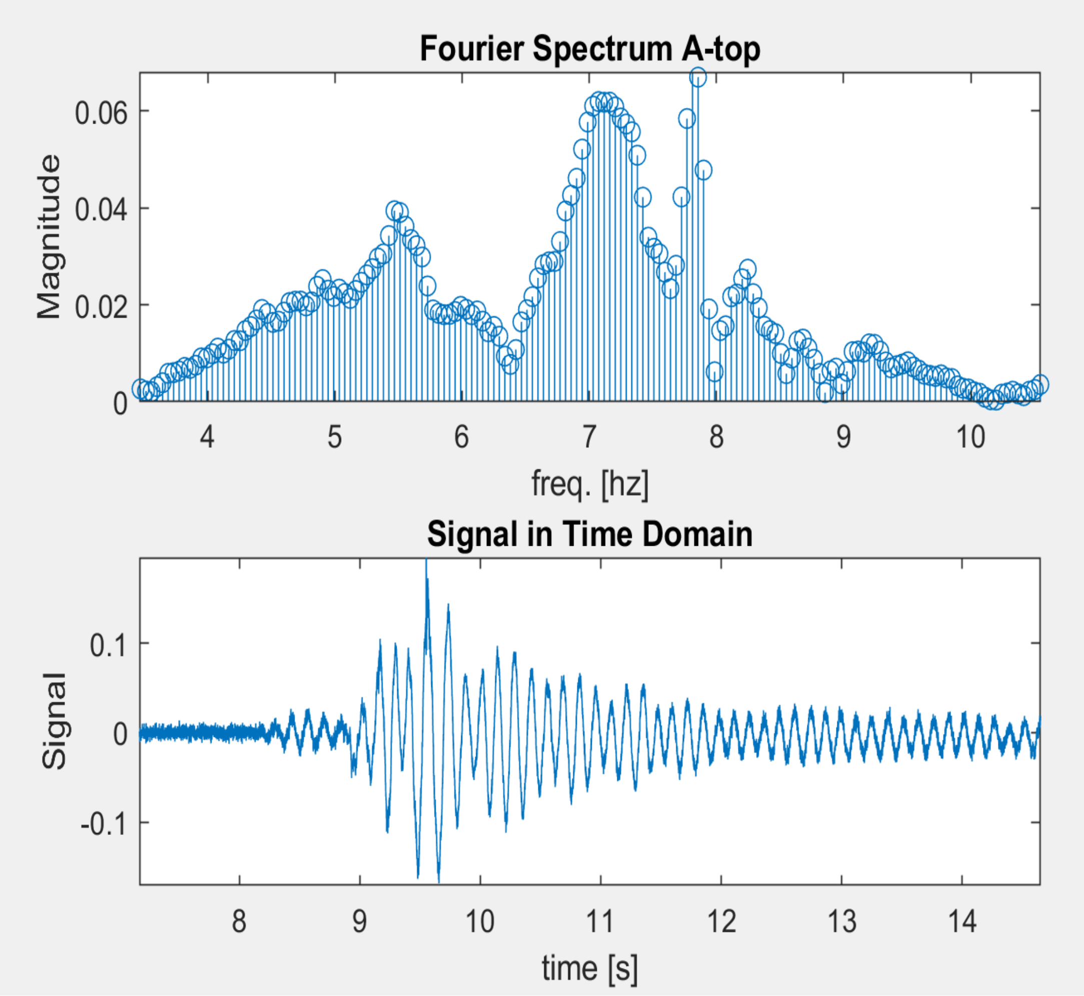
EXCITATION VS RESPONSE OF THE SYSTEM

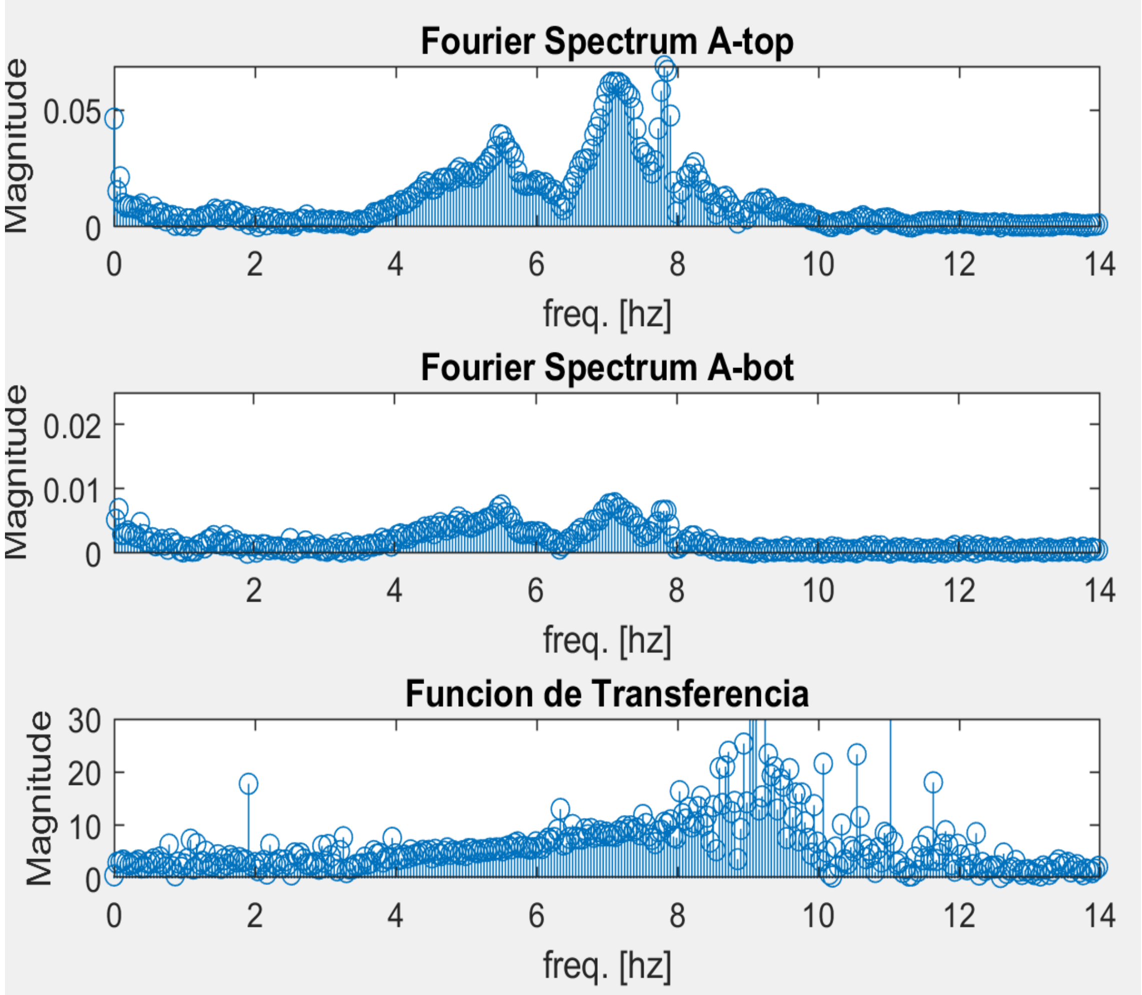


Experimental Run: "Setup 3"
Loma Prieta

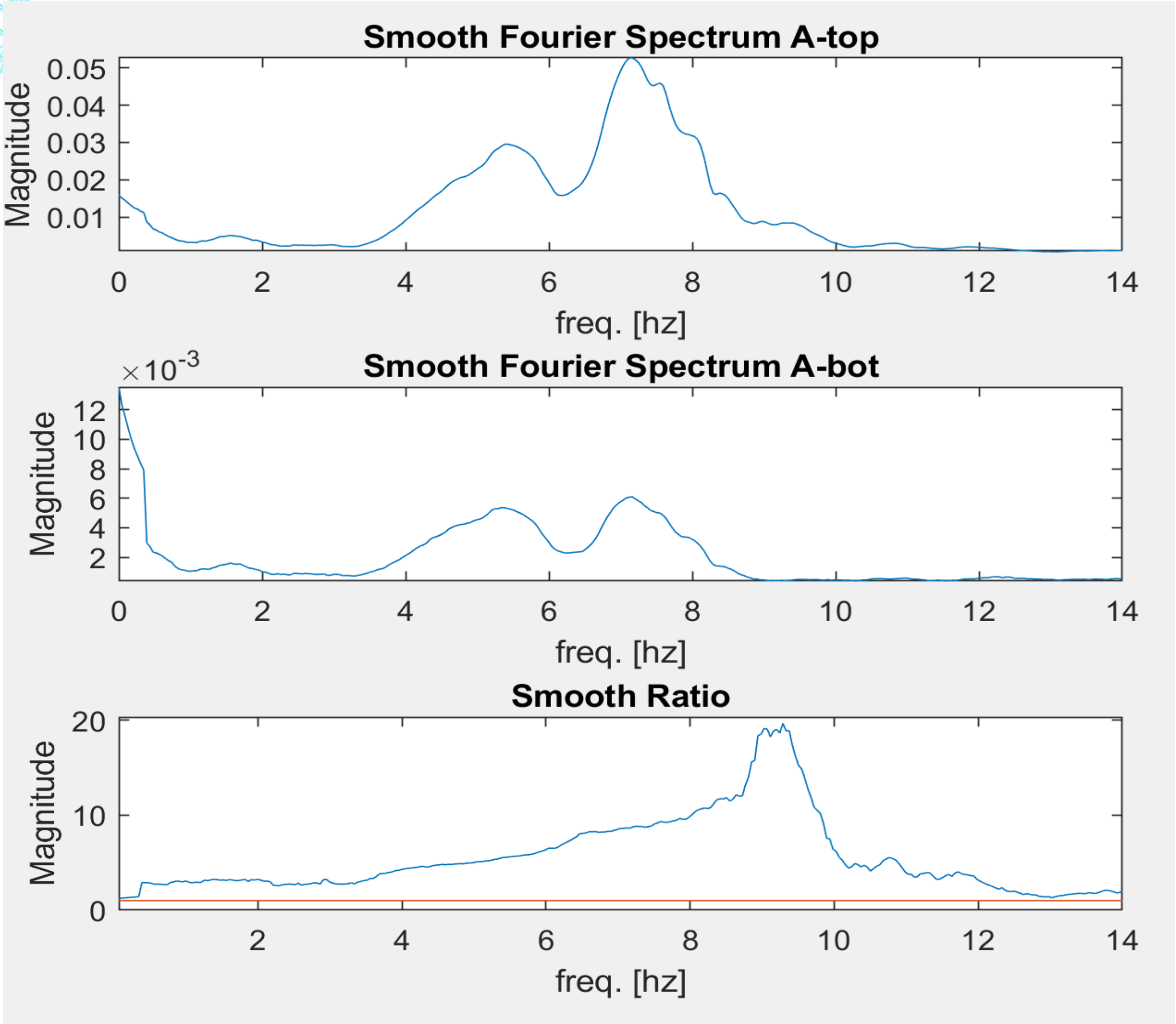
Top => at floor 3
Bot => Shake Table

FOURIER TRANSFORM





ACCELERATION TOP VS BOTTOM RATIO



Natural frequency of Structure:

From Analytical SAP2000 model
8.282 Hz

From MATLAB Modal Analisis model
9.706 Hz

Run ID "Set-up 3" : Loma Prieta

RECOMMENDATIONS

1 – For rigid diaphragm action a steel plate welded all around to the perimeter holding angles shall be used instead of the actual grating which reflects a semi-rigid diaphragm action instead.

2 – The effects of the column splices at mid-height shall be taken into account on the numerical model representing the additional stiffness they provide to the columns.

3 - The beam-to-column joints shall be modeled as semi-rigid joints instead of fixed joints or, as an alternative, gusset plates between beams and columns could be welded.

4- Maintain a data base of the calibration parameters used in previous studies in order to have these as starting points.