Ambient versus Forced Vibration Modal Testing of Buildings

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Outlines

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Modal Parameters

Full Scale Modal Tests

- Forced vibration tests
- Ambient vibration tests

Test Structure

- Layout
- Instrumentation

Identification Results

- Frequencies
- Damping
- Mode shapes

Finite Element Model

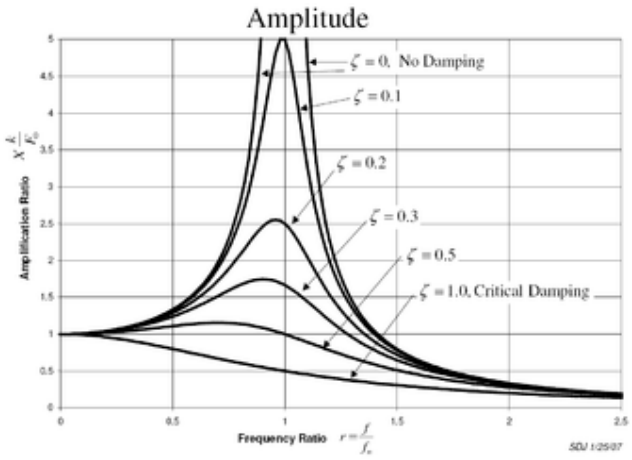
Conclusions

Modal Parameters

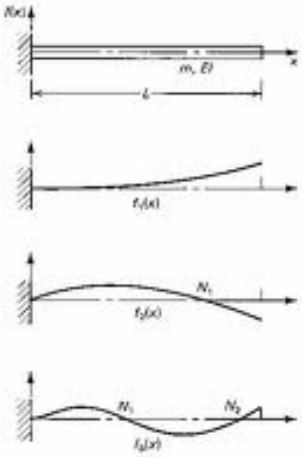
- Natural frequencies
- Damping ratios
- Mode Shapes

- essential task in the course of seismic design of civil engineering structures
- understand and interpret structural response during strong earthquake ground motion
- compare observations with theoretical results.

Tacoma Narrows Bridge



Damping ratio and natural frequency



Mode Shapes

Full Scale Dynamic Tests

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Forced vibration tests:

- Vibration induced by external force
- Effective in obtaining accurate estimation of higher modes
- Expensive, time consuming to conduct and often require special permissions

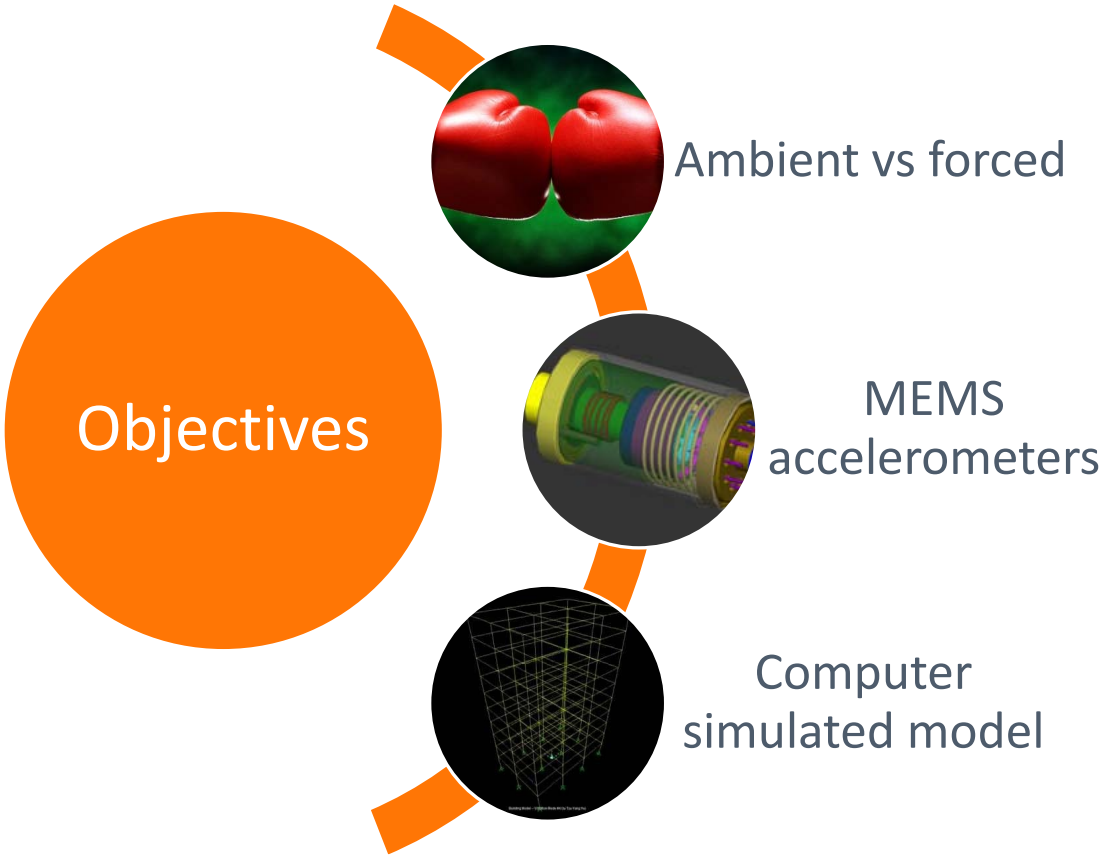
Eccentric Mass Exciter

Ambient vibration tests:

- Vibration induced by wind, traffic, operational use.
- Economical, non-destructive, fast and easy to conduct.
- Low signal to noise ratio.

Operational Use of Building

Objectives


Objectives
Ambient vs forced
MEMS accelerometers
Computer simulated model

Test Building

- 13 storey office tower (Engineering Building 401, UoA)
- Constructed in 1964
- Height 40.54m
  Plan dimensions 18.3m x 18.3m
- Structurally separate the adjoining 3-4 storey buildings

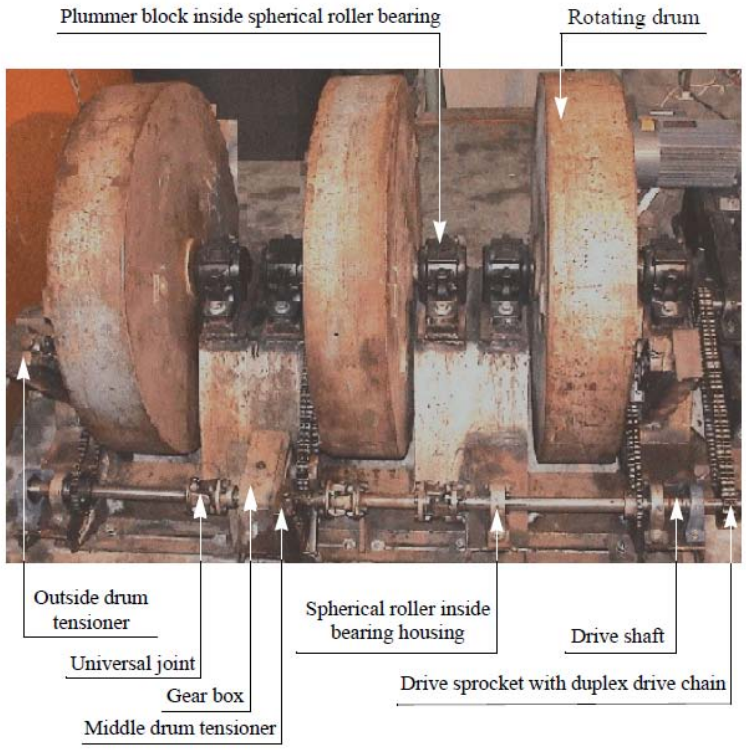
Engineering Office Tower (401)

Eccentric mass shaker

$$F = m_e e \omega^2 cos\omega t$$

m_e is the resultant eccentric mass of the exciter,
e is the eccentricity of the exciter's eccentric masses,
ω is the driving frequency (rad/s).

Resultant eccentric mass (per set)	Contributing eccentric weights		Eccentricity (mm)	Max driving frequency	Force Amplitude
	Outside drums	Middle drum			
10 kg	2 - 2.5 kg	5 kg	325	9.0 Hz	13 kN (or 26 kN peak to peak)
20 kg	2 - 5 kg	10 kg		6.75 Hz	
40 kg	2 - 10 kg	20 kg		4.5 Hz	



Jin Hee Lee, Assessment of Modal Damping From Full Scale Structural Testing, Master Thesis, University of Auckland 2003

Instrumentation
a) Forced vibration test

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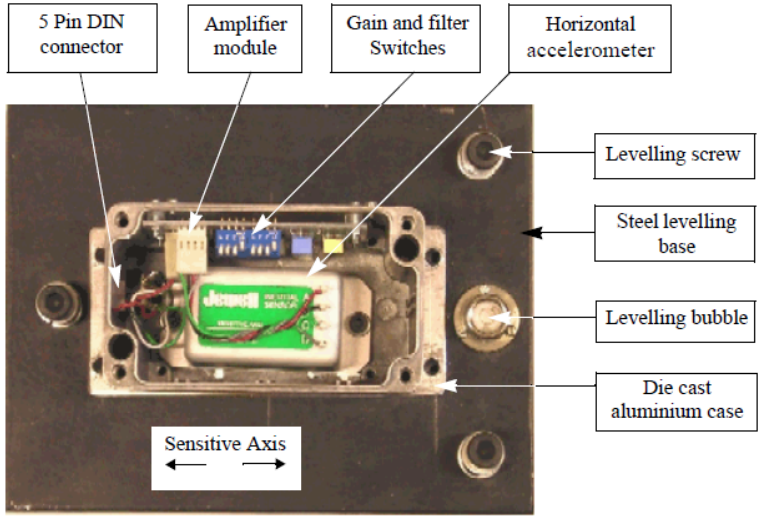
Accelerometers

Measurement range: ± 0.25 g
ADC: 12 bit
Low pass filter: 20 Hz
No of accelerometers: 6



LCF-100-14.5 servo accelerometers

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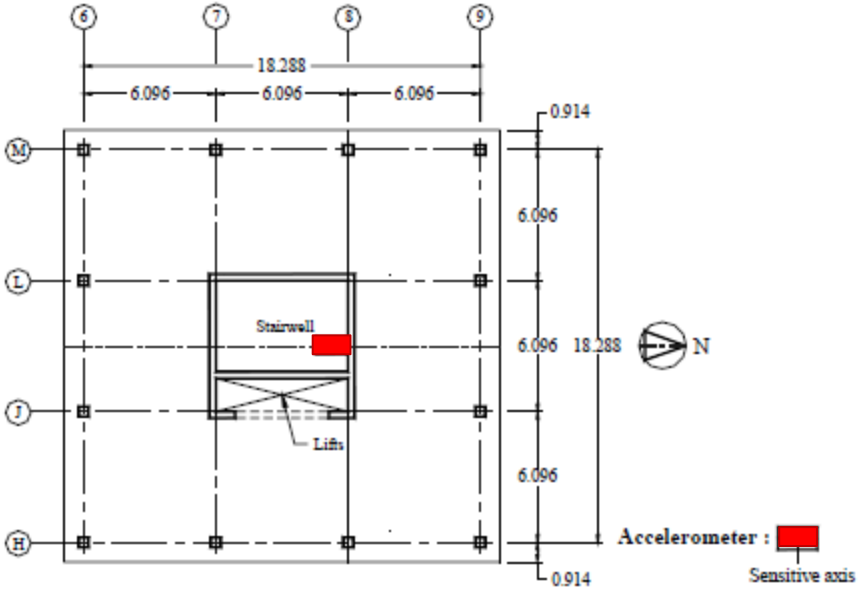
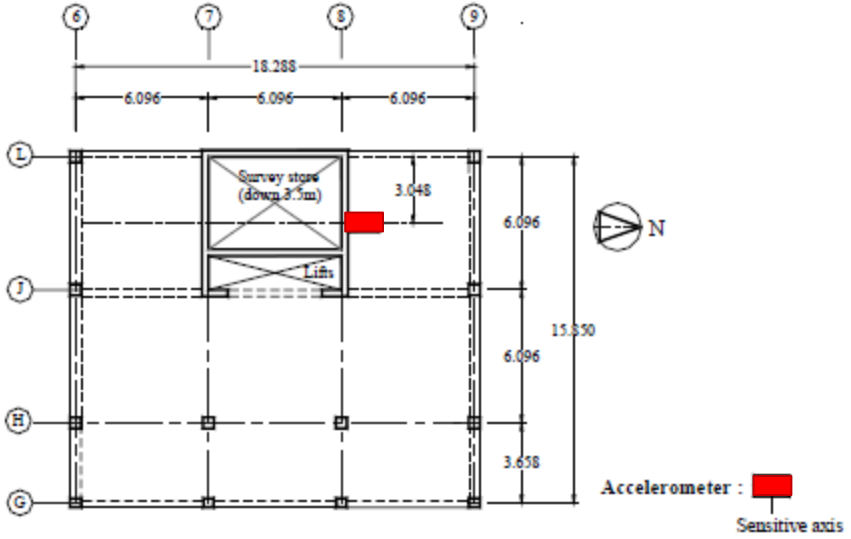


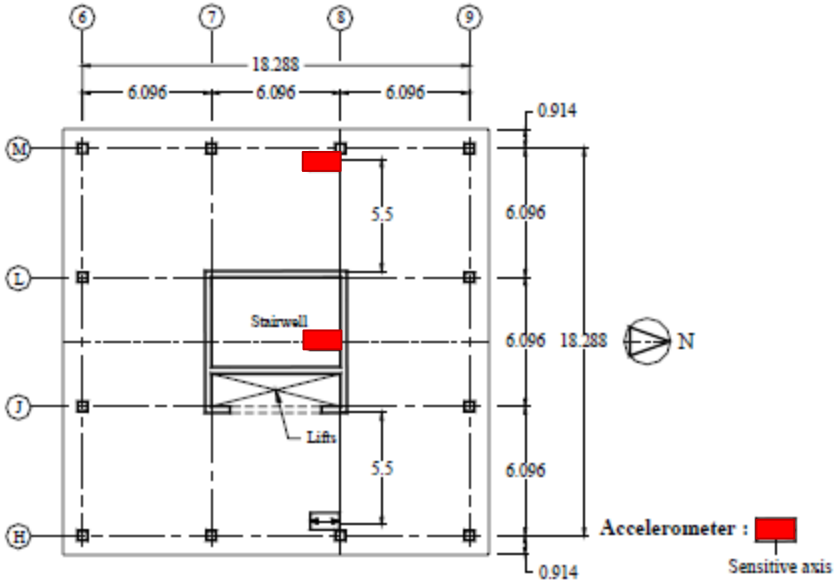
(a) Position of accelerometers at levels 14, 13, 10, 7 and 5



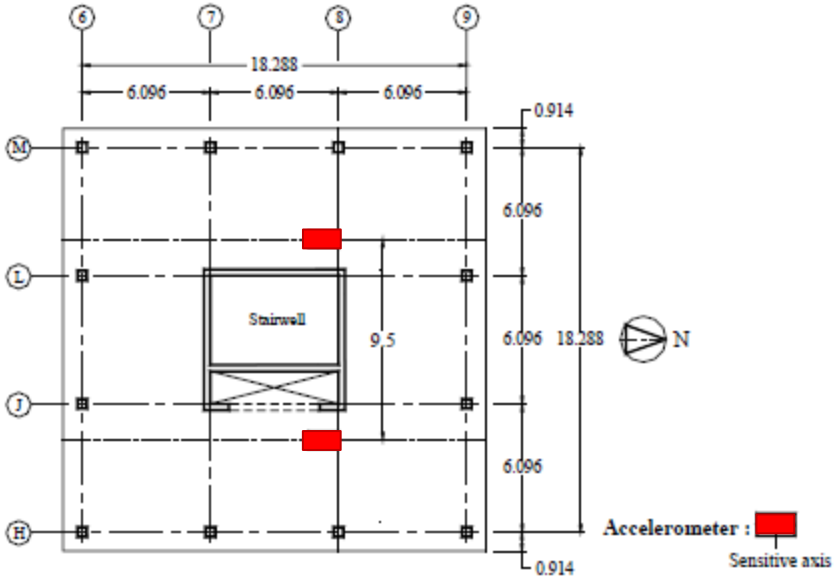
(b) Position of accelerometer at level 2 (Ground level)

Figure 5.10: Position of accelerometers - Translational modes for the mode shape test.

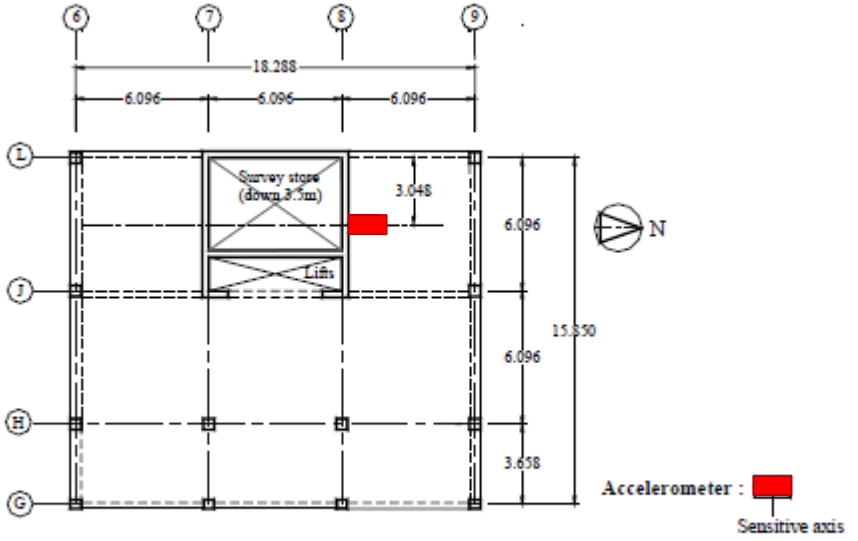
*Jin Hee Lee, Assessment of Modal Damping From Full Scale Structural Testing, Master Thesis, University of Auckland 2003



(a) Position of accelerometers at level 13 - Torsional modes



(b) Position of accelerometers at level 7 - Torsional modes



(c) Position of accelerometer at level 2 (Ground level)

Figure 5.11: Position of accelerometers - Torsional modes for the mode shape test.

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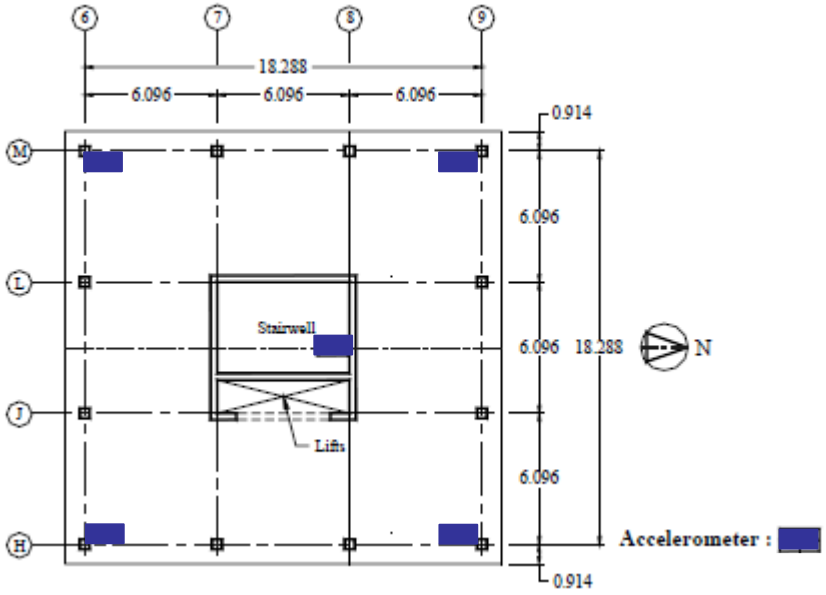
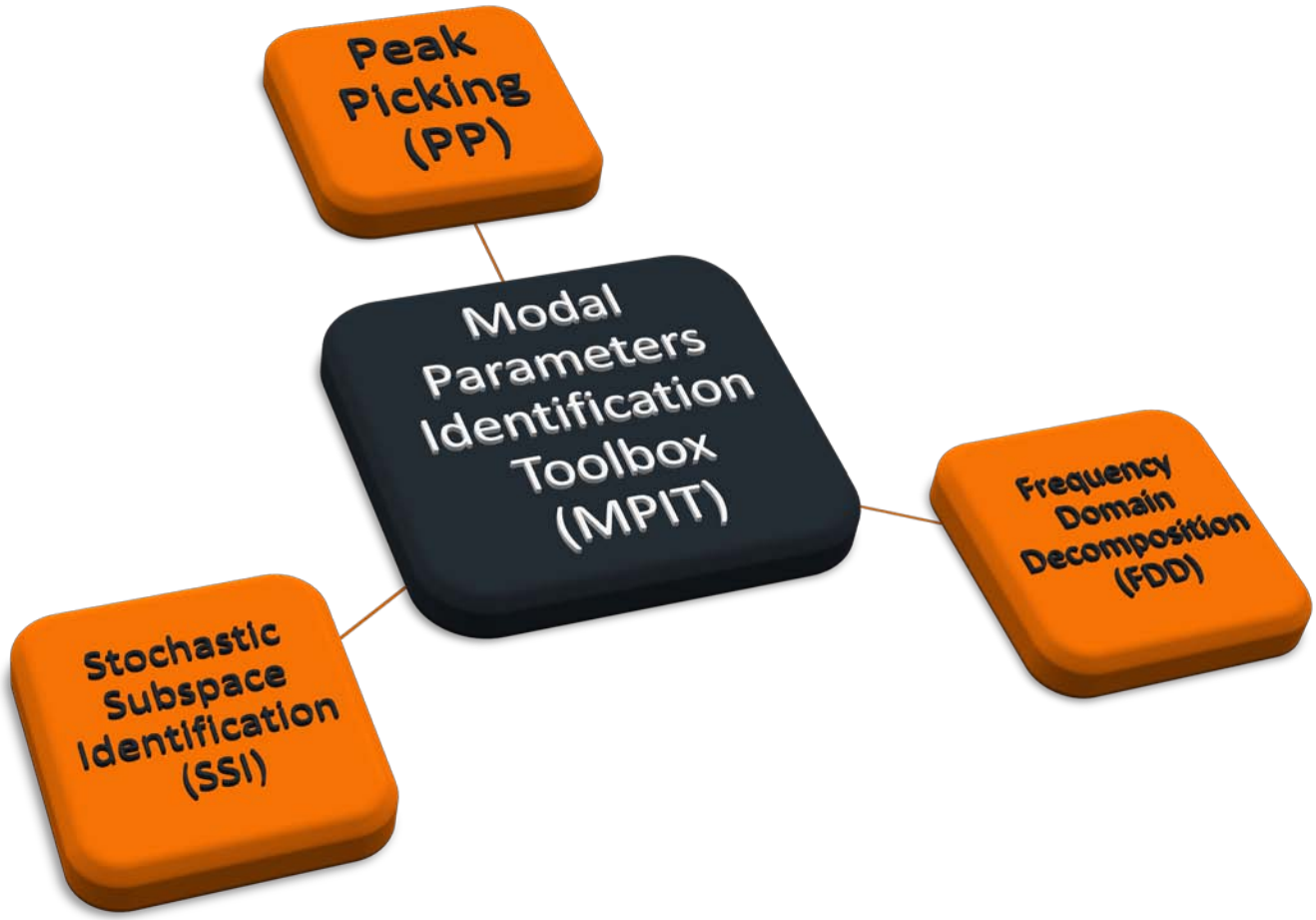
Instrumentation
b) Ambient vibration test

Micro-Electro-Mechanical System (MEMS) Accelerometers

Measurement range: ± 2.0 g
ADC: 16 bit
No of accelerometers: 49
Sampling rate: 40Hz
Test duration: 3 weeks



Modal Parameters Identification



Earthquake

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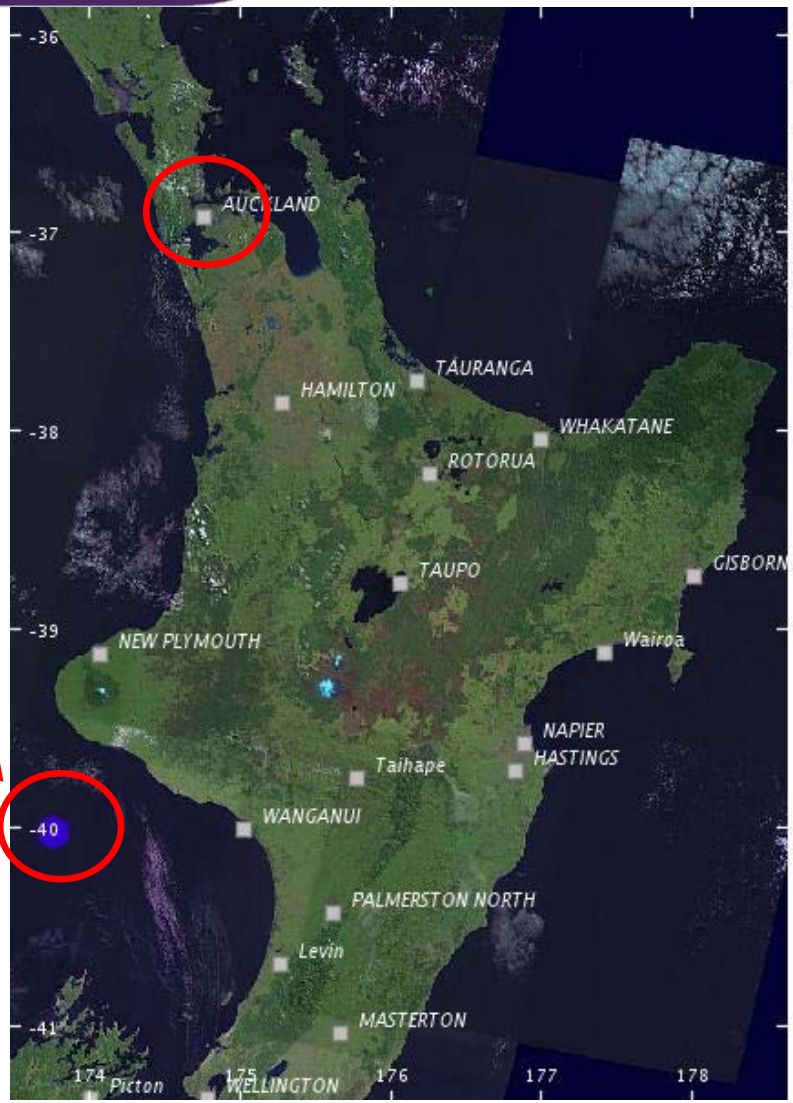
Magnitude: 7.1
Depth: 230 km
Distance: 350 km
Date: 3 July 2012
Time: 22:36



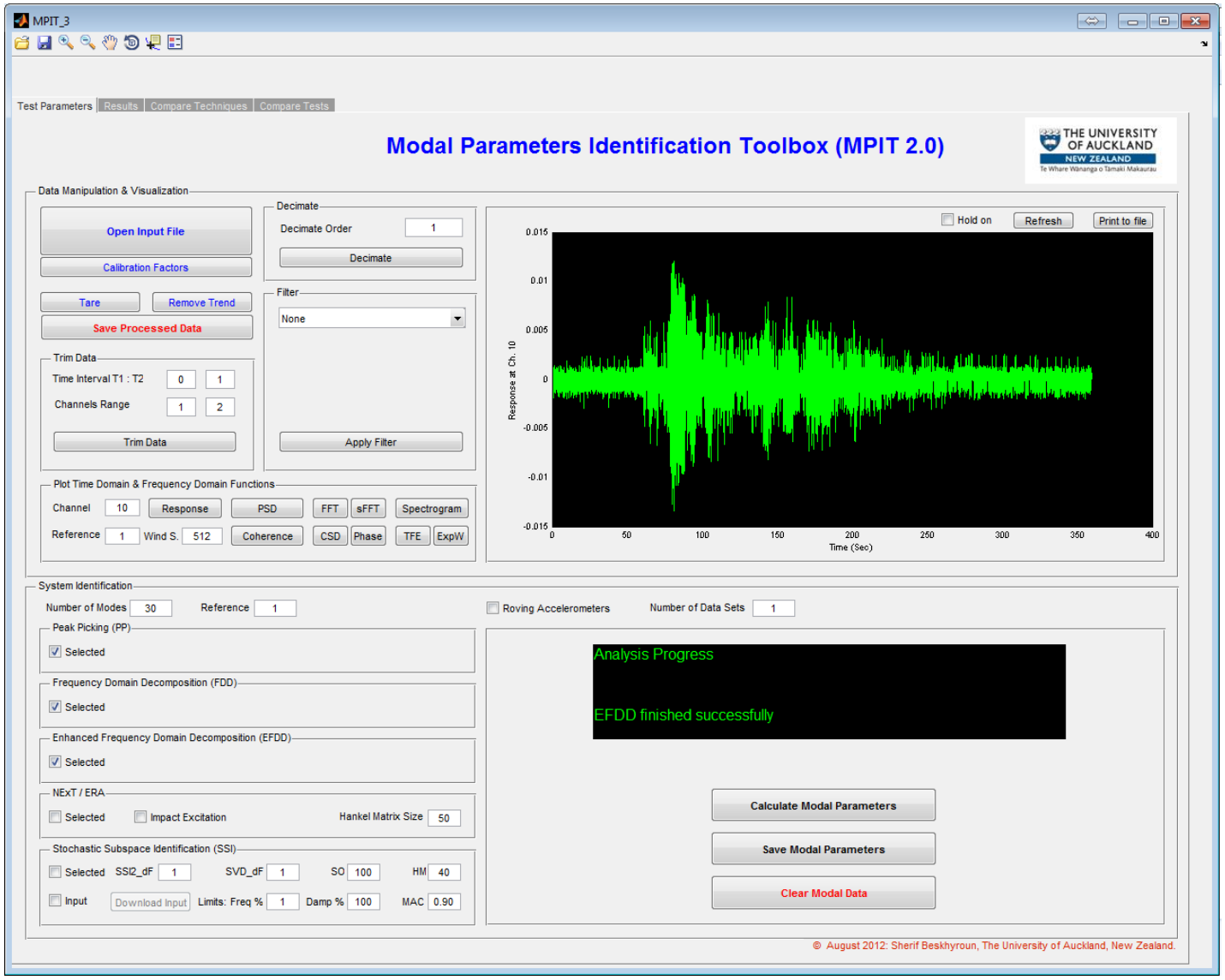
Legend

- Depth less than 40 km
- Depth between 40 km and 69 km
- Depth between 70 km and 99 km
- Depth between 100 km and 149 km
- Depth between 150 km and 199 km
- Depth between 200 km and 299 km
- Depth greater than 300 km

- Magnitude less than 3.9
- Magnitude between 4 and 4.9
- Magnitude between 5 and 5.9
- Magnitude between 6 and 6.9
- Magnitude greater than 7

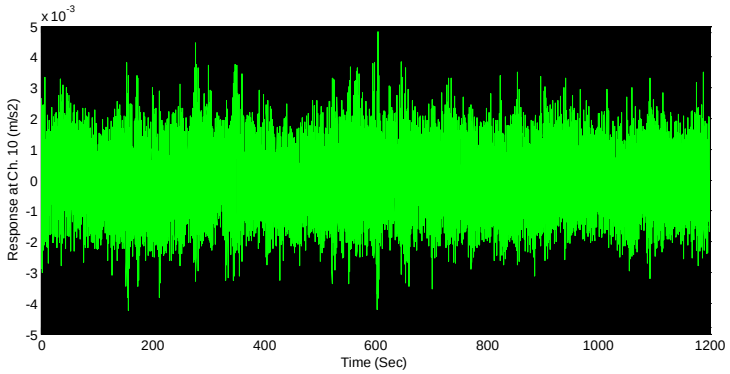
GeoNet
www.geonet.org.nz

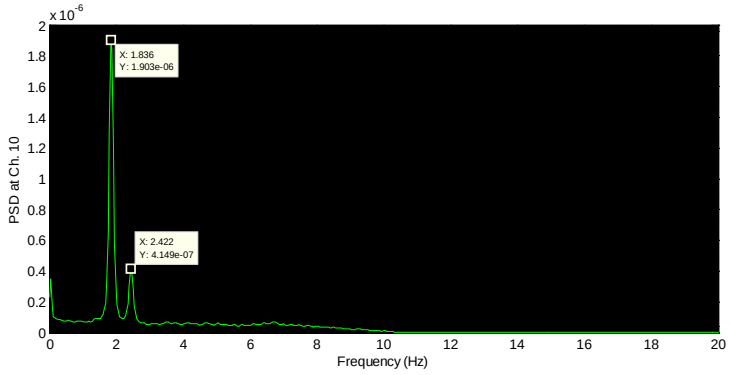
Modal Parameters Identification Toolbox



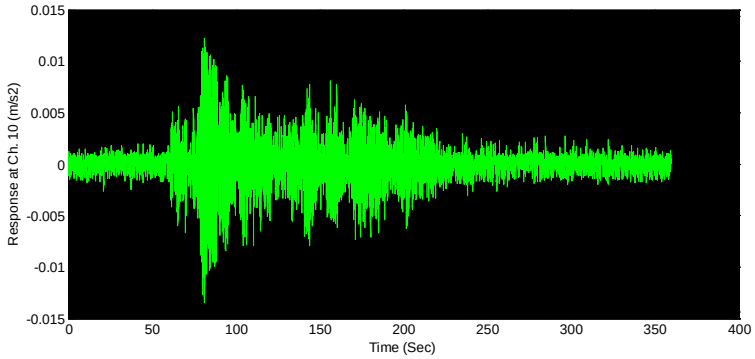
Response

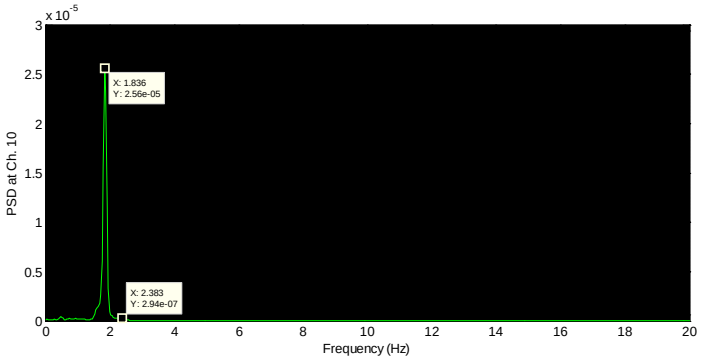
Wind excitation





Earthquake excitation





Frequencies & Damping

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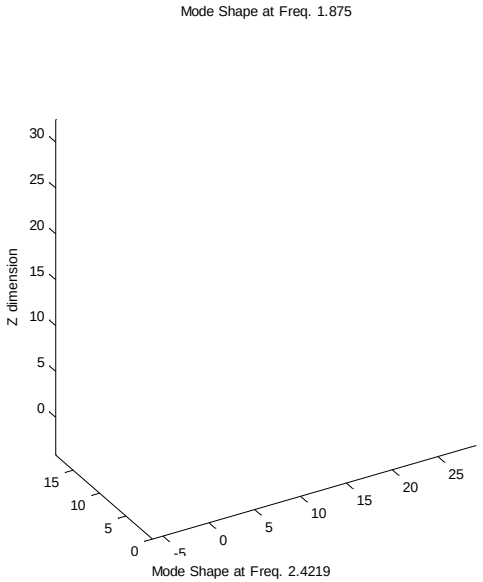
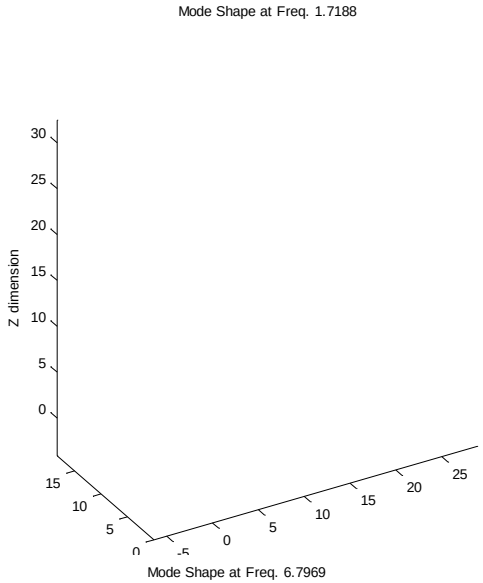
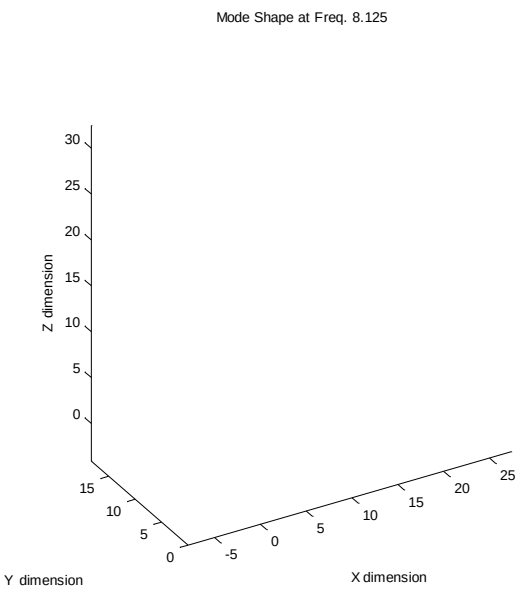
Ambient vibration test results

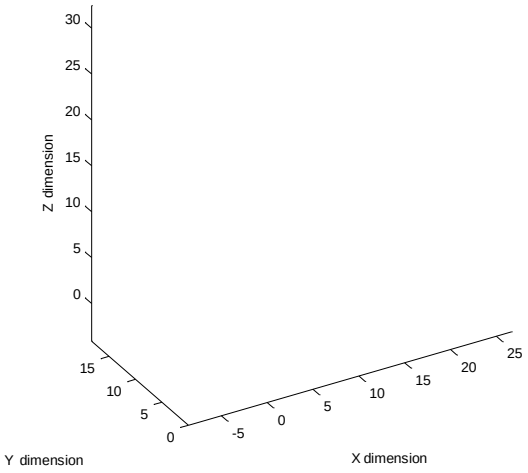
Mode Shape	PP	FDD	SSI1		SSI2	
	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
Wind						
First Translational (NS)	**1.836**	1.836	1.848	**1.17**	1.848	1.17
First Translational (EW)	1.719	1.719	1.730	1.00	1.730	1.00
First Torsional	2.422	2.422	2.446	1.41	2.446	1.4
Operational Use						
First Translational (NS)	**1.875**	1.875	1.87	**1.95**	1.87	1.95
First Translational (EW)	1.758	1.758	1.749	1.01	1.749	1.02
First Torsional	2.461	2.461	2.444	1.77	2.444	1.77
Earthquake						
First Translational (NS)	**1.836**	1.836	1.842	**1.23**	1.842	1.22
First Translational (EW)	1.719	1.719	1.725	0.97	1.725	0.97
First Torsional	2.305	2.305	2.412	1.62	2.412	1.62

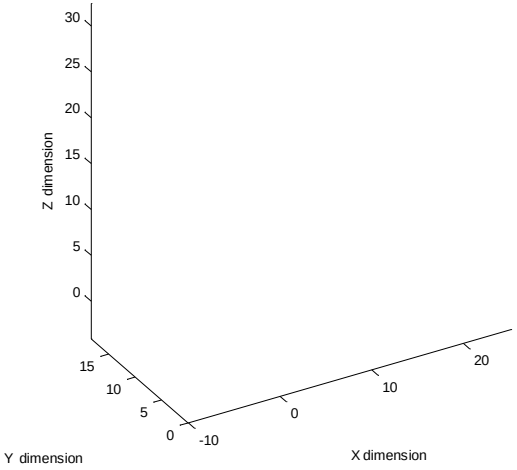
Mode Shapes


Mode Shape at Freq. 1.875
Z dimension
Mode Shape at Freq. 2.4219


Mode Shape at Freq. 1.7188
Z dimension
Mode Shape at Freq. 6.7969

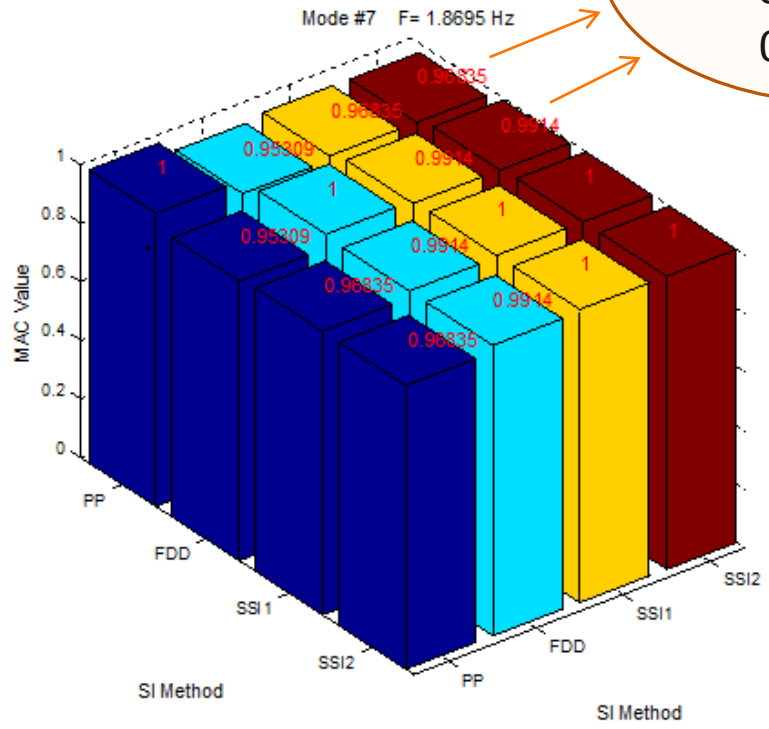

Mode Shape at Freq. 8.125
Z dimension
Y dimension
X dimension

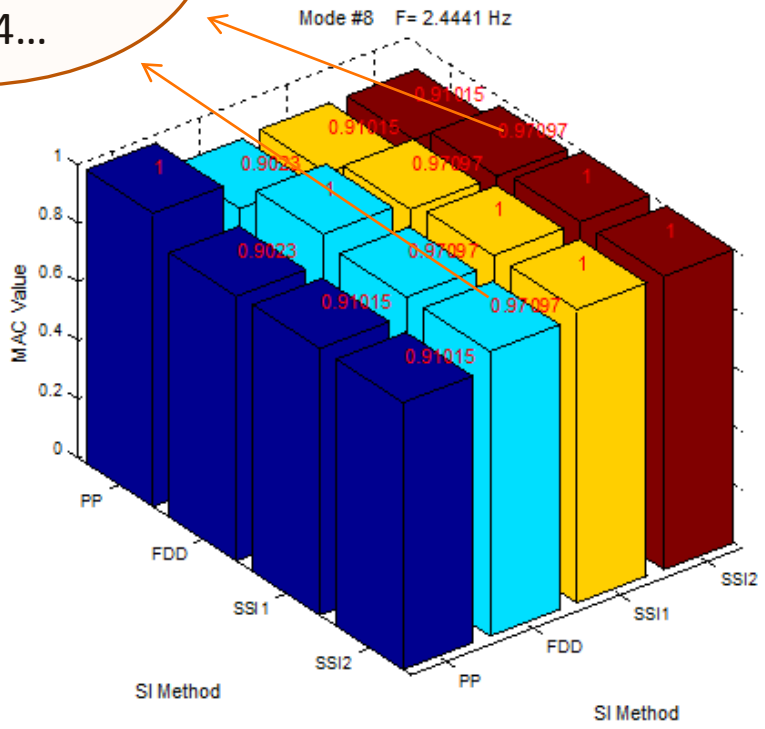

Z dimension
Y dimension
X dimension


Z dimension
Y dimension
X dimension

MAC Values

0.96335,
0.9914,
0.97997,
0.9914…





MAC values for 1st translational mode (NS)

MAC values for 1st torsional modes

Discussion

Ambient vibration test

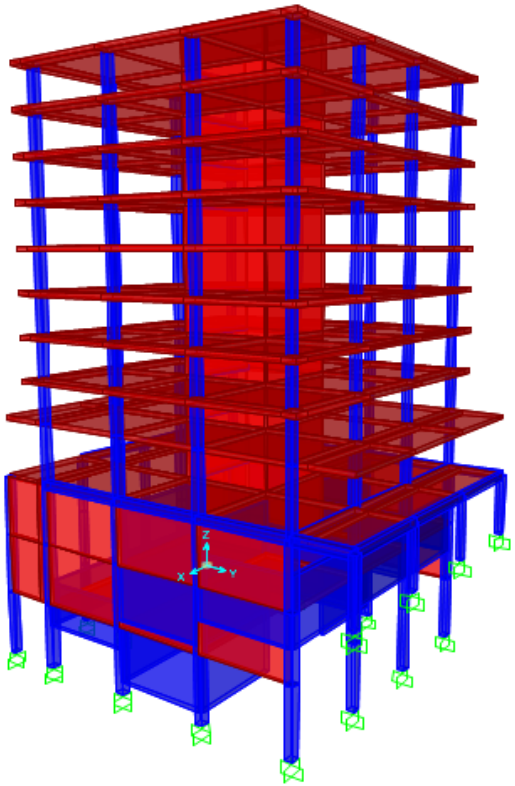
Mode Shape	PP	FDD	SSI1		SSI2	
	Frequency (Hz)	Frequency (Hz)	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
Earthquake						
First Torsional	2.305	2.305	2.412	1.62	2.412	1.62

Force vibration test*

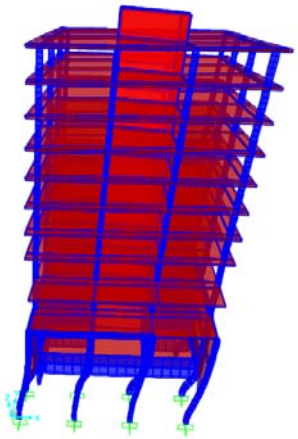
Mode Shape	Level of excitation					
	10kg		20kg		40kg	
	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
First Translational (NS)	1.911	1.525	1.9	1.556	1.88	1.707
First Torsional	2.48	1.394	2.463	1.466	2.447	1.64

*Jin Hee Lee, Assessment of Modal Damping From Full Scale Structural Testing, Master Thesis, University of Auckland 2003

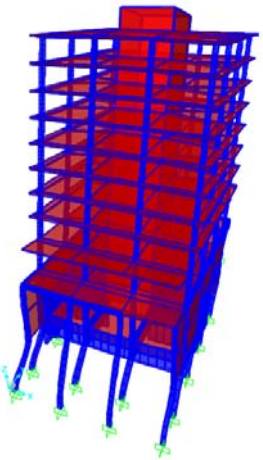
SAP2000 model



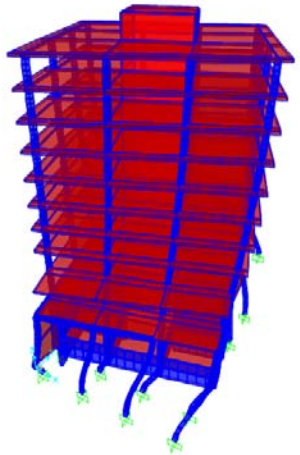
SAP2000 model



First translational mode (EW)
1.681 Hz (1.719 Hz)



First translational mode (NS)
1.803 Hz (1.836 Hz)



First torsional mode
2.5 Hz (2.461 Hz)

Conclusions

- Ambient vibration tests have proved that a small force can be used effectively to get the global modes of vibration.

- Very good correlation was observed between modal parameters from forced and ambient vibrations tests.

- Low cost MEMS accelerometers were successfully utilised to measure very small response amplitudes. The recorded data produced accurate estimates of the modal parameters.

Acknowledgement

- AP John Butterworth
- Jin Hee Lee
- Bharat Popli
- Morgan Wang