Workshop on **"Determination of the Seismic Performance of the Existing Buildings by Full Scale Tests"** ***October 20[nd], 2014, Istanbul – ISTKA Project***

Field testing of substandard RC buildings: *Ambient and forced vibration tests*

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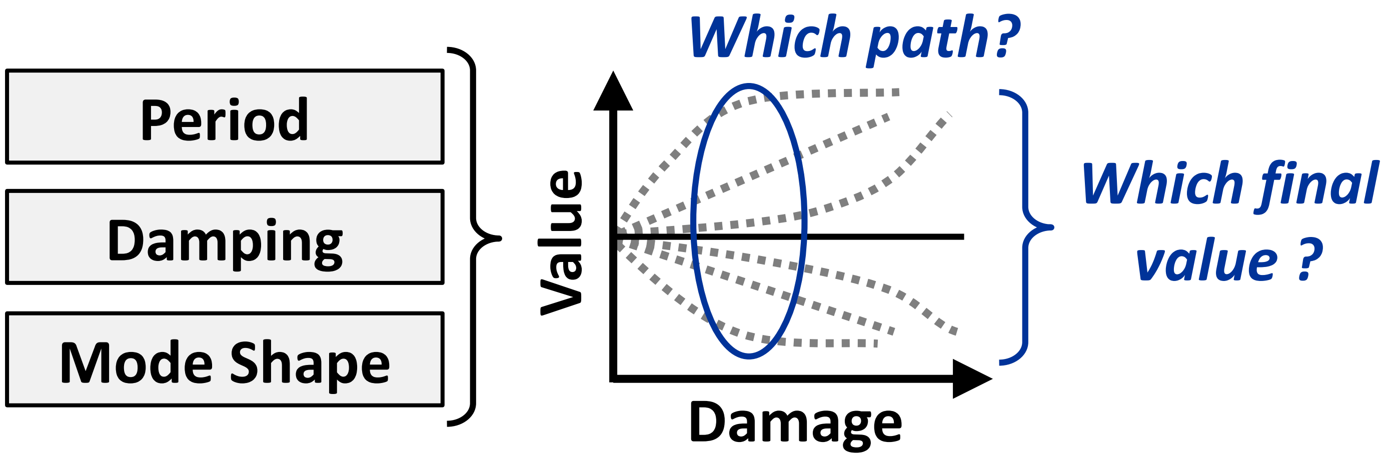
INTRODUCTION

- Dynamic characteristics of the test buildings were investigated by means of forced and ambient vibration measurements.
- Changes in the dynamic characteristics were traced for the increasing levels of damping.
- Substandard RC buildings representative of buildings with high seismic risk were considered.



TESTING SETUP and BUILDINGS

- **Reminder of the presentation on the static cyclic test results**

Building 1

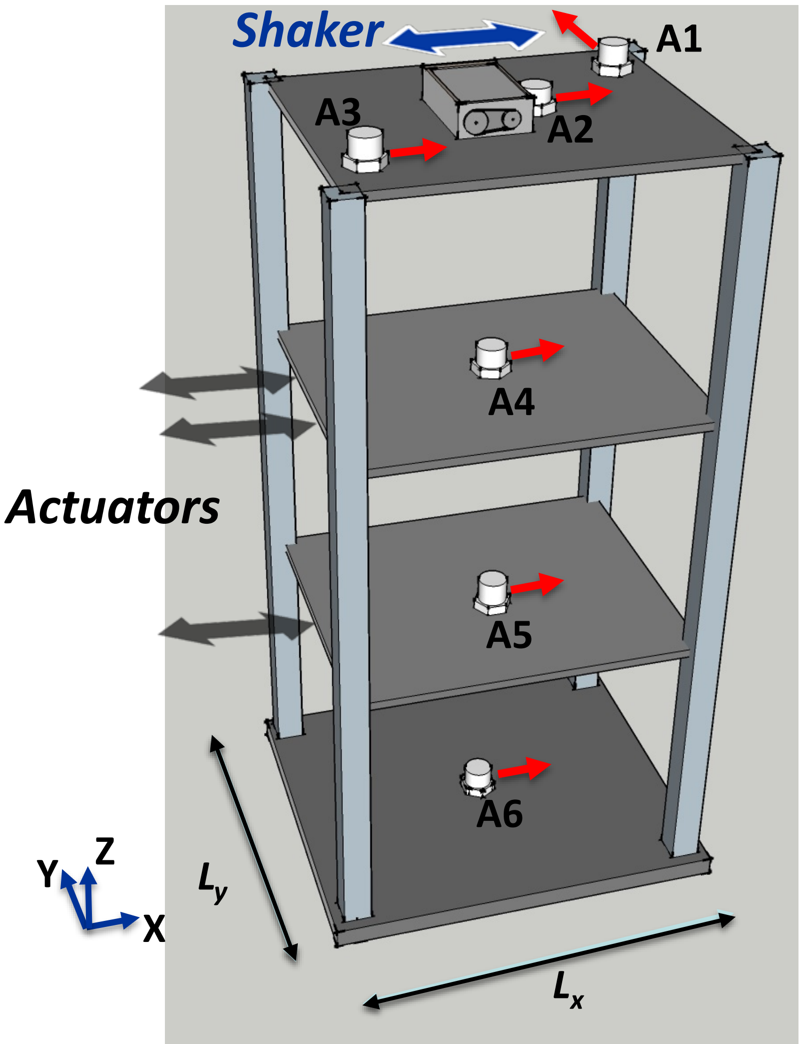
Strong column weak beam mechanism
Normal axial load (i.e. 10%)
Constructed in early 90s

Building 2

Weak column strong beam mechanism
High axial load (i.e. 25%)
Representative of 70's construction

TESTING SETUP and BUILDINGS

- Accelerometer locations



Building 1:

Sensor	X (m)	Y (m)	Z (m)
A1	1.6	1.9	8.4
A2	0	0	8.4
A3	-1.6	-1.9	8.4
A4	0	0	5.6
A5	0	0	2.7
A6	0	0	0

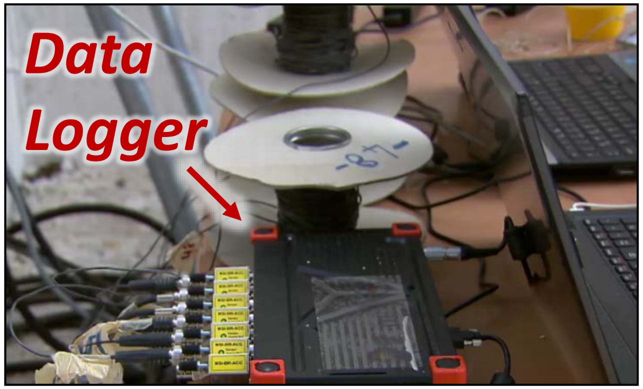
Building 2:

Sensor	X (m)	Y (m)	Z (m)
A1	1.85	2.15	9
A2	0	0	9
A3	-1.85	-2.15	9
A4	0	0	6
A5	0	0	3
A6	0	0	0

- For performing **Y-direction testing** sensors at the centers of the slabs (i.e. **A2-4-5-6)** were rotated towards Y.

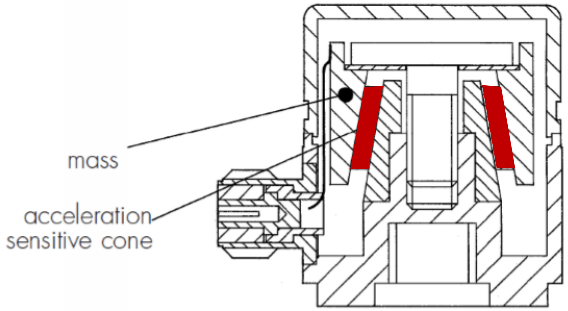
TESTING SETUP and BUILDINGS

- **Accelerometers**



Piezoelectric acceleometers:

A/1800 IEPE
by DJB Instruments



Conversion Mode	Konic
Voltage sensitivity mV/g	10V/g
Resonant frequency kHz	≈4
Voltage sensitivity deviation re 20℃	5% @ -50℃ +5% @ +125℃ +10% @ +185℃
Case Material	s/steel 303 S31
Supply Voltage V	15/ 35
Supply Current mA	2/ 20
Bias Voltage V (20°C)	8.5/ 9.5
Cross axis error % max	5%
Frequency Response ±5%	0.2Hz – 1kHz
Mounting	Base tapped ¼ UNF x 4mm deep
Maximum continuous g level	500
Weight gm	400/407 (TC)
Connector	Microdot skt, 10/32 UNF thd (A/1800/V & T) TNC skt. (A/1800/TC)
Case Seal	Welded, hermetic connector (TNC)

TESTING SETUP and BUILDINGS

- **Ground vibration sources around the site**

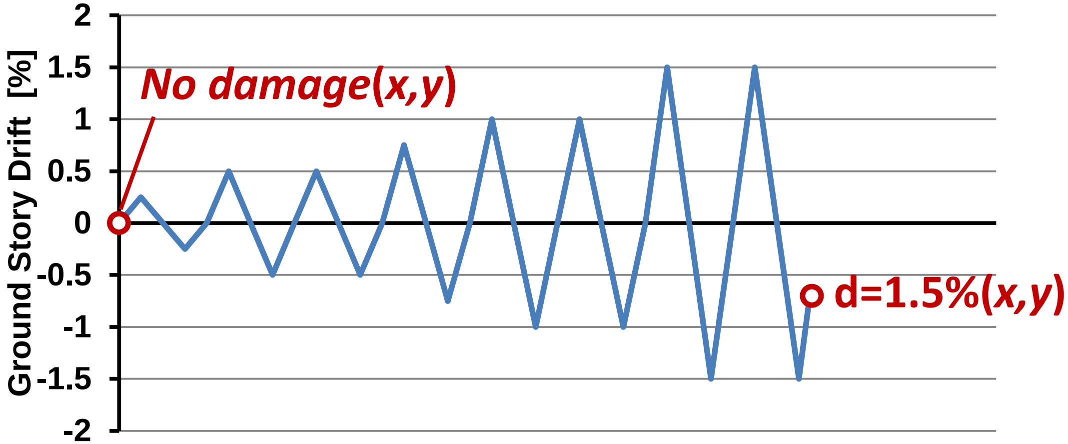
Construction sites are located around the site. Closest construction site is 50[m] away.

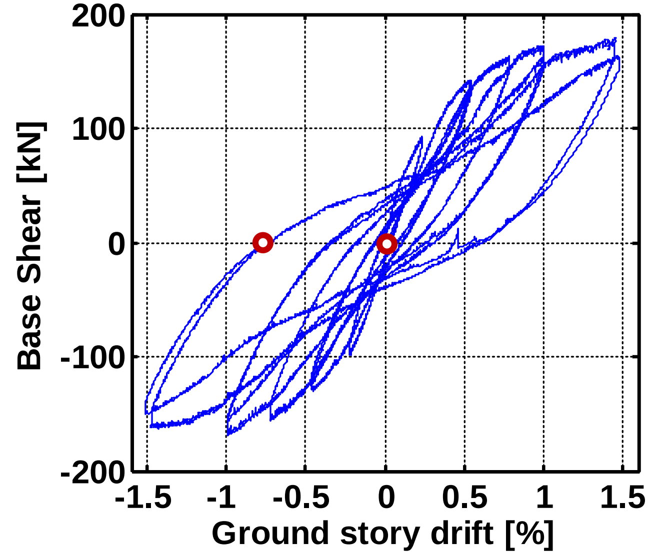
A busy highway is passing approx. 350[m] away from the site

MEASUREMENT PROGRAM

Building 1

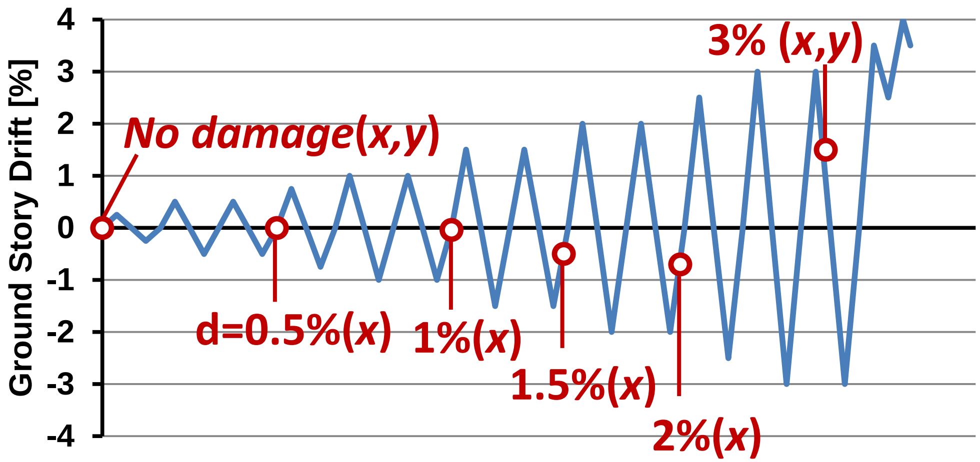
- *4 forced vibration tests*

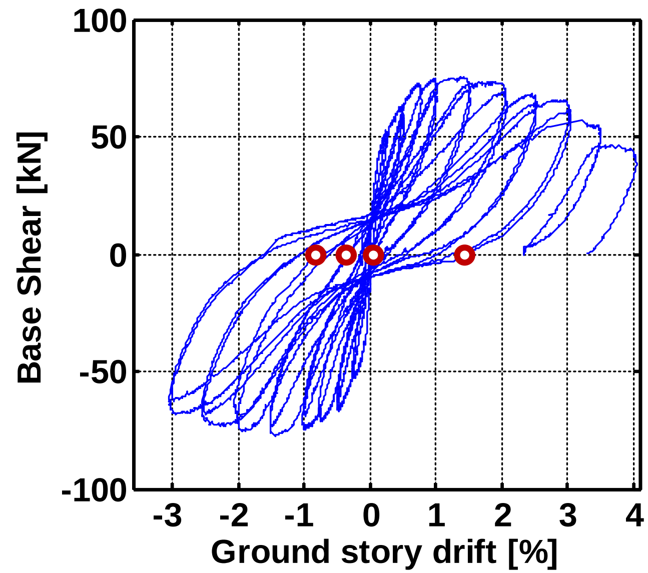




Building 2

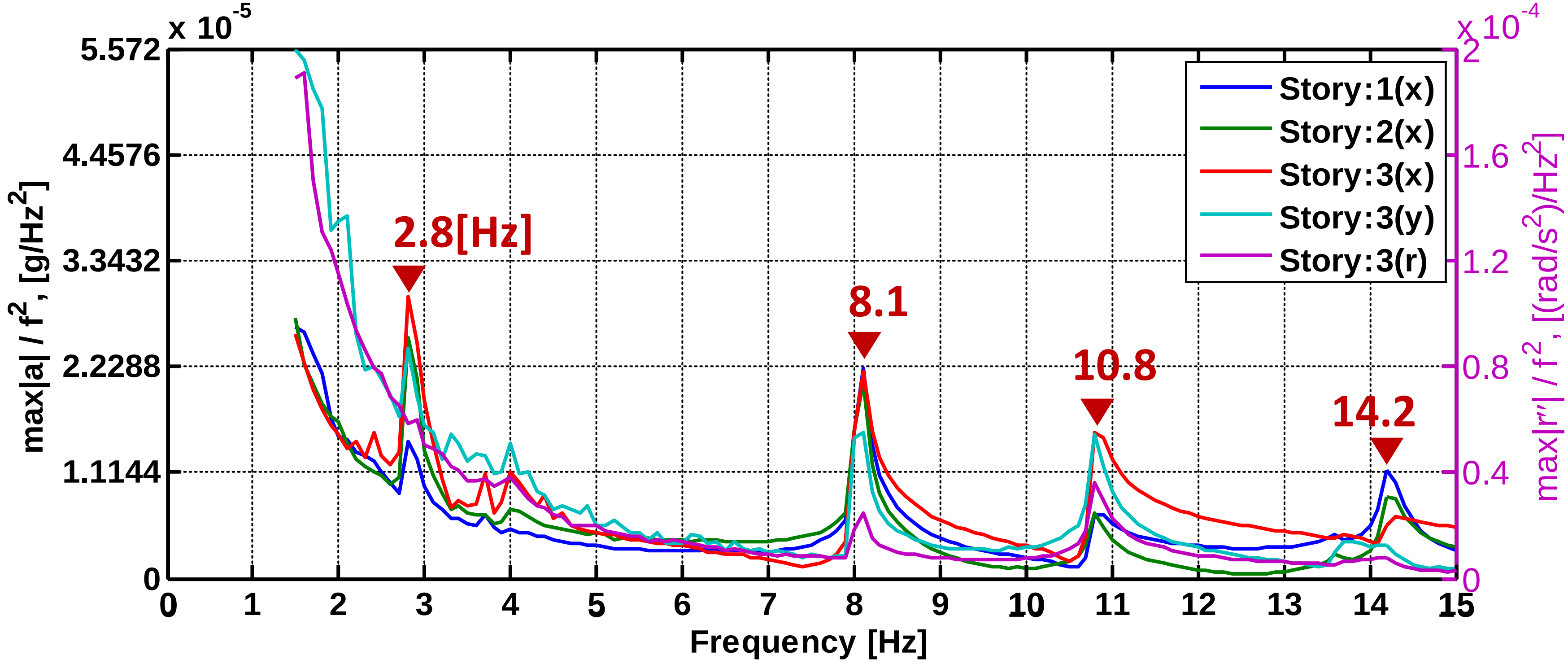
- *8 forced vibration tests*



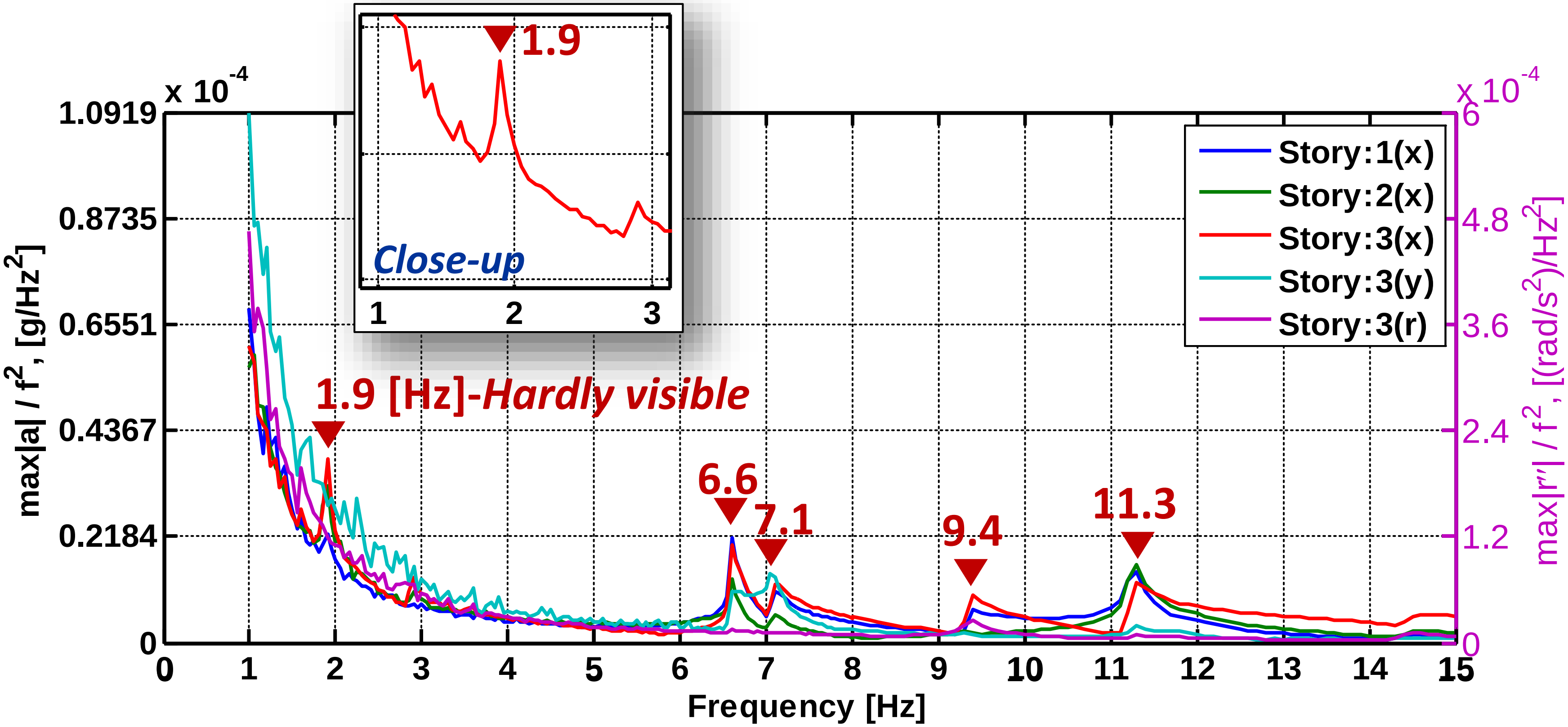


FREQUENCY RESPONSE FUNCTIONS

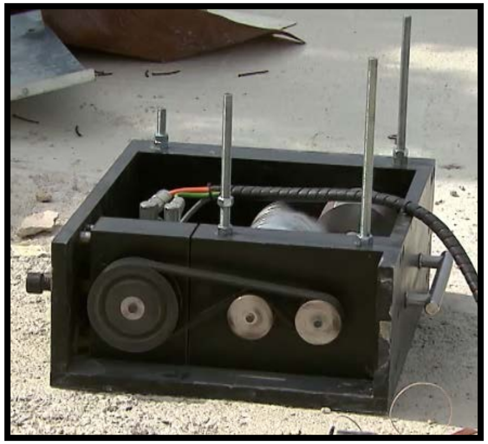
- **Building 1, x-direction, no damage**

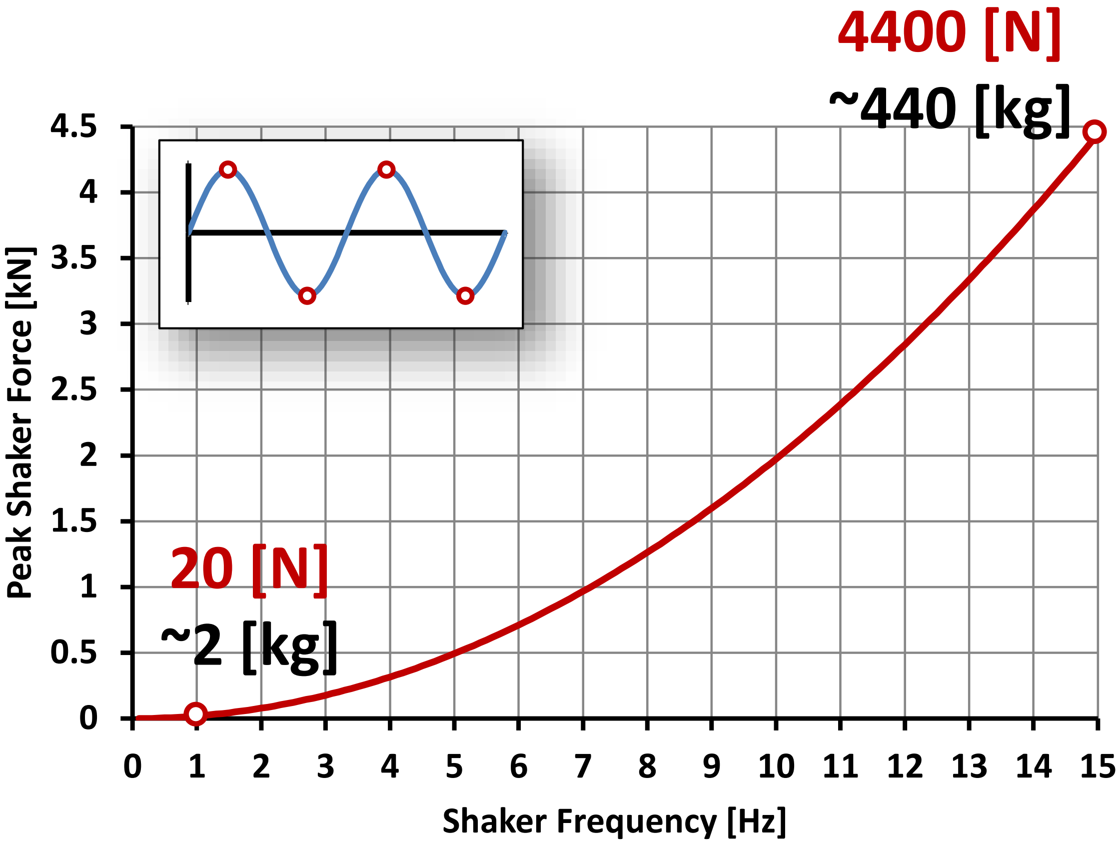


- **Building 1, x-direction, d=1.5%**



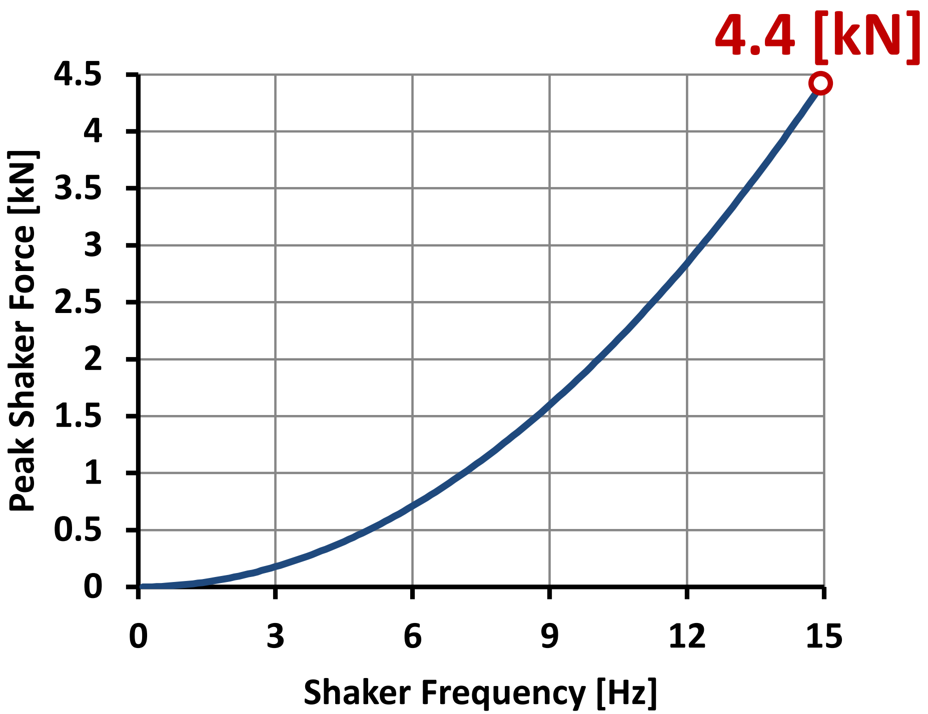
- **Peak force at maximum eccentricity**

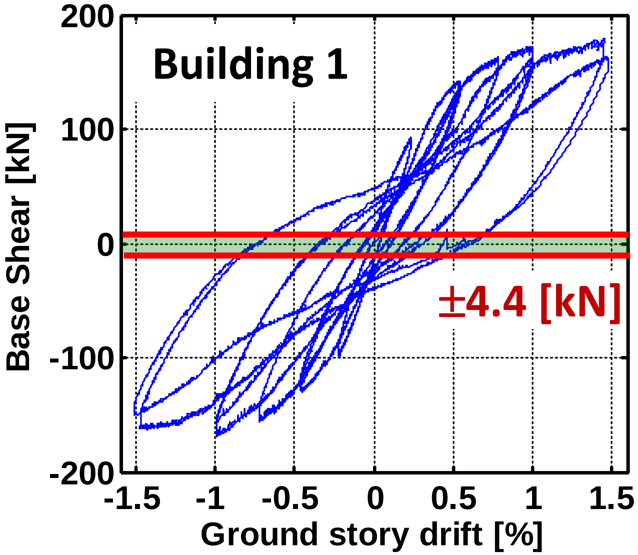


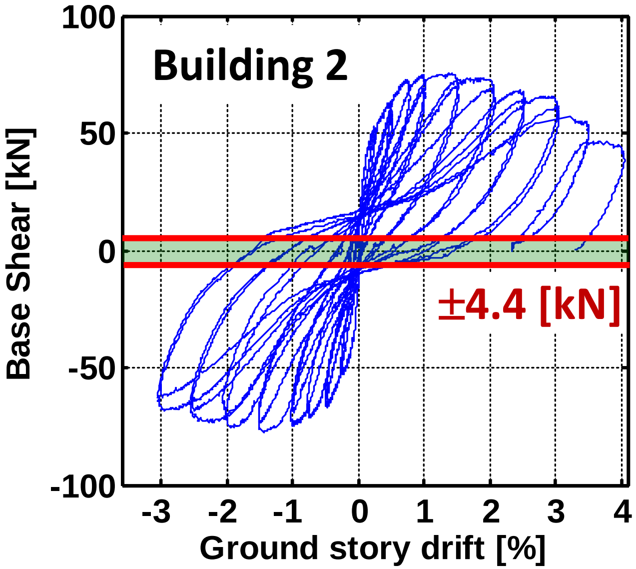


SHAKER FORCE

- **Risk of large deformations**

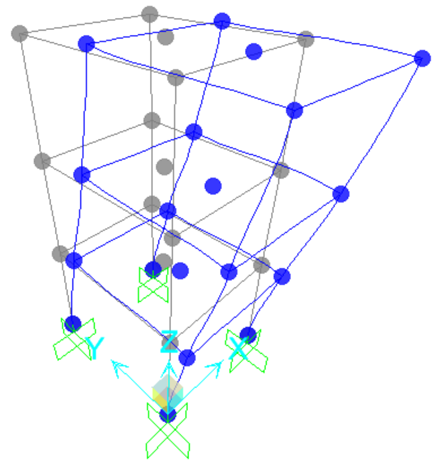




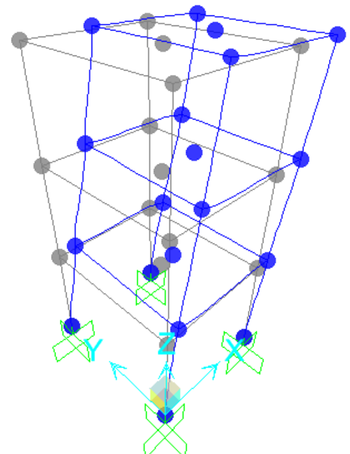


FINITE ELEMENT MODEL

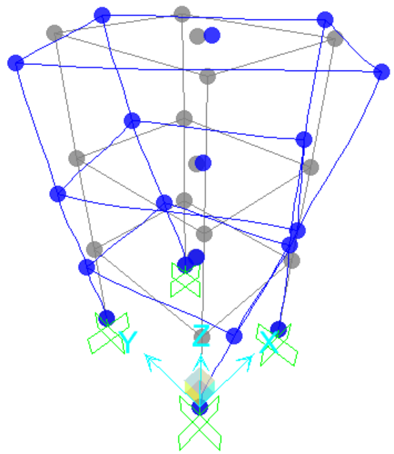
- **Building 1**



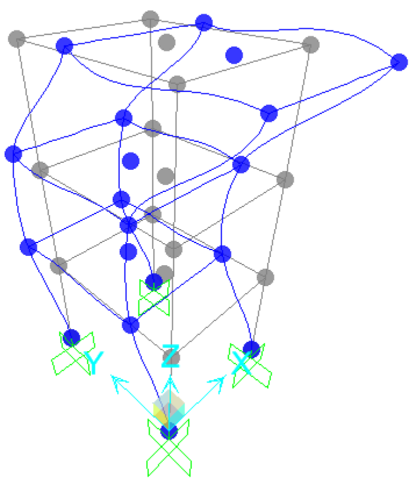
Mode 1



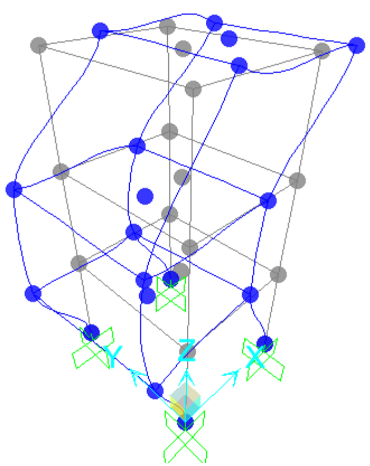
Mode 2



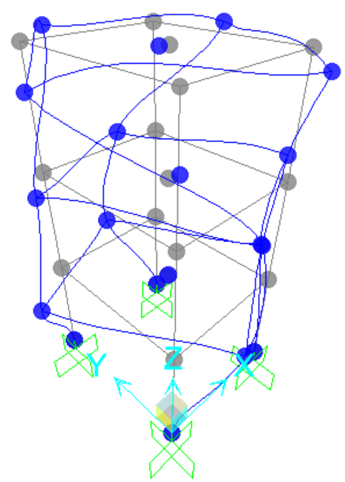
Mode 3



Mode 4



Mode 5



Mode 6

Mode	Freq. [Hz]	Period [s]
1	3.29	0.304
2	3.47	0.289
3	4.43	0.225
4	10.0	0.100
5	10.6	0.094
6	12.9	0.077
7	17.7	0.056
8	18.9	0.053
9	22.8	0.044

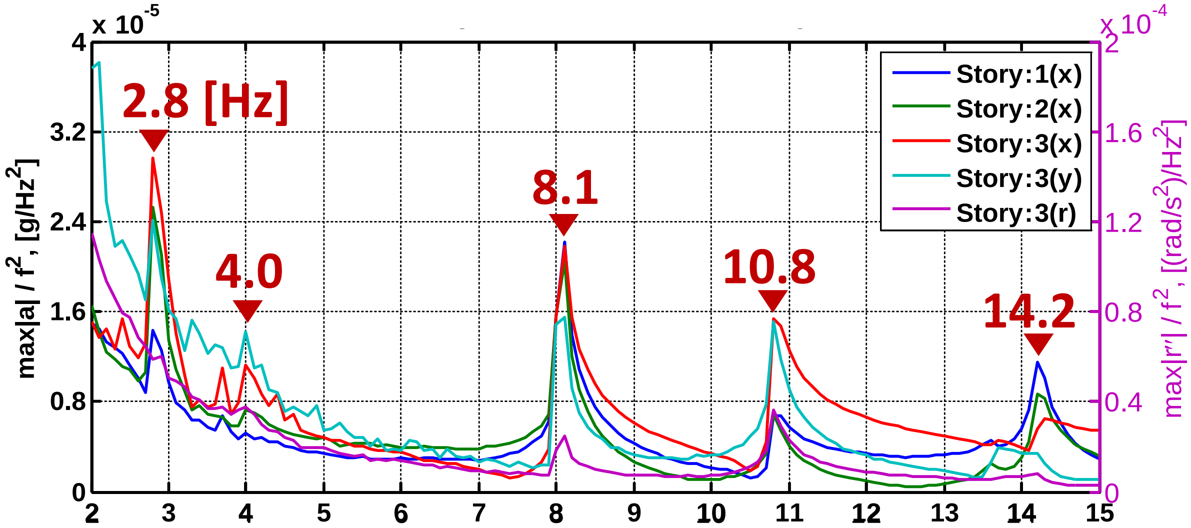
E_c estimated simply using TS500 (Eq.3.2) to obtain a preliminary value.

SAP2000 Ultimate 16.0.0
Structural Analysis Program

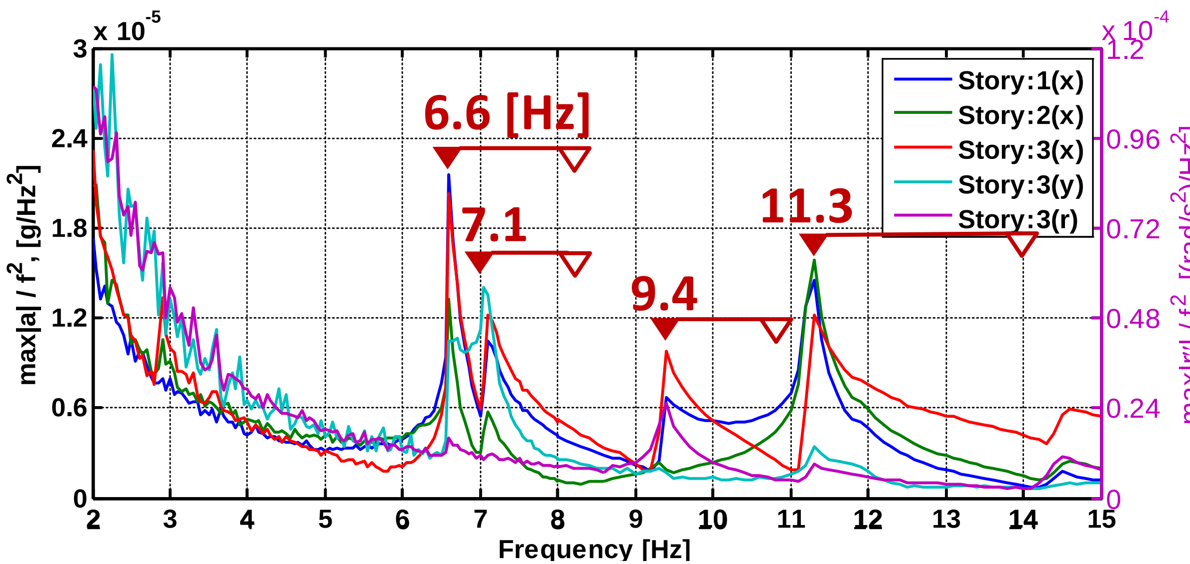
FREQUENCY RESPONSE FUNCTIONS

- **Building 1, X-direction**

No damage



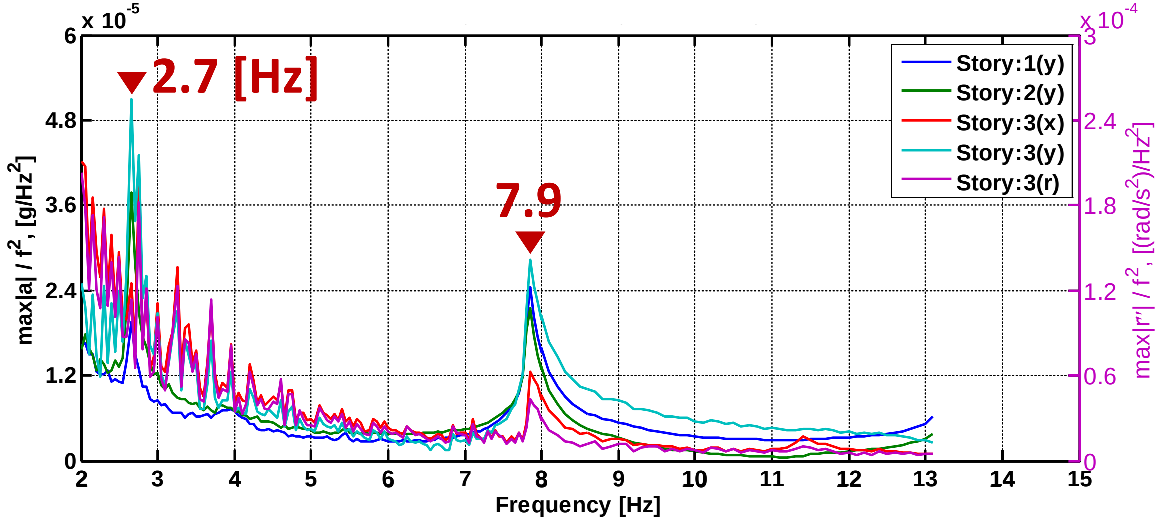
After 1.5% drift



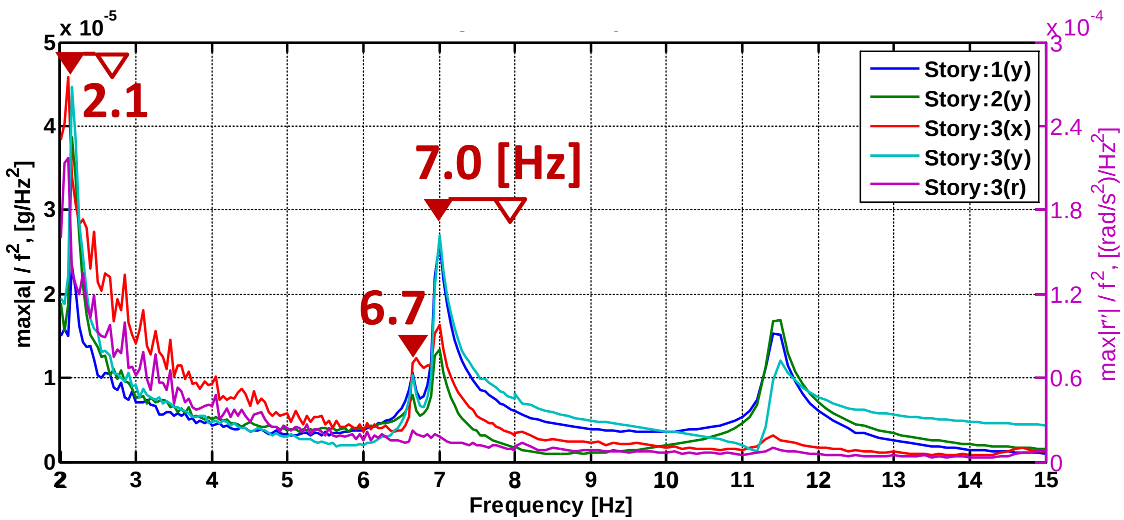
FREQUENCY RESPONSE FUNCTIONS

- **Building 1, Y-direction**

No damage



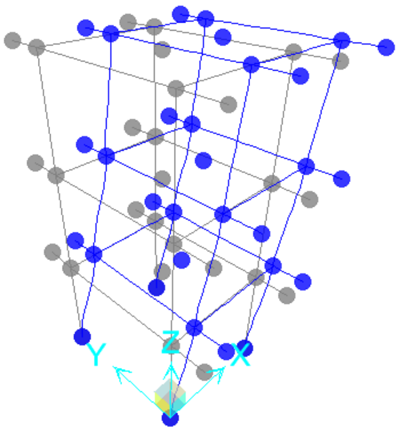
After 1.5% drift



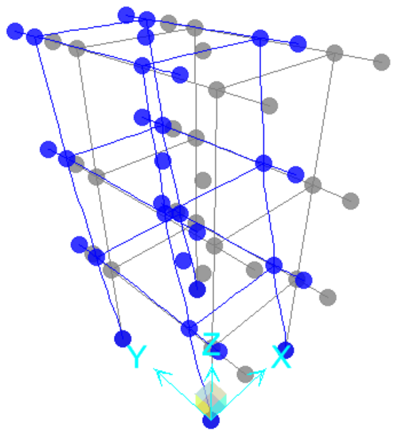
FINITE ELEMENT MODEL

İTÜ

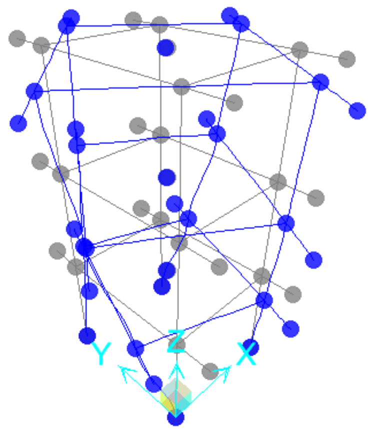
- **Estimated Modal Characteristics of Building 2**



Mode 1

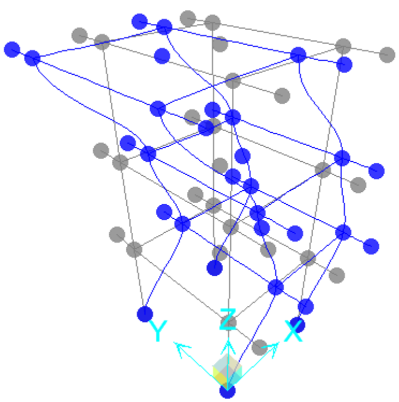


Mode 2

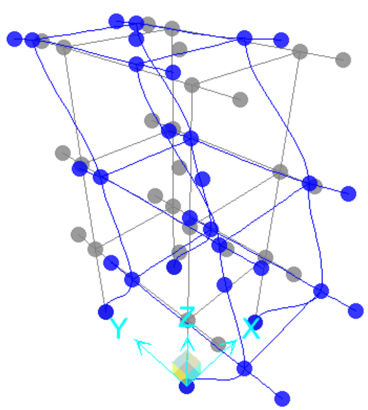


Mode 3

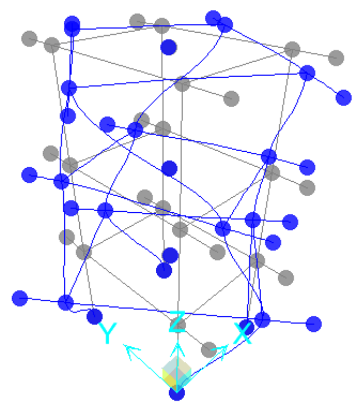
Mode	Freq. [Hz]	Period [s]
1	2.11	0.473
2	2.12	0.473
3	2.79	0.358
4	6.00	0.166
5	6.02	0.166
6	7.86	0.127
7	8.89	0.112
8	8.89	0.112
9	11.4	0.0873



Mode 4



Mode 5



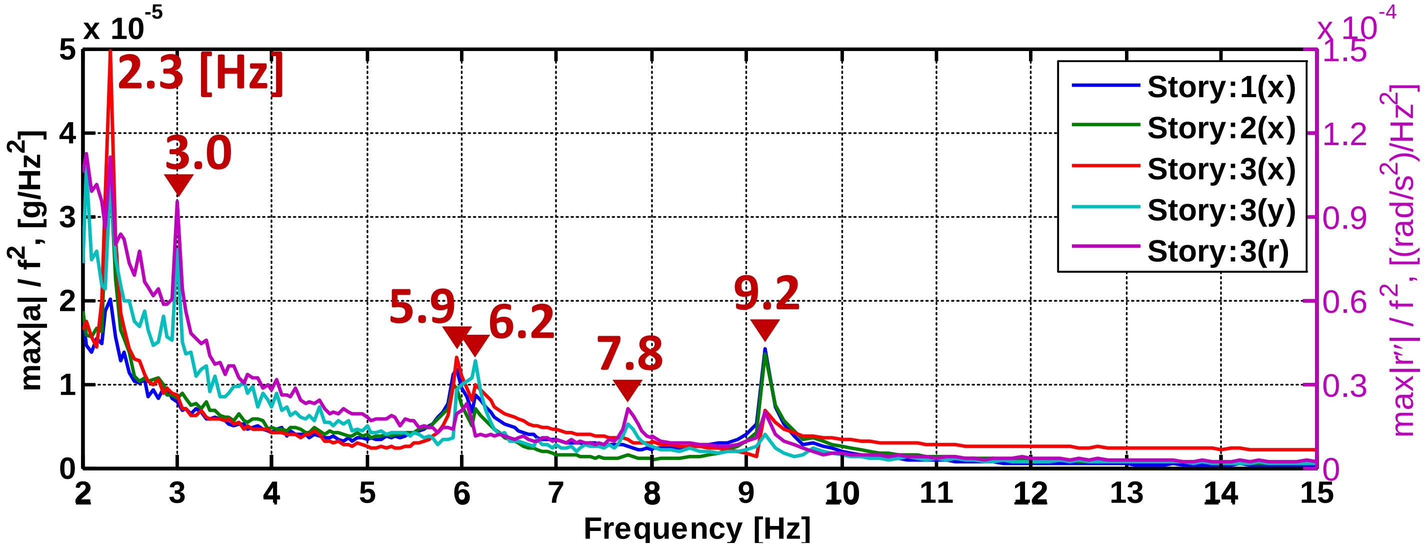
Mode 6

SAP2000 Ultimate 16.0.0
Structural Analysis Program

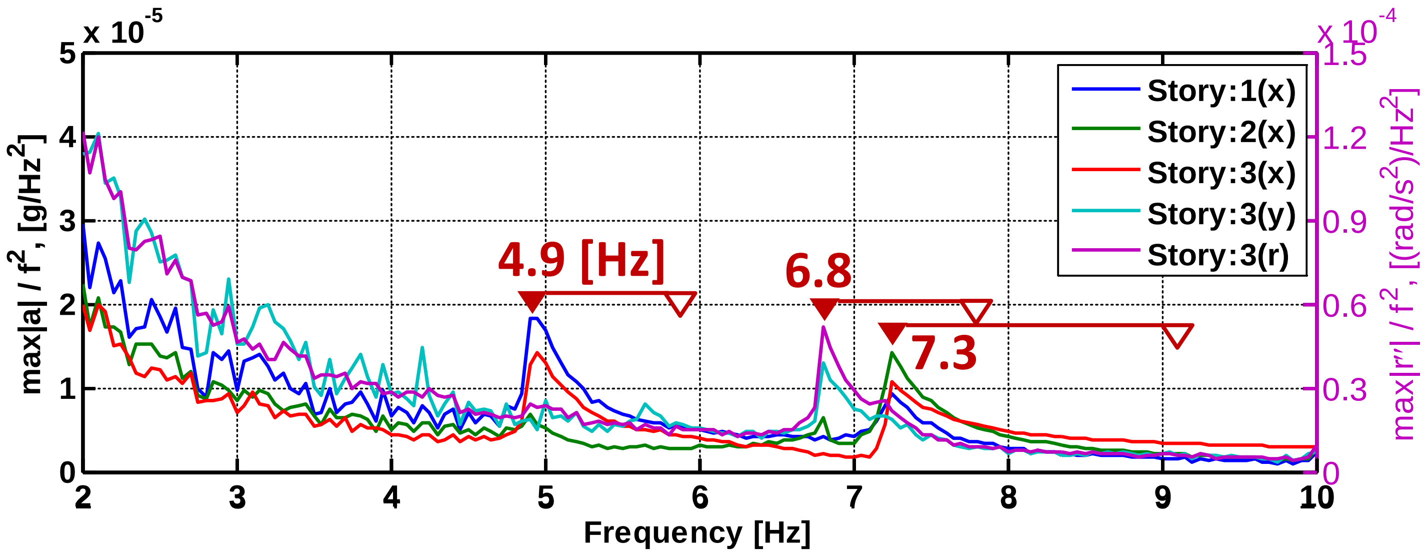
FREQUENCY RESPONSE FUNCTIONS

- **Building 2, X-direction**

No damage

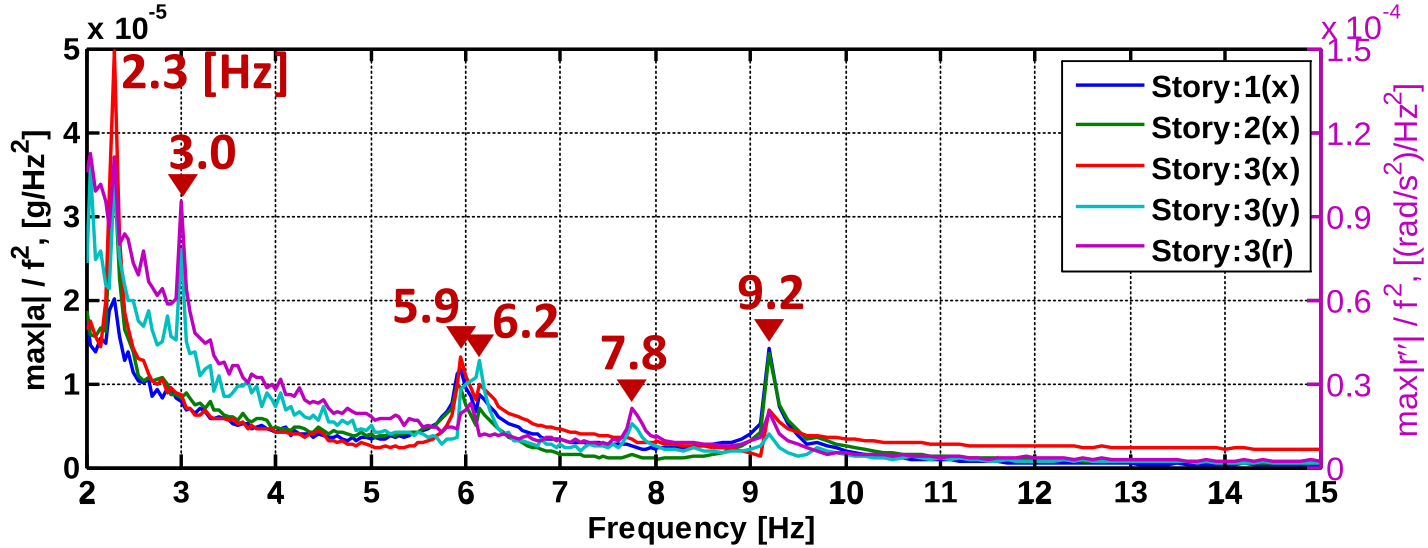


After 0.5% drift

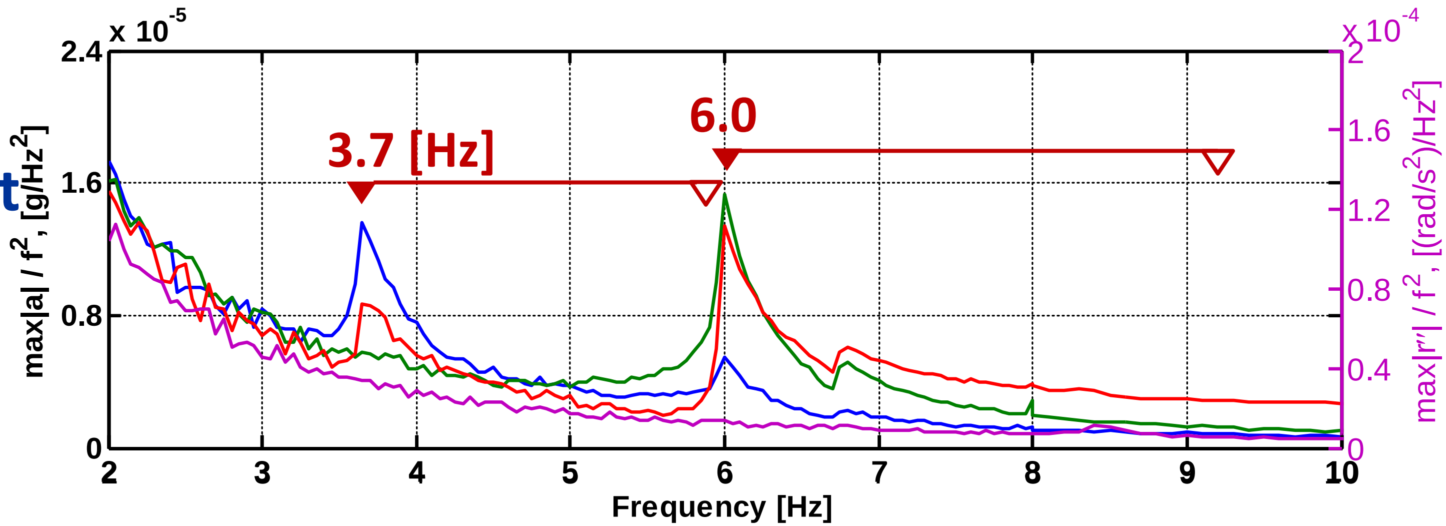


- **Building 2, X-direction**

No damage



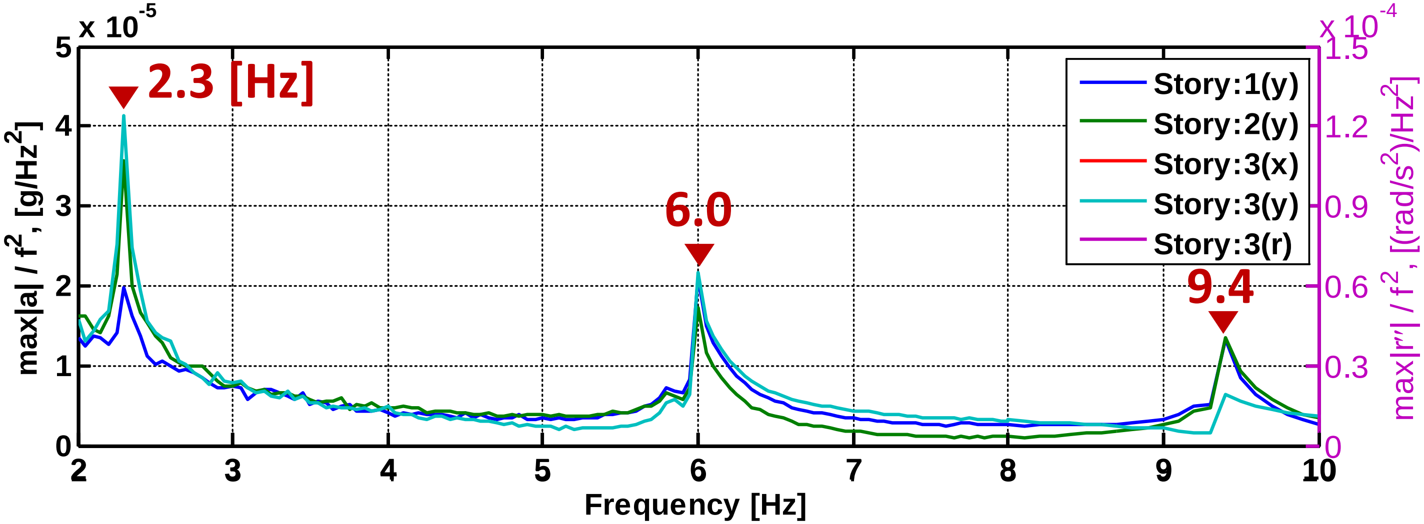
After 3.0% drift



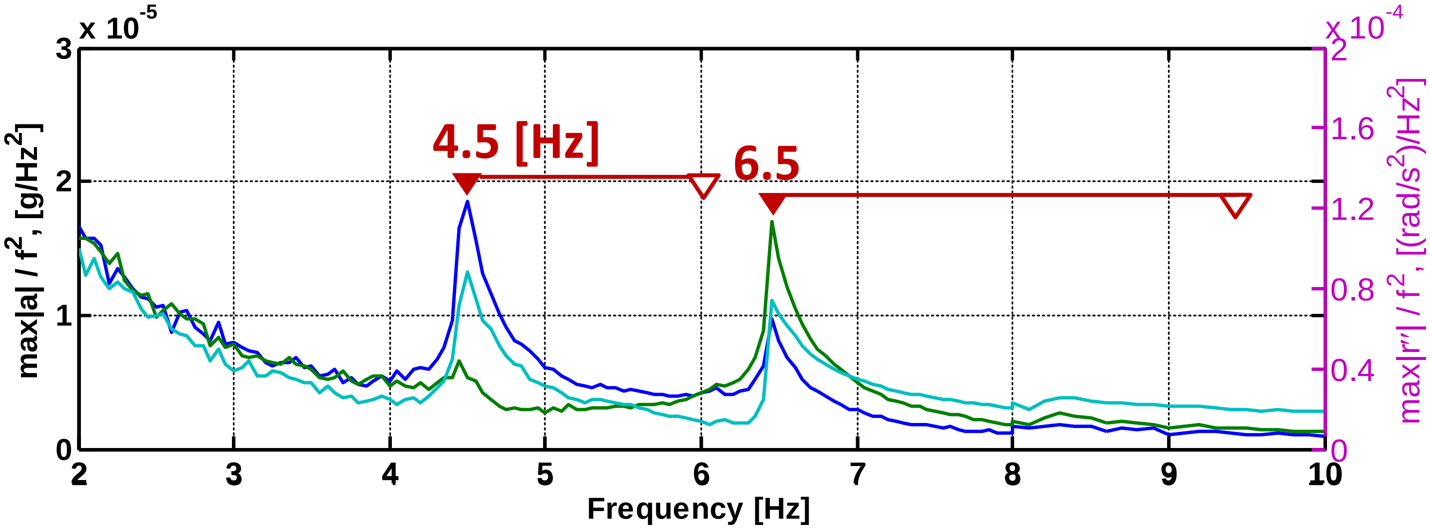
FREQUENCY RESPONSE FUNCTIONS

- **Building 2, Y-direction**

No damage

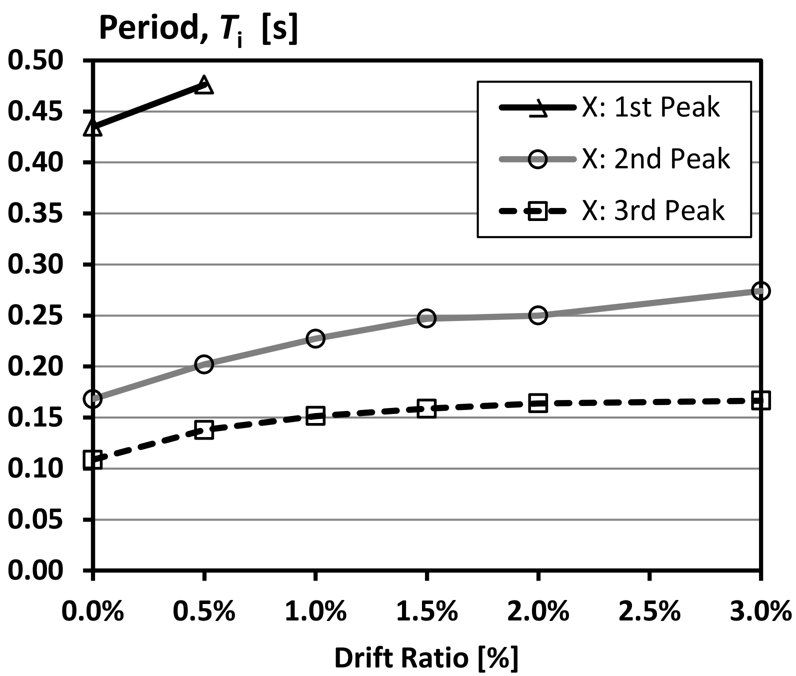


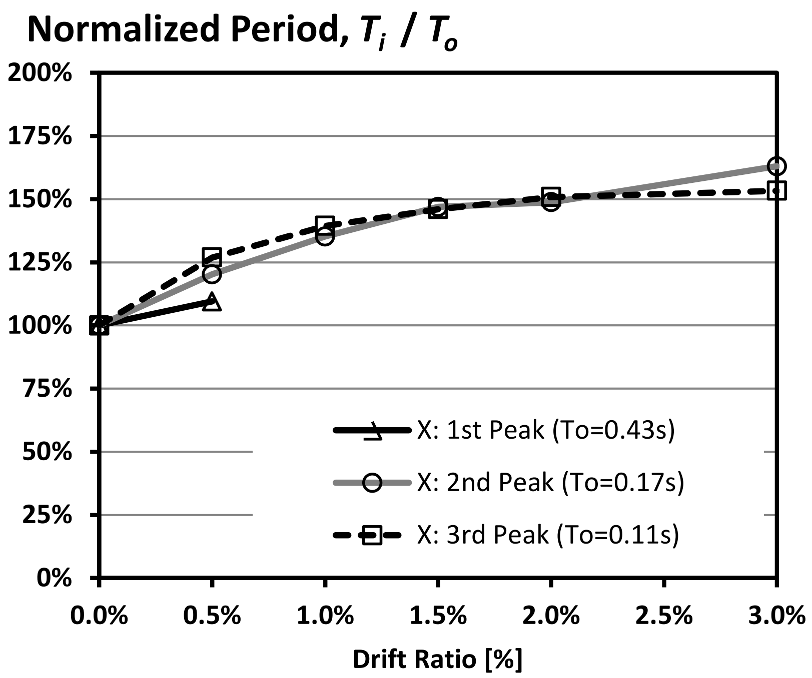
After 3.0% drift



PERIOD ELONGATION

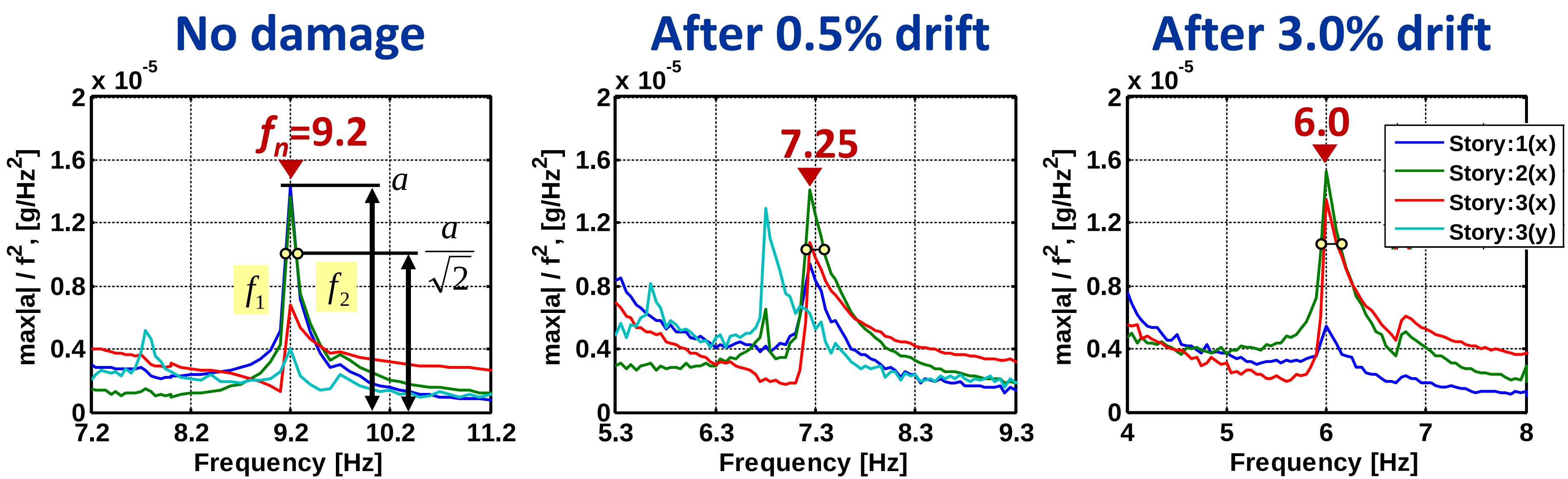
- **Building 2: Elongation of modal periods with increasing damage**





FREQUENCY RESPONSE FUNCTIONS

- **Identification of Damping using Half Power Bandwith Method**



$$\zeta = \frac{f_2 - f_1}{2 f_n}$$ *

ζ= 0.6%

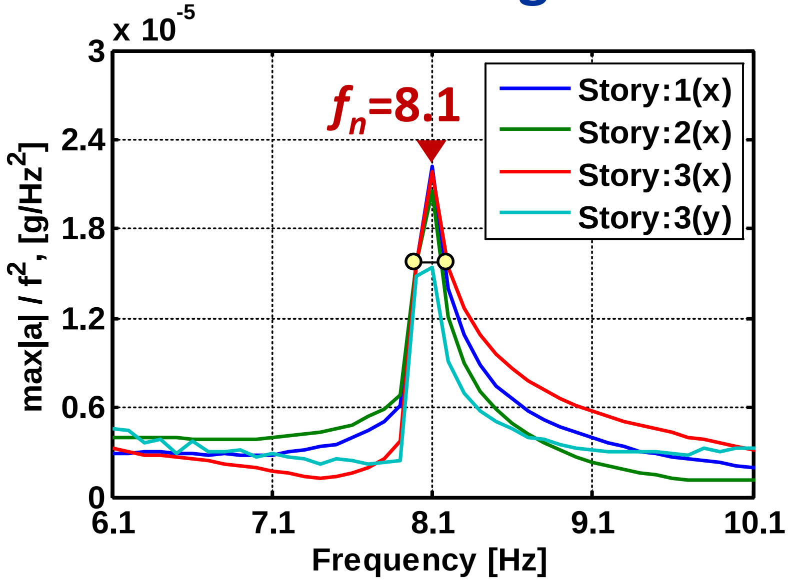
ζ= 1.4%

ζ= 1.4%

*Chopra (2012)

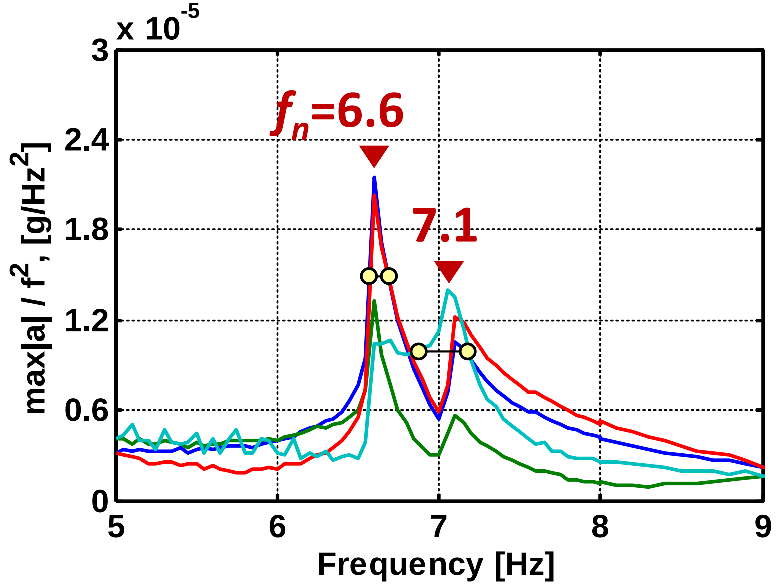
- **Issues related to damping when the peaks are coincident: (Building 1)**

No damage



ζ= 1.3%

After 1.5% drift



ζ= 1.1%

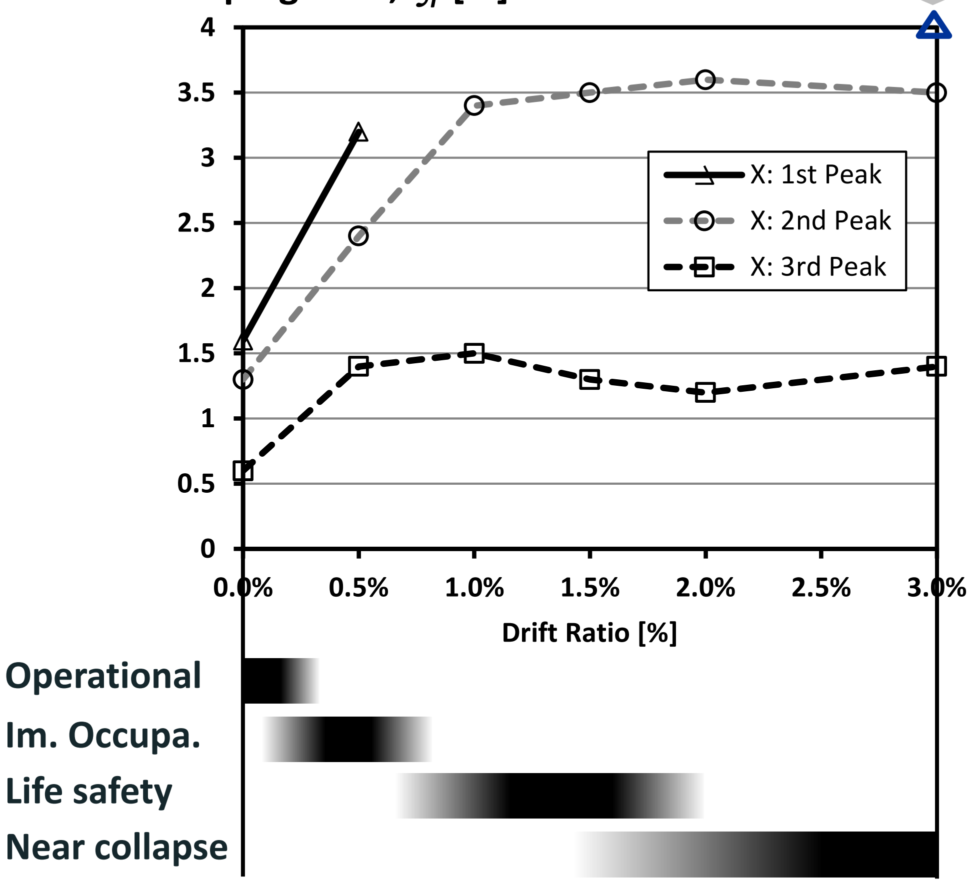
ζ= 2.6%

PERIOD AND DAMPING INCREASE

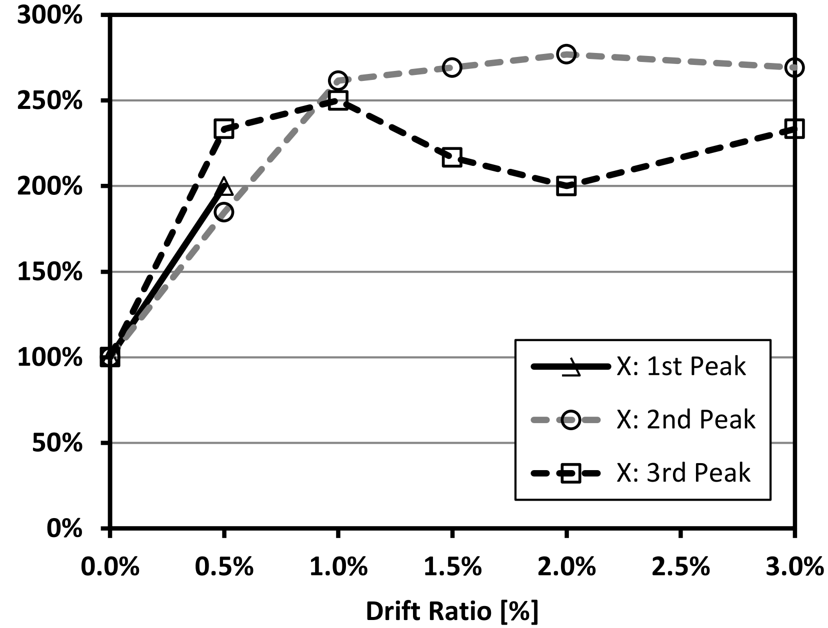
- **Building 2, X-Direction**

***Extrapolated*:**
2.5×(1.6%) = 4%

Damping ratio, ζ_i [%]



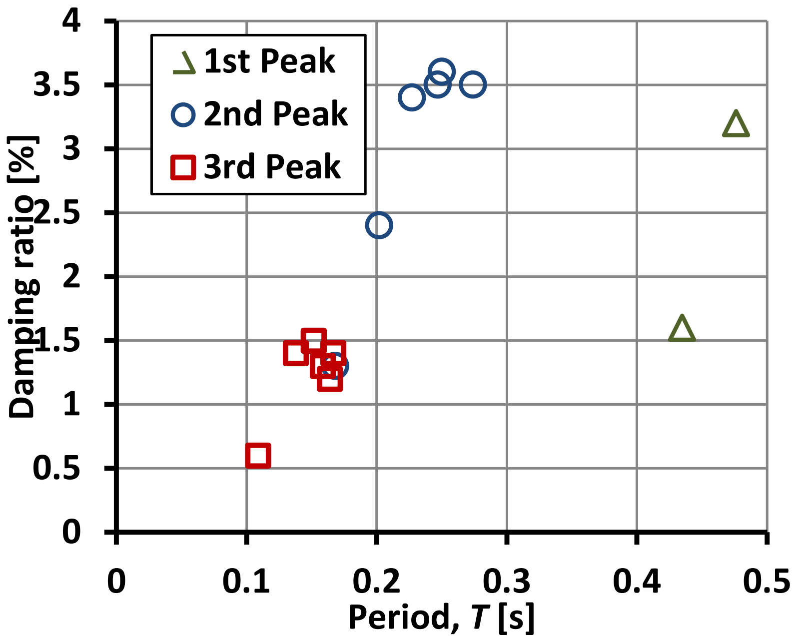
Normalized Damping, ζ_i / ζ_o



DAMPING MODELLING

- Building 2, X-Direction

Observed Repsonse

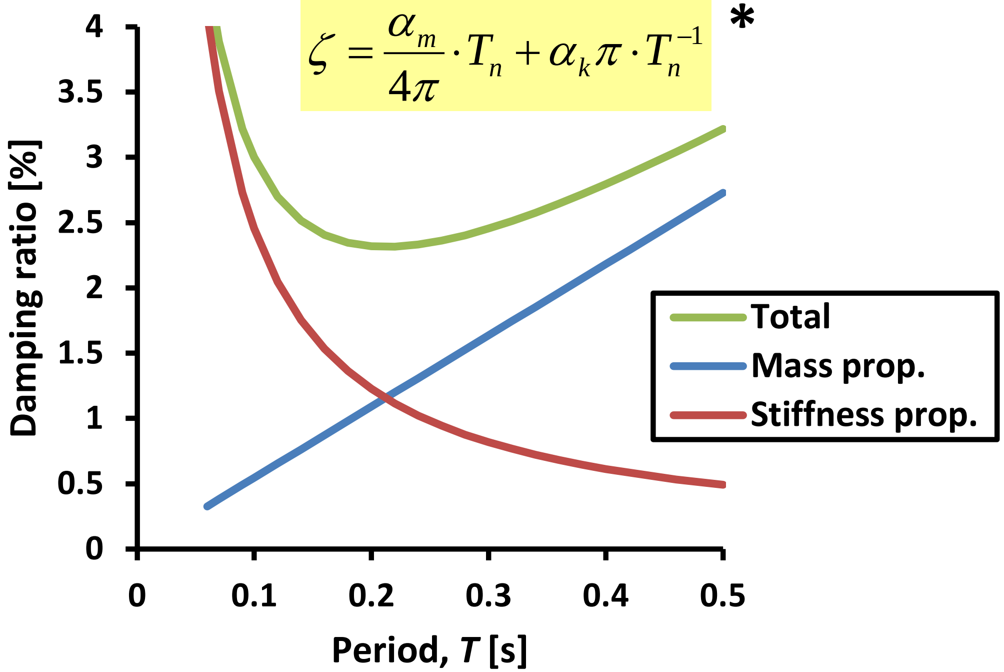


- *Very limited observation set*
- *No soil flexibility*
- *No non-structural elements*

Conventional Model

Rayleigh Damping: $[C]=\alpha_m[M]+\alpha_k[K]$

$$\zeta = \frac{\alpha_m}{4\pi}\cdot T_n + \alpha_k \pi \cdot T_n^{-1}$$ *



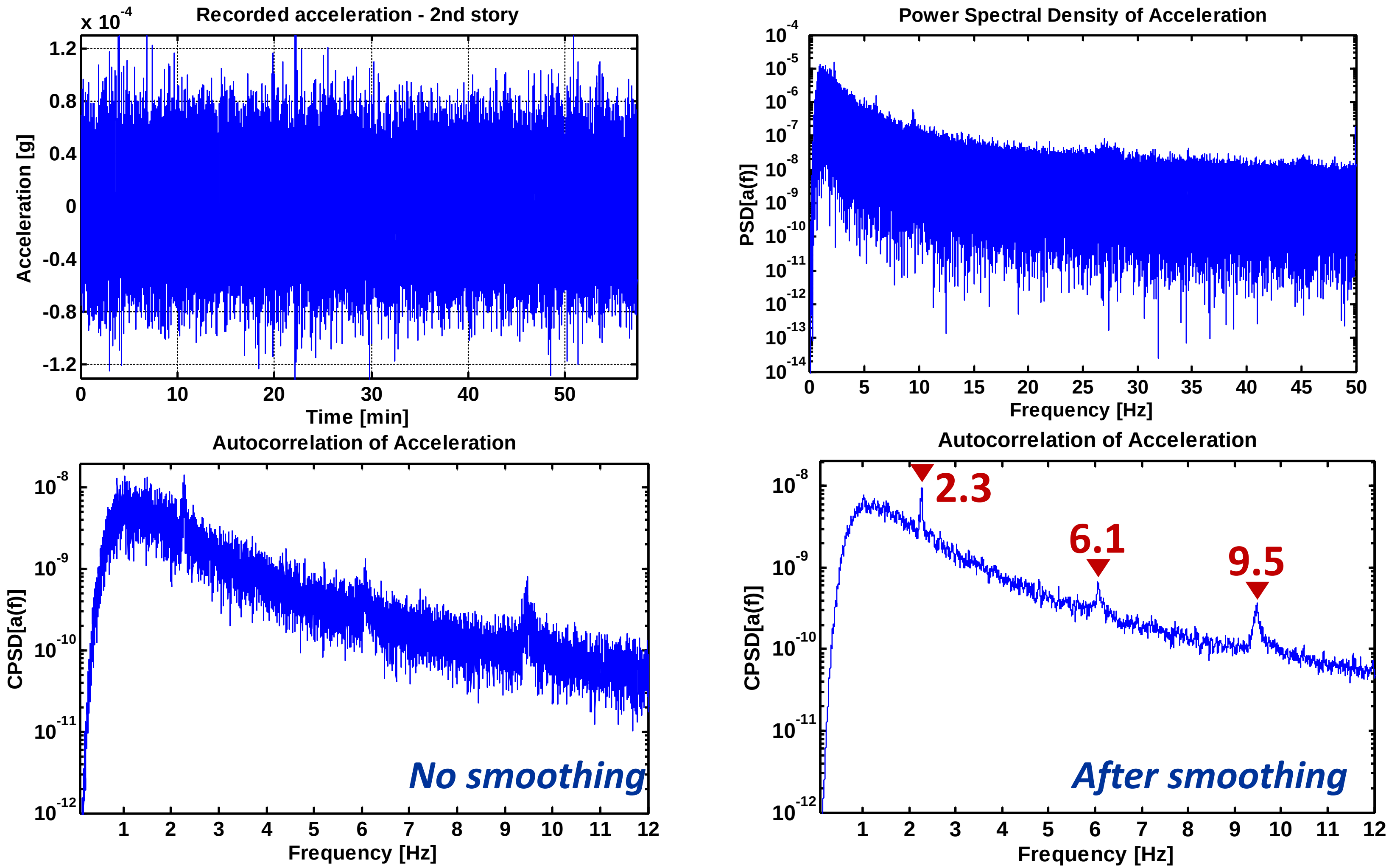
"Extended Rayleigh Damping (with multiple constraints)" or similar models may be more suitable.

*Clough & Penzien (1995)

AMBIENT VIBRATION

- **Ambient vibrations were measured (when the time allowed)**

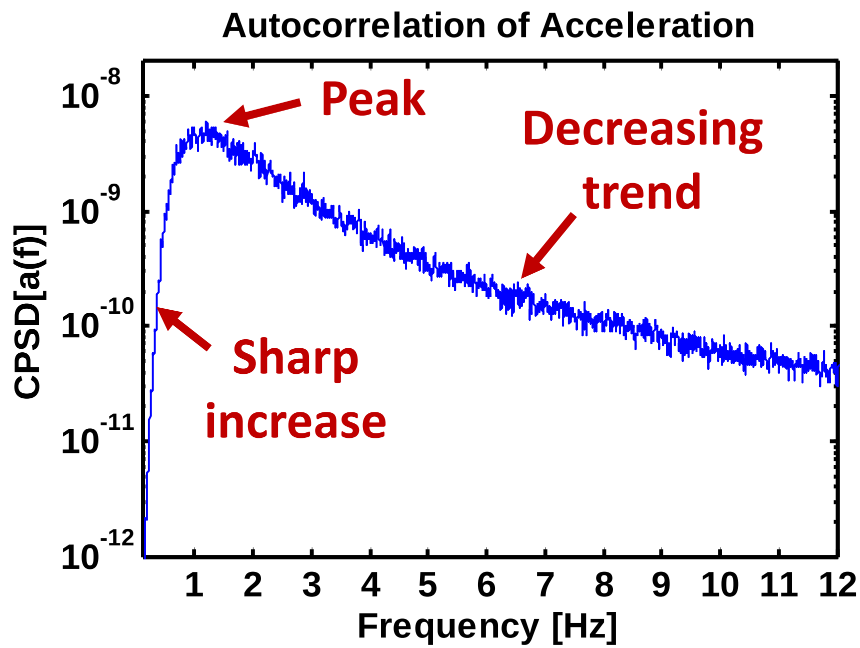
Example: **Building 2, X-Direction, No Damage**

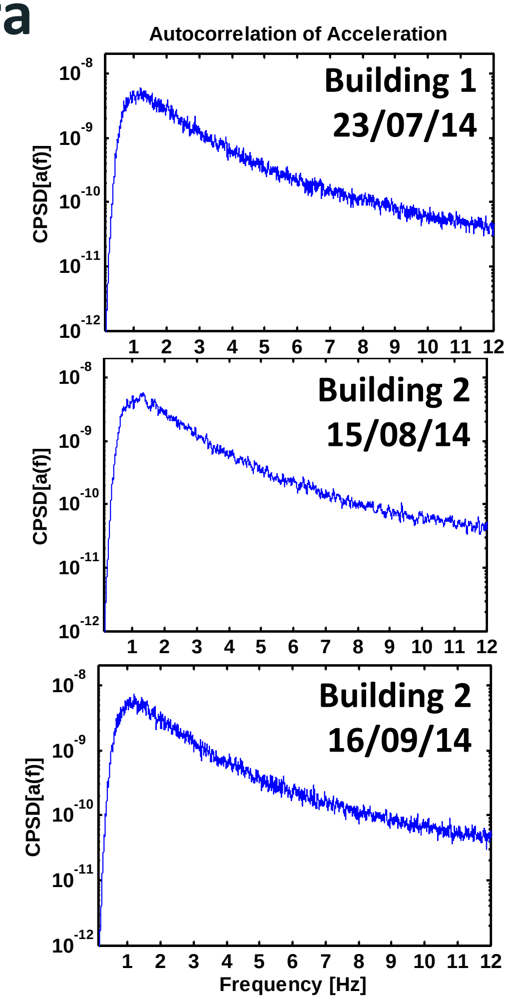


AMBIENT VIBRATION

- **Issues related to the shape of resulting spectra**

Example: Case for sensor at the foundation (which is expected to provide a flat spectrum).





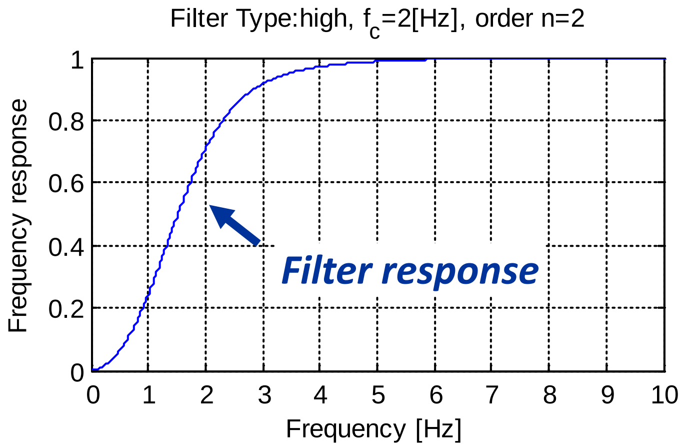
Considered causes:

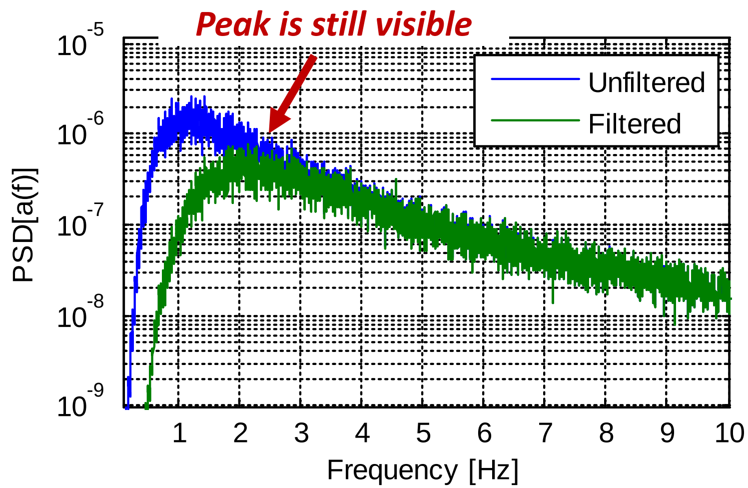
- Sensor limitation
- Cabling limitation
- Connection to data logger
- *Other?*

All have the same trend

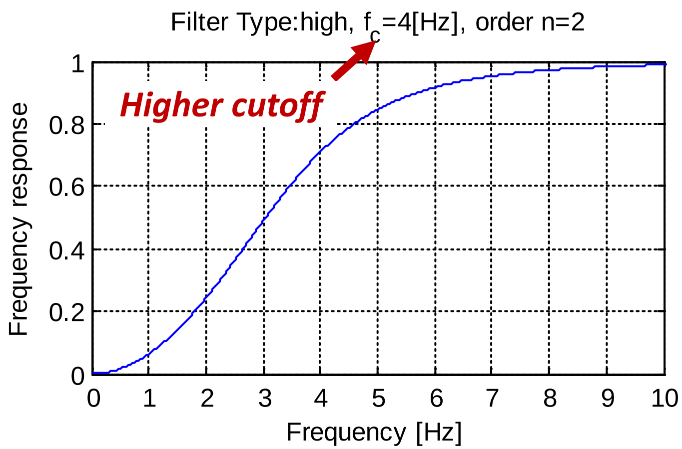
- **Simple filtering did not solve the issue**

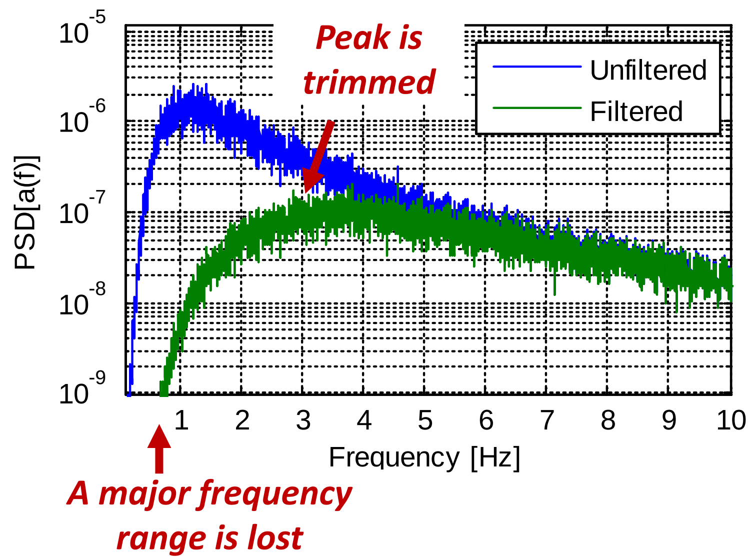
Trial 1





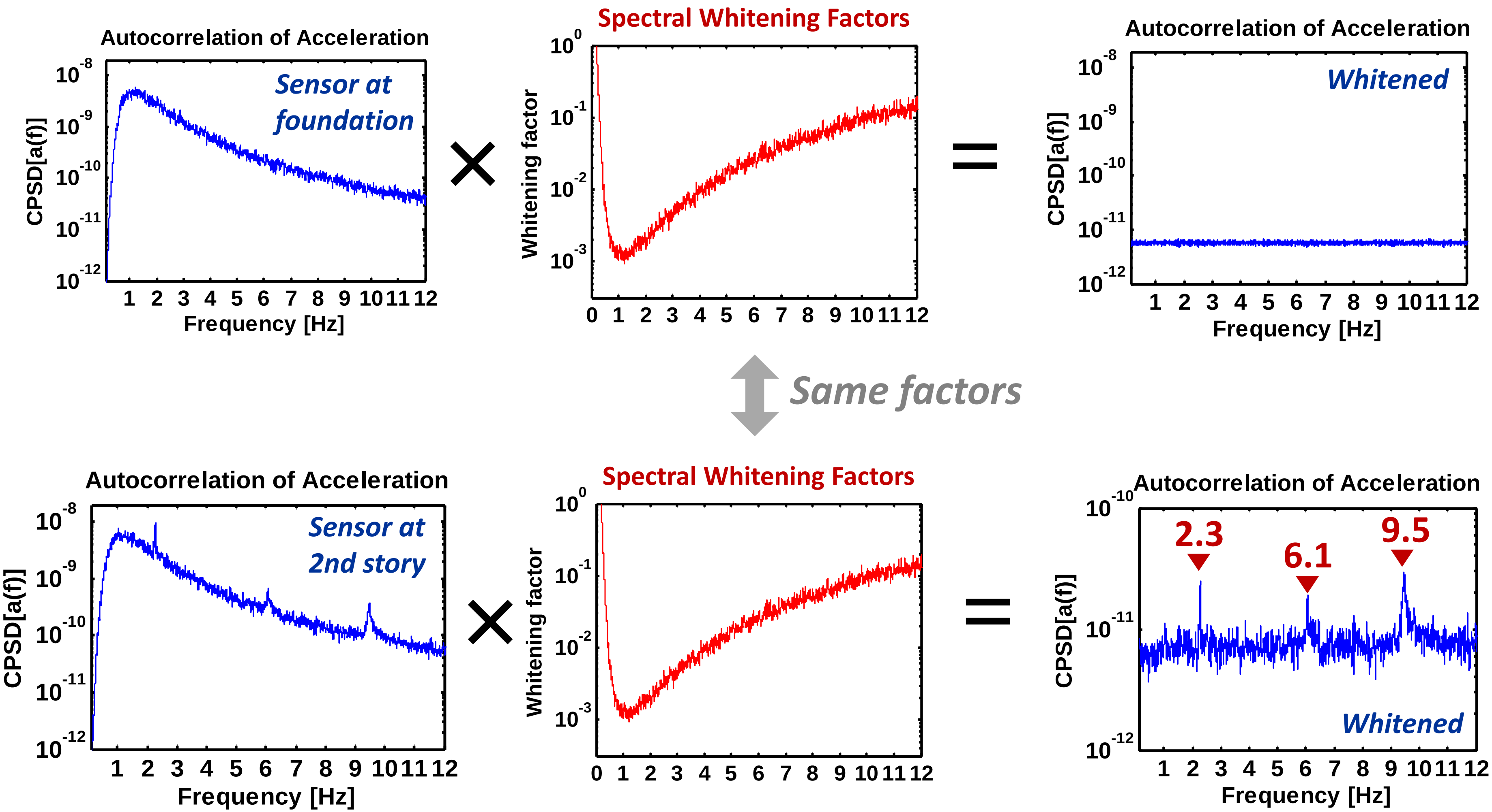
Trial 2





AMBIENT VIBRATION

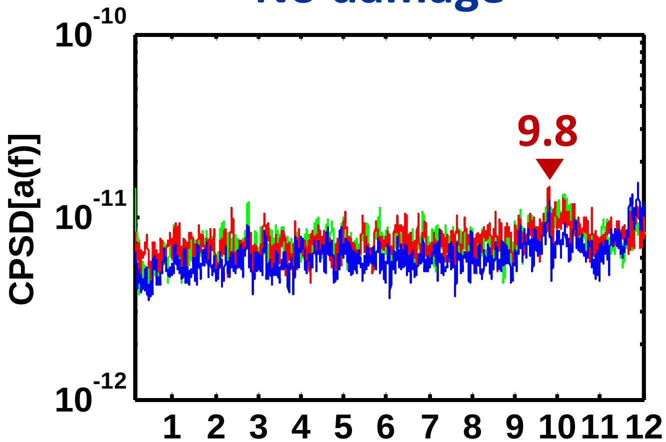
- Application of "spectral whitening"



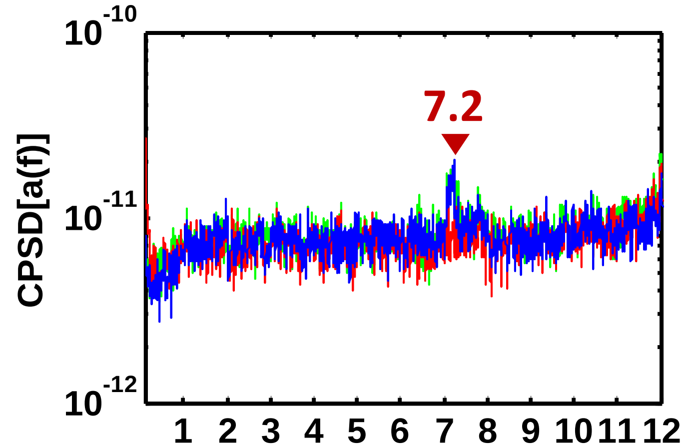
- Resulting "whitened" ambient vibration spectra

Building 1

No damage

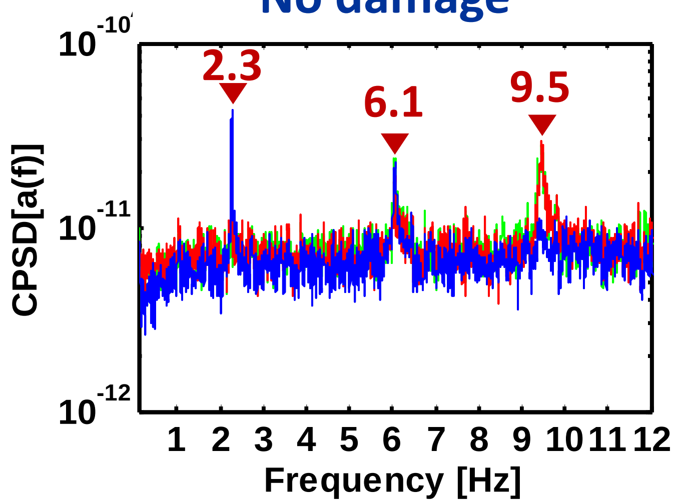


After 1.5% drift

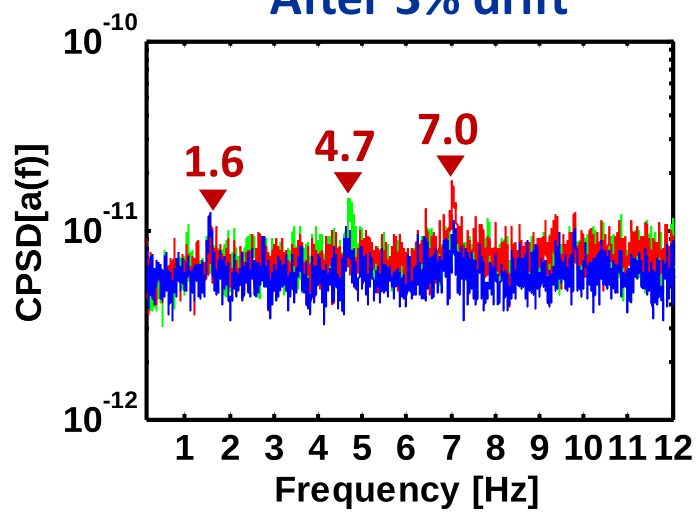


Building 2

No damage



After 3% drift



ONGOING WORK

- **Stiffness evaluation:**
  Forced vibration → K_F , Undamaged v.s. damaged
  Ambient vibration → K_A, " " " "
  Measured static cyclic → K_S, " " " "
  ...
- **Mode shape identification**
  Forced vibration → (ϕ_1, ϕ_2, ...), Undamaged v.s. damaged
  Ambient vibration → (ϕ_1, ϕ_2, ...) " " " "
  ...
- **Wavelet analysis of the data (together with Prof.Kusunoki)**
- **Application of FE model updating and system identification methods**
  ...

CONCLUSIONS

Preliminary conclusions of the study are, as follows:

- Damping was observed to increase rapidly as the buildings deformed beyond their yield limit.
- Observed damping behaviour is different than that is assumed in the conventional models.
- There are critical issues related to identification of damping in the case for closely spaced modes.
- Ambient vibration measurements required special processing.

Other conclusions are expected to be drawn as the ongoing investigations progress.

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Thank you

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