RC 2018 XVII Reunión del CONCRETO

El evento del Cemento, el Concreto y los Prefabricados

RC 2018 XVII Reunión del CONCRETO

El evento del Cemento, el Concreto y los Prefabricados

Avances en diseño y materiales para edificios super altos

Progress in design and materials for super tall buildings

Carlos Turizo, PE, SI
DeSimone Consulting Engineers
USA

DESIMONE


Biscayne Bay
Biscayne Bay Aquatic Preserve
CESIUM
CyberCity3D
MIAMI DDA


Biscayne Bay
Biscayne Bay Aquatic Preserve
CESIUM
CyberCity3D
MIAMI DDA

Design of High Rise Buildings

- Strength
- Serviceability
- Building Response

Design of Tall Slender Buildings

- Building Response
- Serviceability
- Strength

Design of Tall Slender Buildings

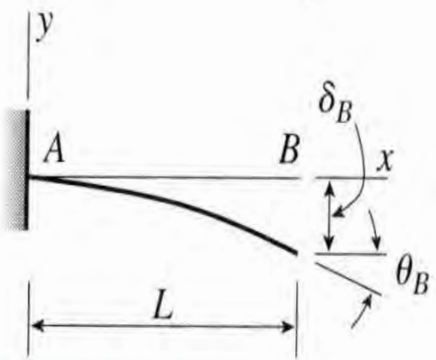
- Building Response
  - Engage Wind Tunnel
  - Identify Building Response and any Aeroelastic Anomalies
  - Identify Damping Strategies
  - If necessary, Study Shaping Options and Perform Sensitivity Analysis
- Serviceability
- Strength

Factors Affecting Tall Slender Building Response

- Shape
- Damping
- Height
- Slenderness
- Weight

  F = Ma

Tall Building As Cantilever Beam



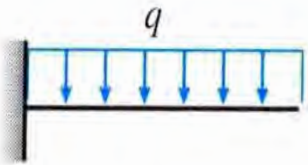
v = deflection in the y direction (positive upward)

$v' = dv/dx$ = slope of the deflection curve

$\delta_B = -v(L)$ = deflection at end B of the beam (downward)

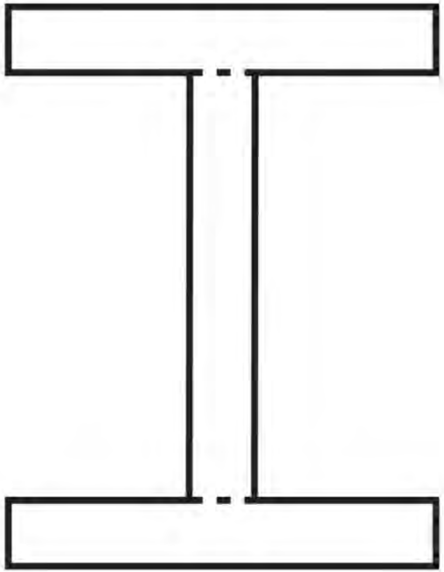
$\theta_B = -v'(L)$ = angle of rotation at end B of the beam (clockwise)

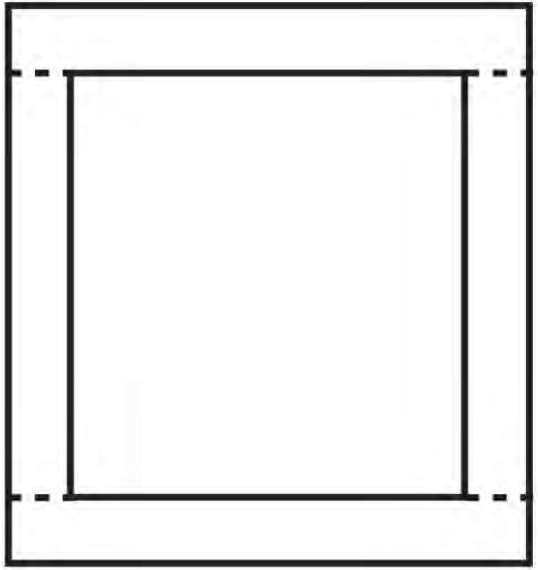
EI = constant



$$v = -\frac{qx^2}{24EI}(6L^2 - 4Lx + x^2) \qquad v' = -\frac{qx}{6EI}(3L^2 - 3Lx + x^2)$$

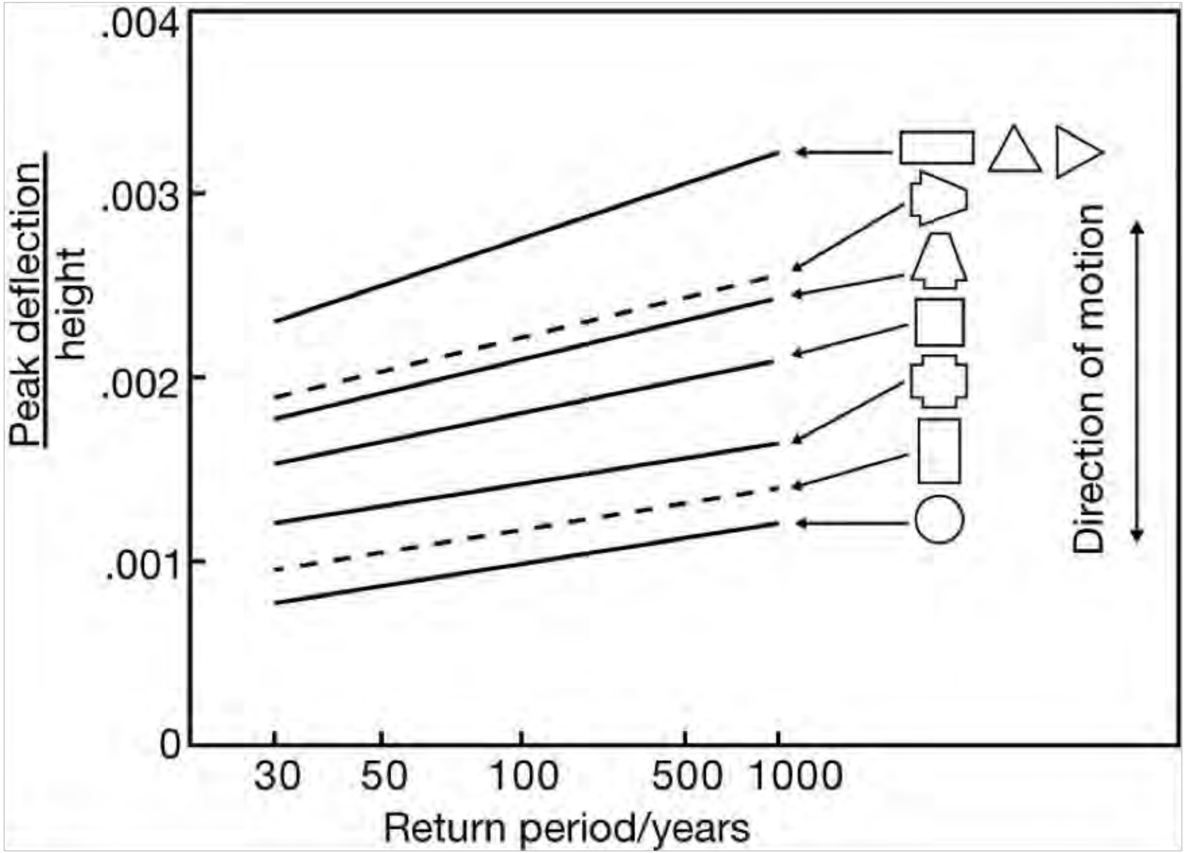
$$\delta_B = \frac{qL^4}{8EI} \qquad \theta_B = \frac{qL^3}{6EI}$$



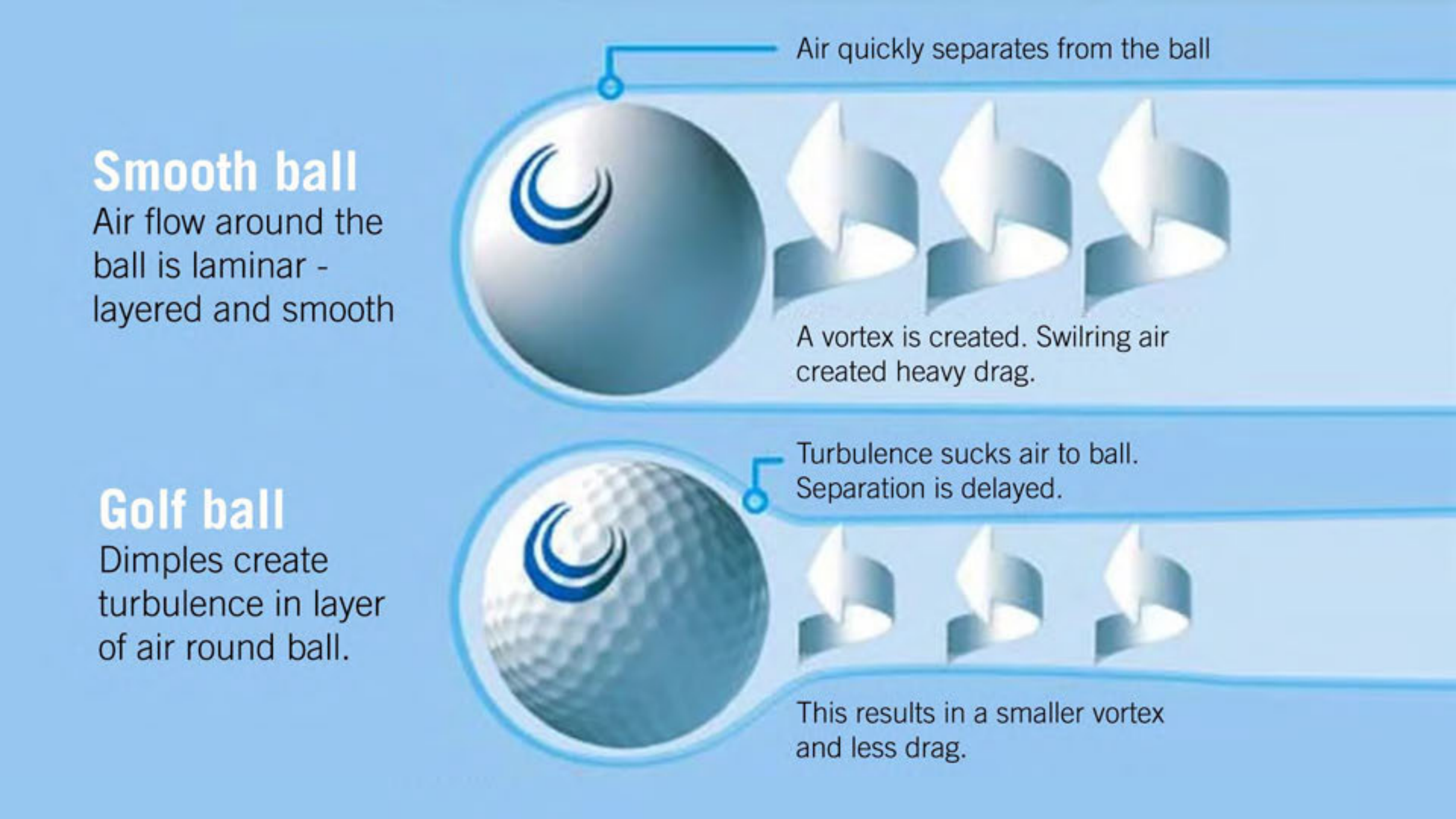


Wind Effects on Slender Buildings

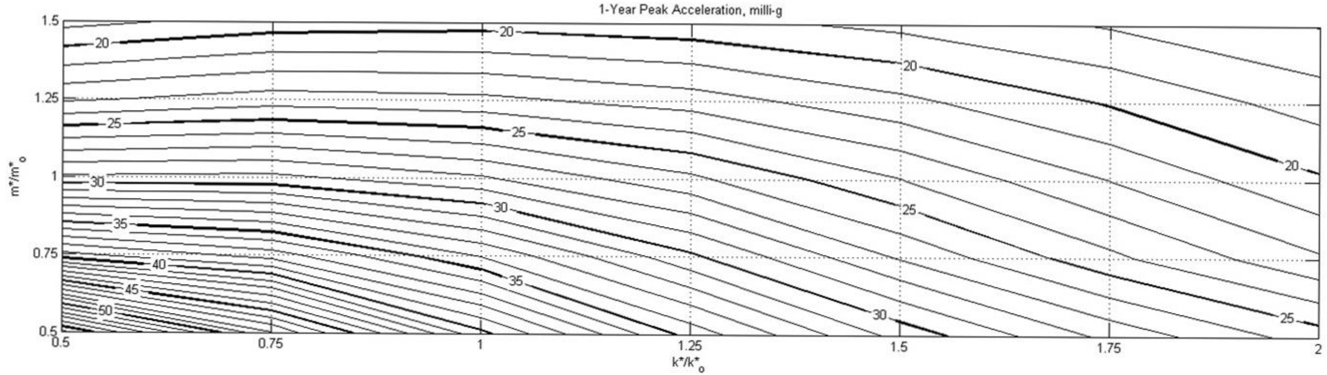
- For slender buildings, a longer period and a smaller footprint combine to create across-wind motions at wind speeds that occur more frequently
- Two design strategies:
  - Modify the architecture to lessen the wind force
  - Structural options – stiffness, mass, damping
- As the slenderness of buildings increases, a combination of these strategies is necessary

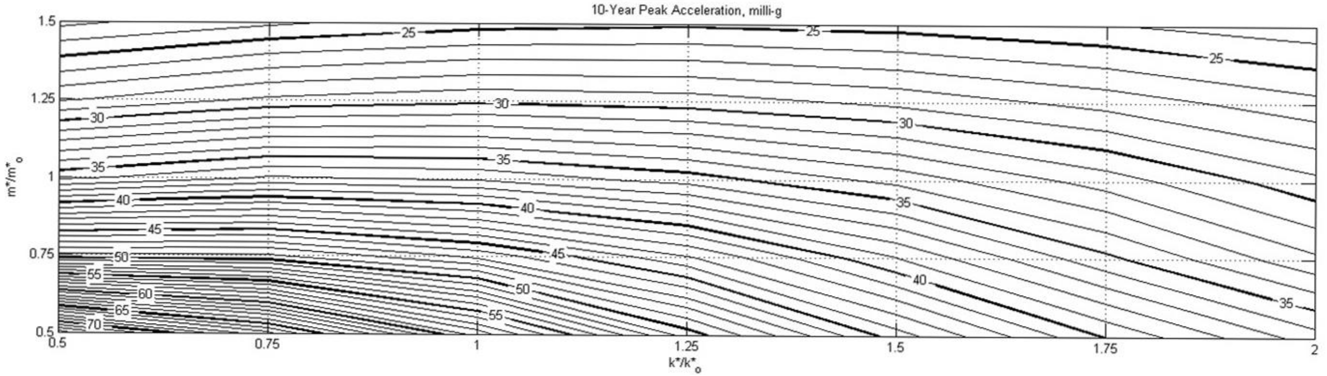


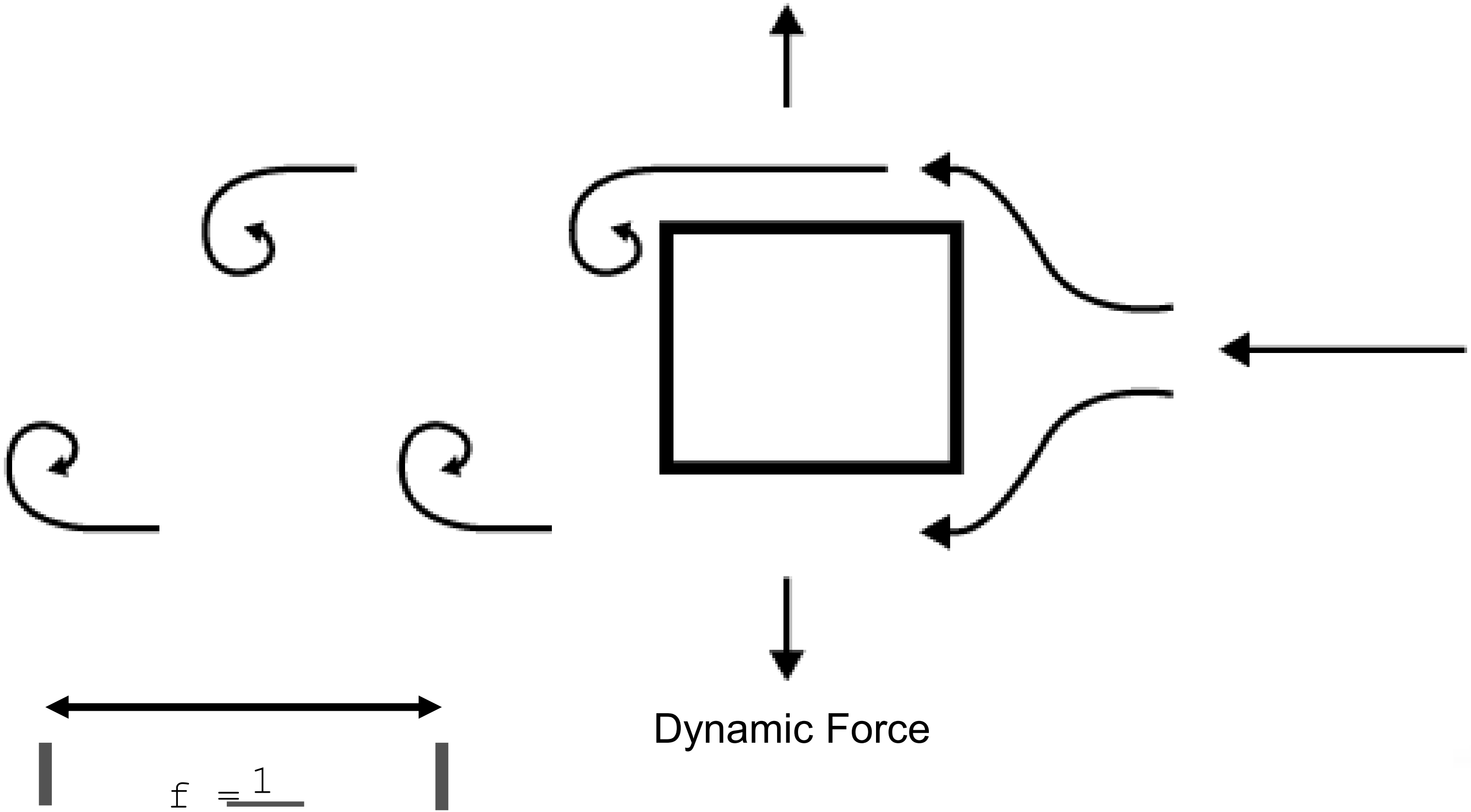
.004
.003
.002
.001
0
Peak deflection / height
30
50
100
500
1000
Return period/years
Direction of motion


Smooth ball
Air flow around the ball is laminar - layered and smooth
Air quickly separates from the ball
A vortex is created. Swilring air created heavy drag.
Golf ball
Dimples create turbulence in layer of air round ball.
Turbulence sucks air to ball. Separation is delayed.
This results in a smaller vortex and less drag.

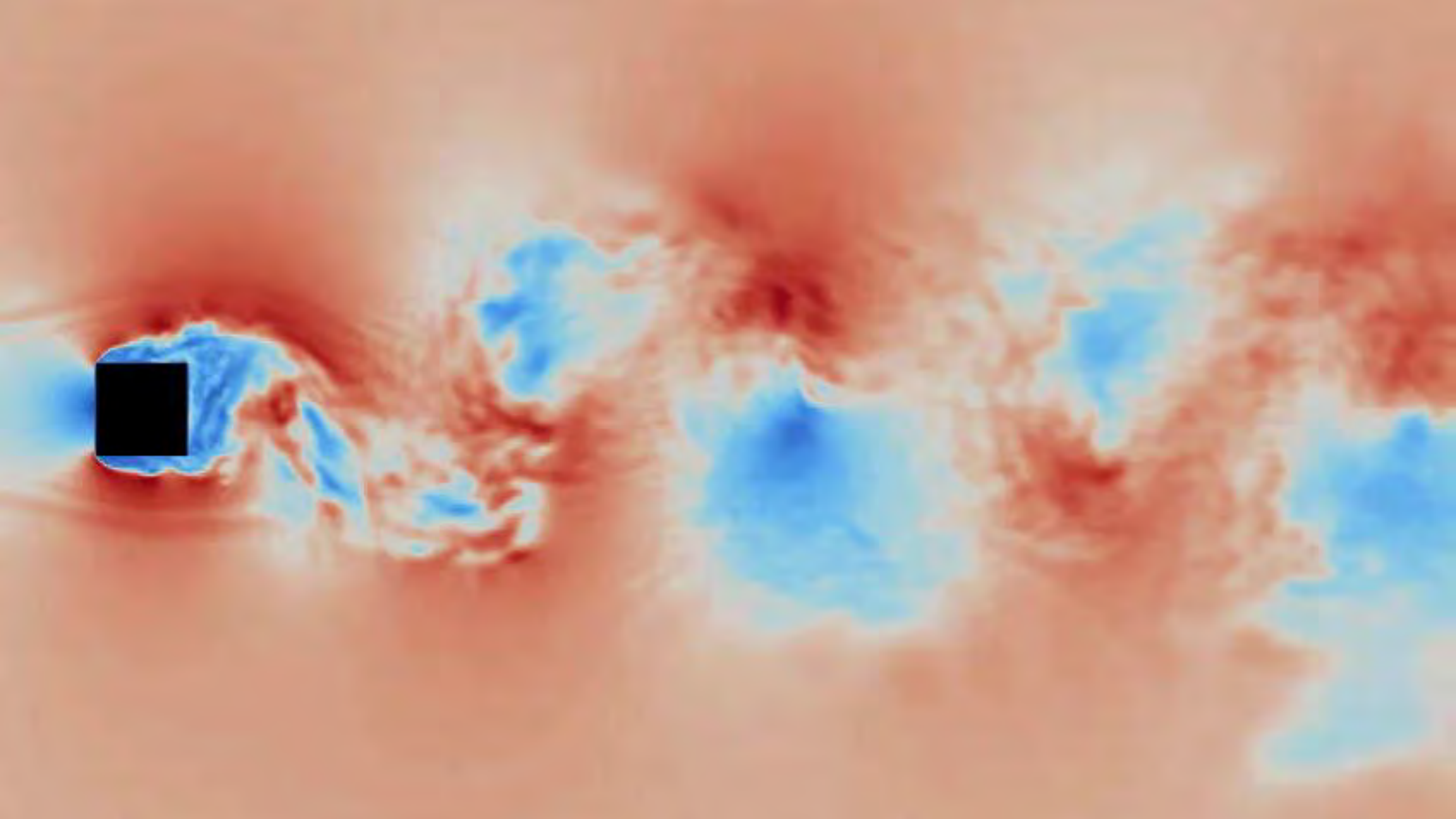
Sensitivity Analysis







$$f = \frac{1}{T}$$



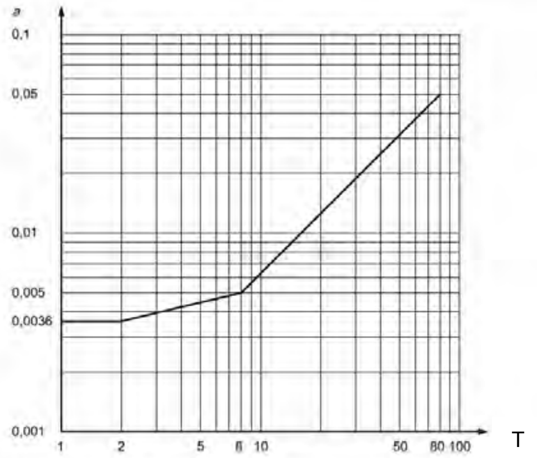
Return Period (Years)	Peak Total Accelerations (milli-g)
	Industry Standard
1	8
10	15-18

Return Period (Years)	Peak Torsional Velocities (milli-rads/sec)
	CTBUH[(6)] Criteria
1	1.5
5	-
10	3

Acceptance Criteria-Frequency Dependence

Return Period (Years)	Peak Total Accelerations (milli-g)
	ISO 10137
1	6-10 Depending on Frequency

ISO 10137:2007(E)



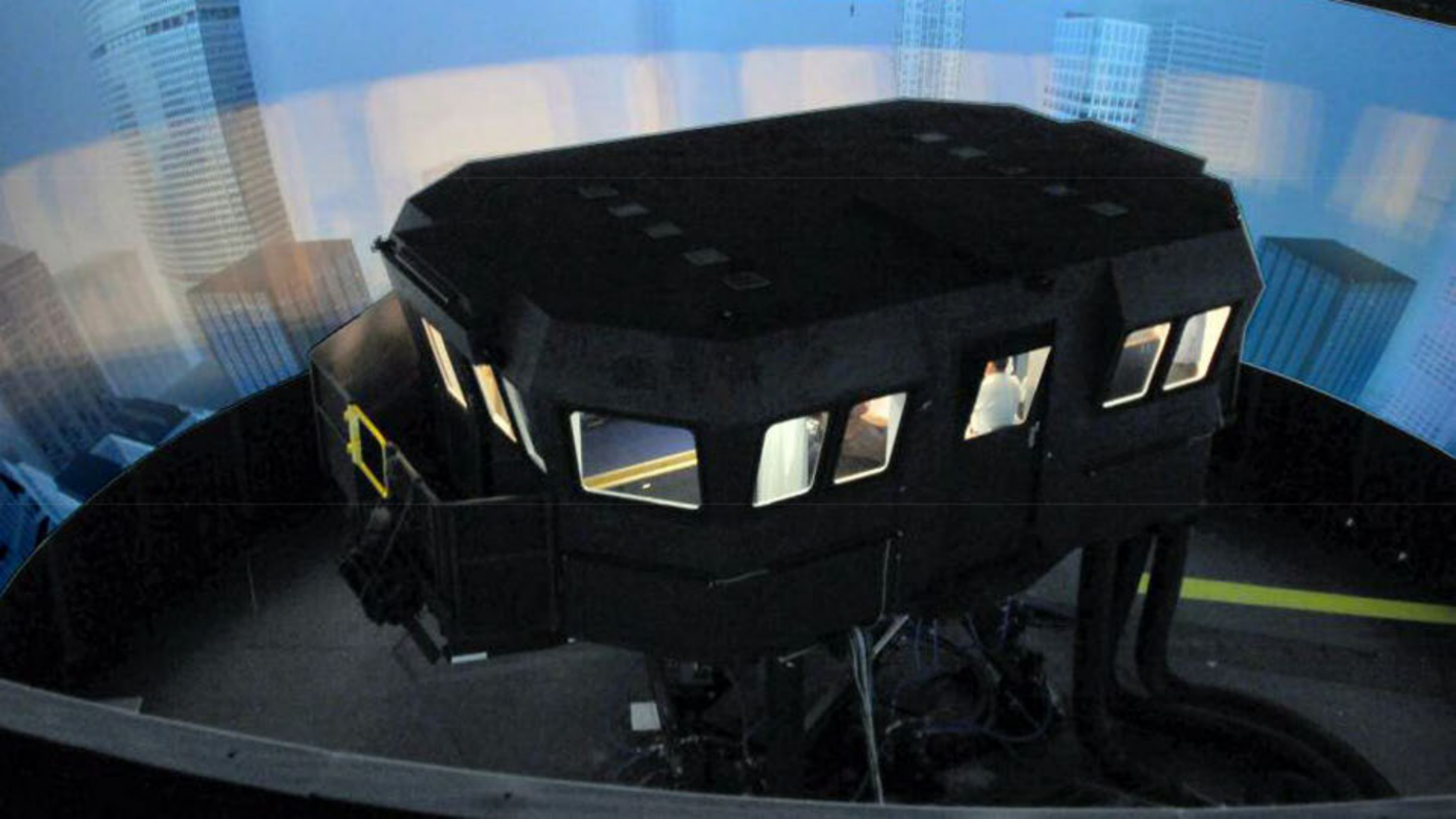
Key

a acceleration (r.m.s.), m/s²

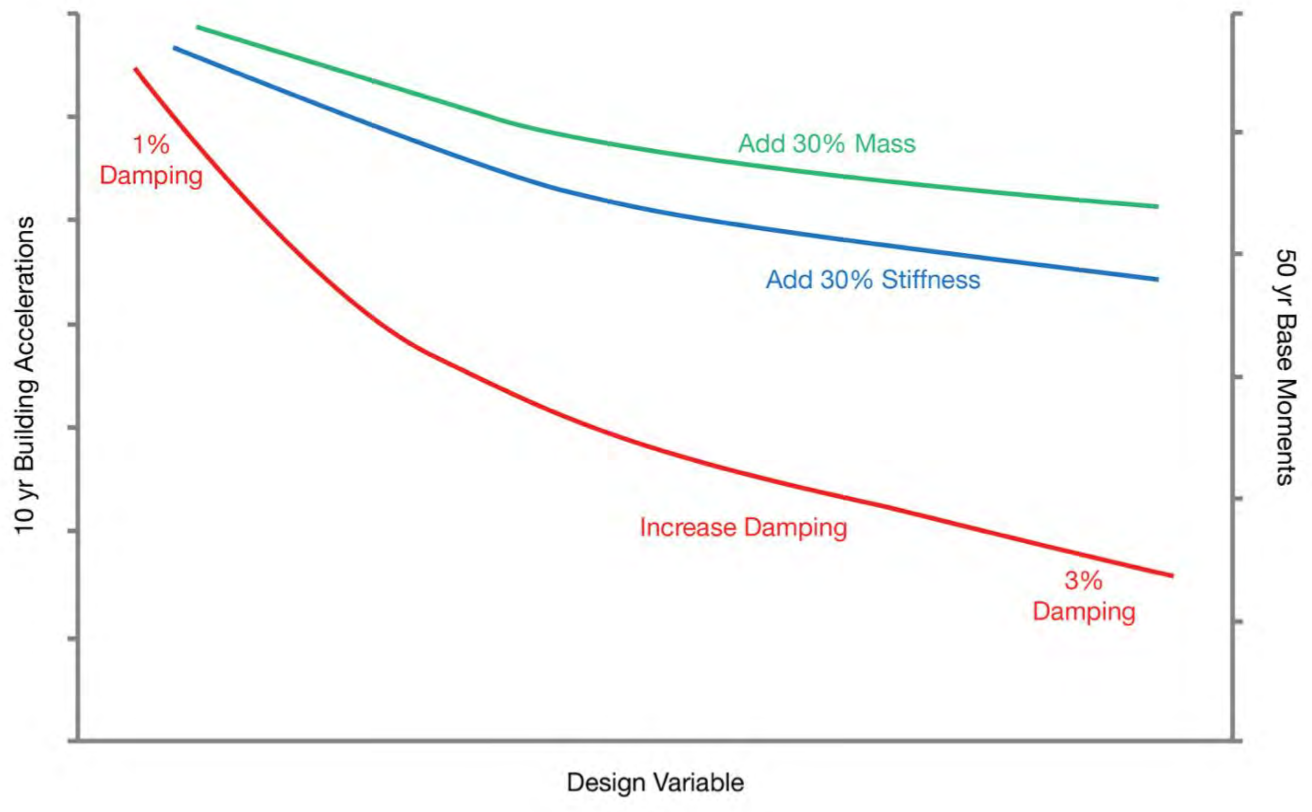
Figure C.3 — Building vibration combined direction (x-, y-, z- axis) acceleration base curve

High Frequency - Short Period

Low Frequency - Long Period



Damping Strategies


10 yr Building Accelerations
50 yr Base Moments
Add 30% Mass
Add 30% Stiffness
1%
Damping
Increase Damping
3%
Damping
Design Variable

$$a \propto \frac{1}{\sqrt{damping}}$$

If we assume 2% inherent damping $\frac{1}{\sqrt{.02}} = 7.07$

If we assume 4% inherent damping $\frac{1}{\sqrt{.04}} = 5.0$

If we assume 6% inherent damping $\frac{1}{\sqrt{.06}} = 4.0$

Going from 2% damping to 6%

$$\frac{4.0}{7.07} = 0.56 \approx 40\% \text{ Reduction}$$

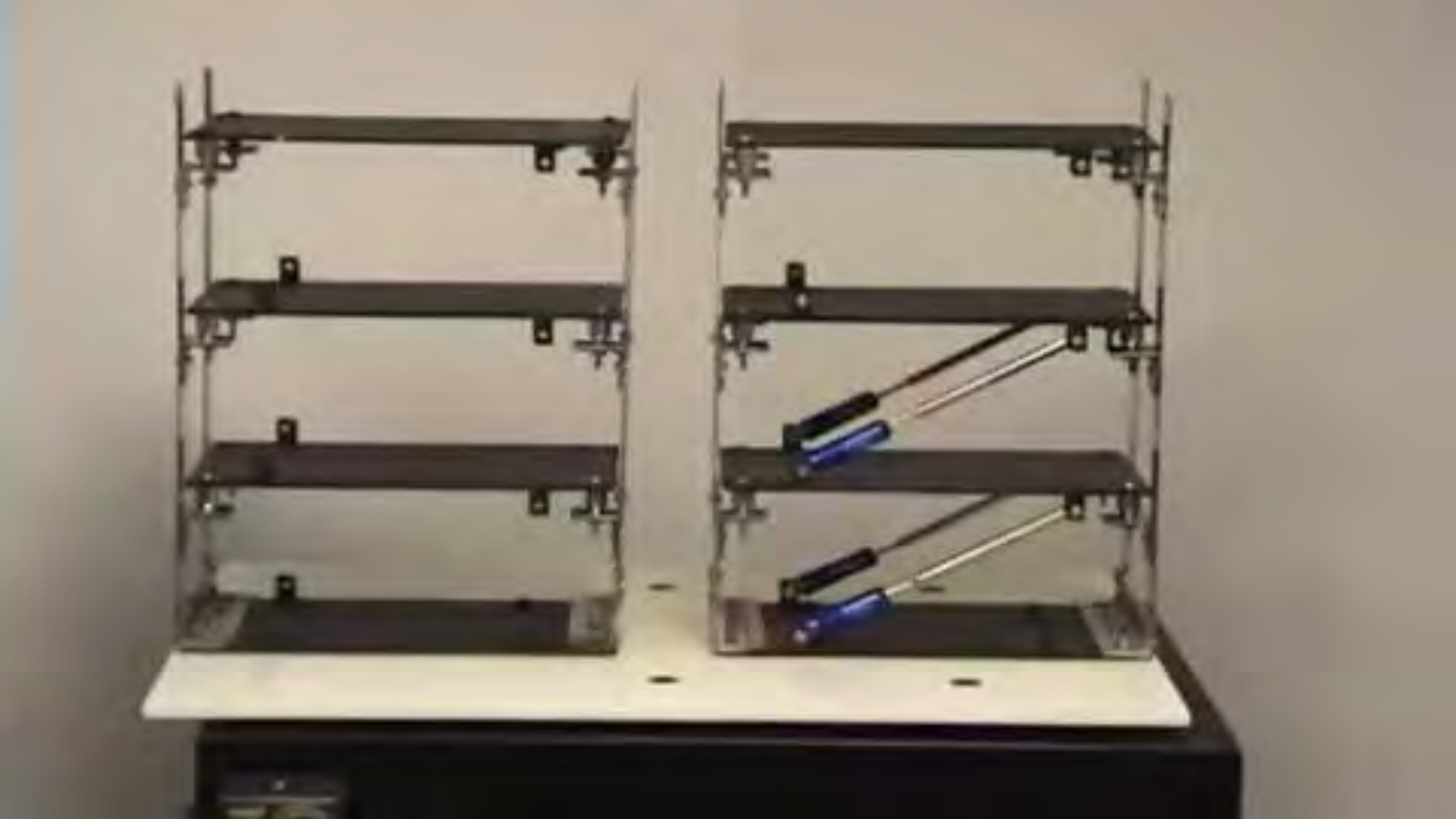
If we set target acceleration = 18 mg

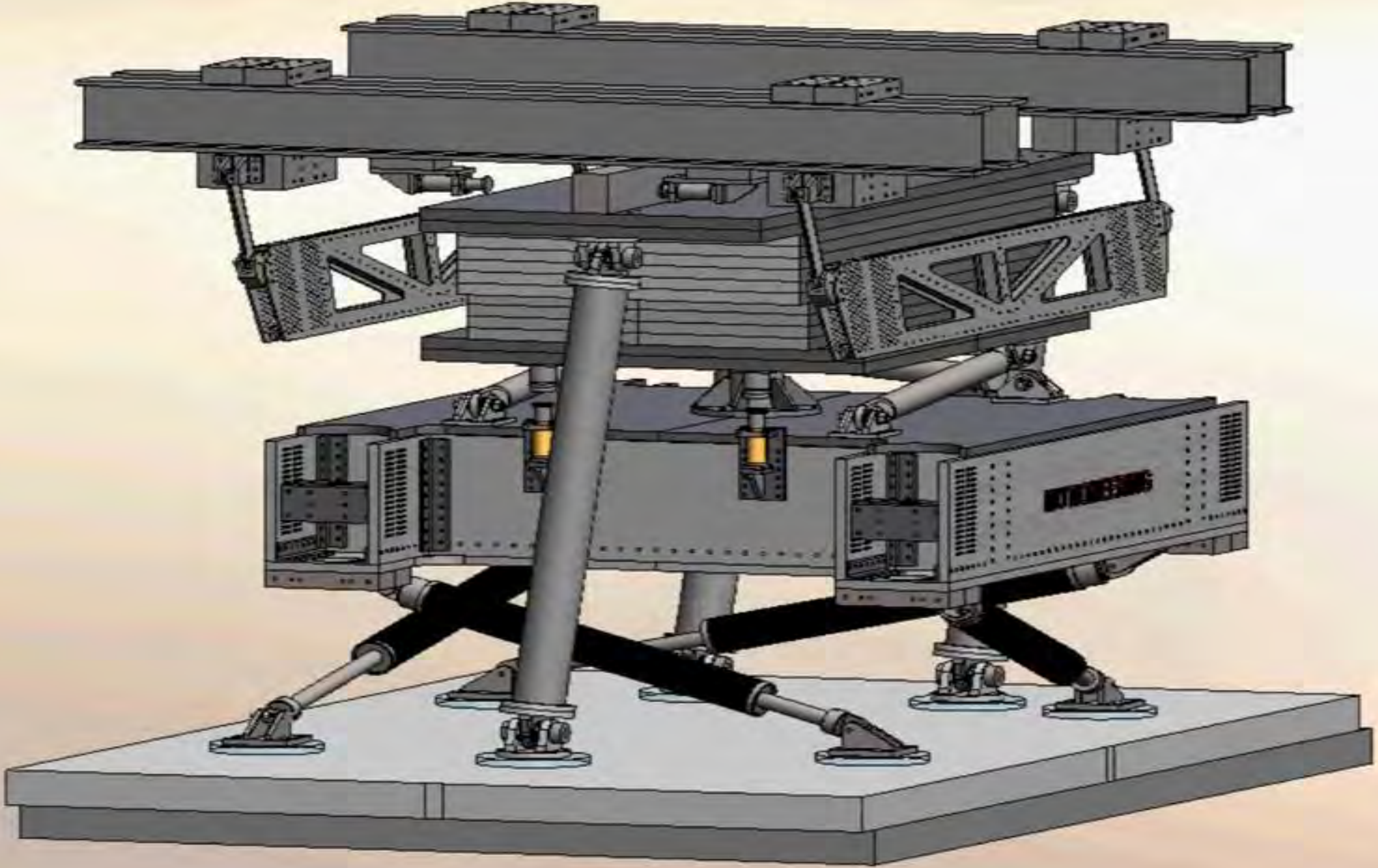
and
If we assume a maximum damping ratio = 6%

Maximum Undamped Building Response

$$= \frac{18}{0.56} = 32 \text{ mg}$$

Assumes Significant Dynamic Response number closer to 29-30 mg

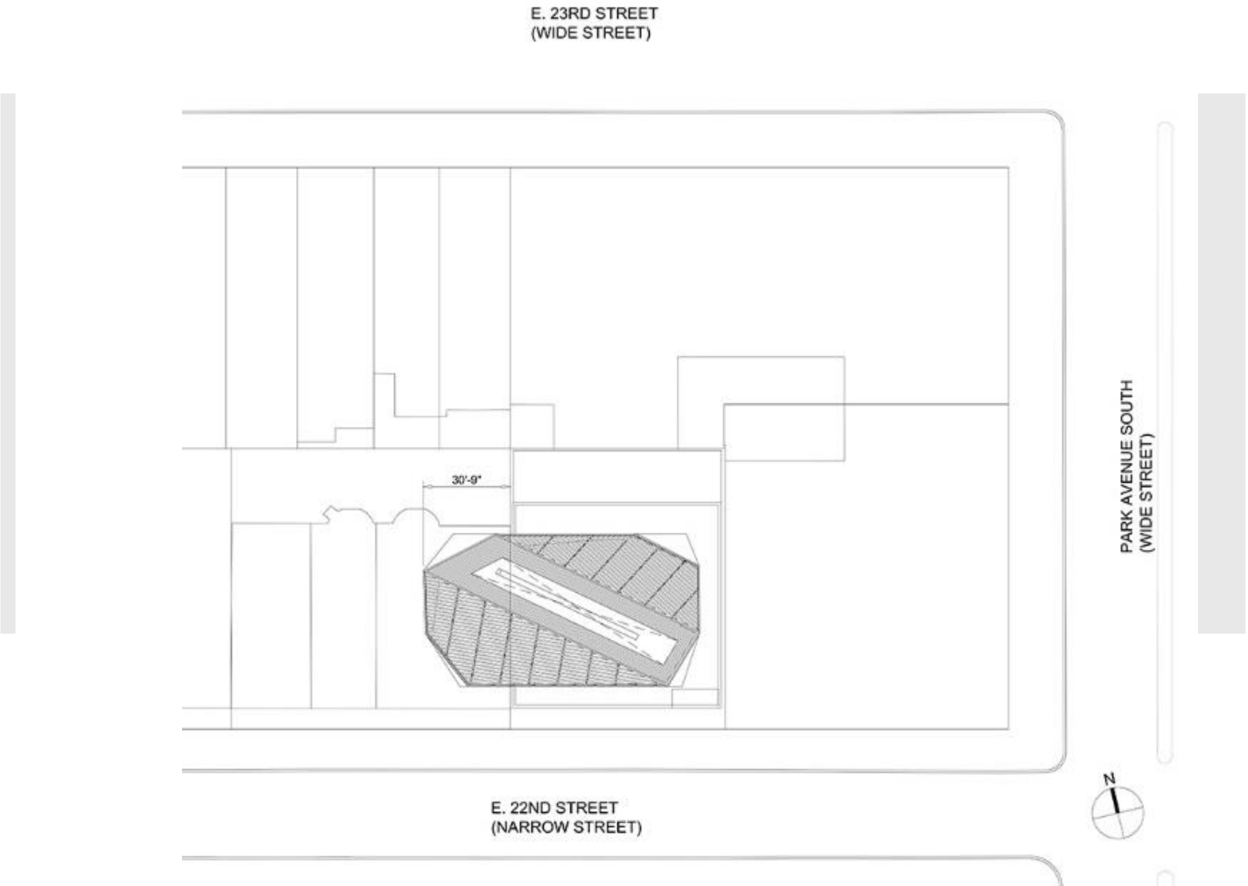




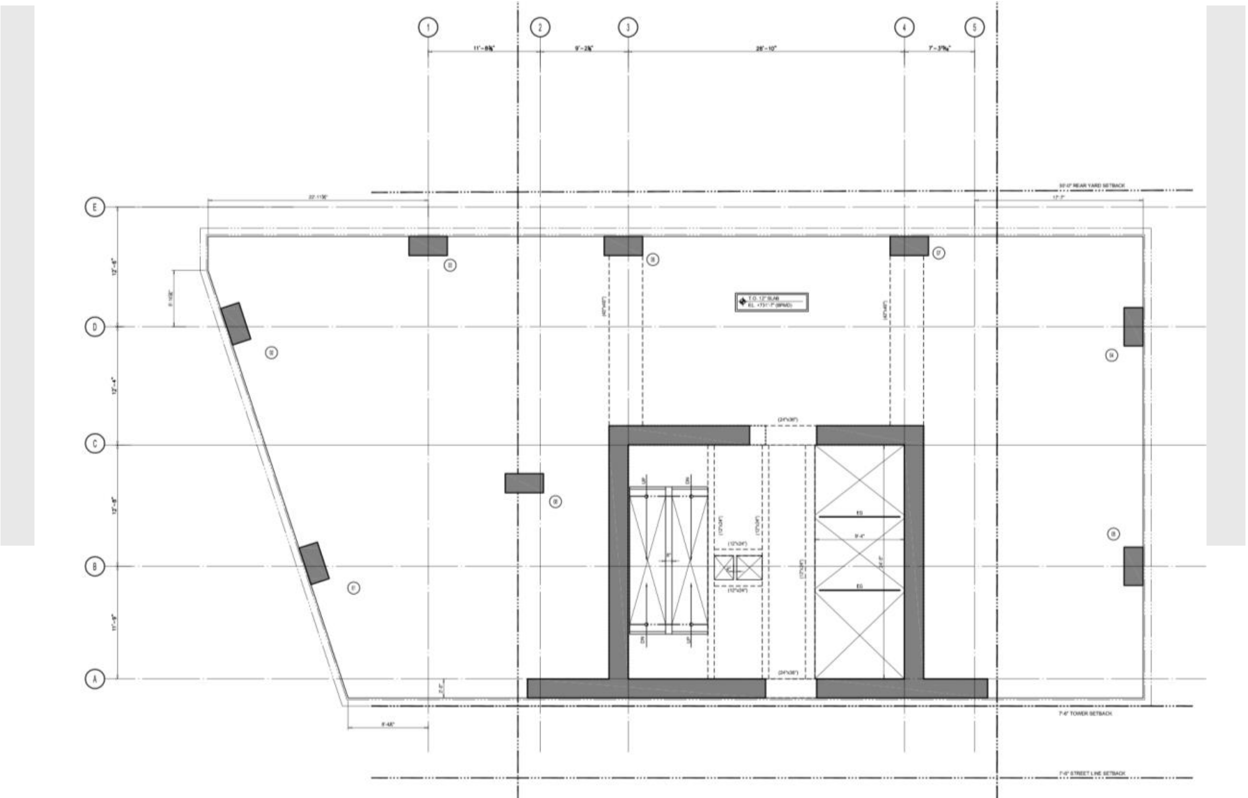

G3

Madison Tower

New York, New York

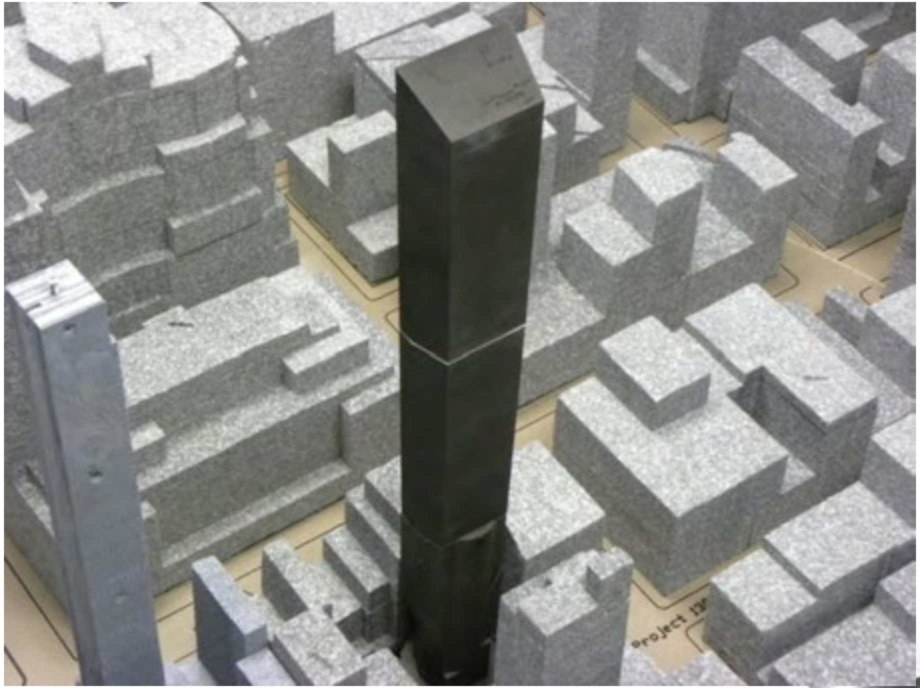

E. 23RD STREET
(WIDE STREET)
30'-9"
PARK AVENUE SOUTH
(WIDE STREET)
N
E. 22ND STREET
(NARROW STREET)

Base Model - 59th Floor
Peak Acceleration (10-Year, 2% Damping): 52 milli-g



Wind Engineering Studies

- The original design was tested in a wind tunnel at RWDI.
- All wind directions were considered combined with the wind climate for New York.
- The testing indicated high building accelerations caused by winds into the building faces with East and South being the more dominant directions.



Wind Tunnel Test at RWDI

Preliminary Results - Wind-Induced Peak Accelerations
Continuum Project, New York, New York, RWDI Project #1301398
May 2, 2013

Case	Damping (% of critical)	Peak Accelerations (milli-g) Return Period (years)		
		1	5	10
Baseline	2.0	28.6	48.6	55.2
Baseline Frequencies x 0.9	2.0	34.9	49.5	54.9
Baseline Frequencies x 1.1	2.0	24.0	41.8	51.4
Baseline	5.0	18.1	30.7	34.9
Baseline Frequencies x 0.9	5.0	22.1	31.3	34.7
Baseline Frequencies x 1.1	5.0	15.2	26.4	32.5

> 18 milli-g

Notes:

(1) The Baseline case is based on dynamic properties received by RWDI on April 25, 2013, with frequencies of 0.1611, 0.1786, and 0.7905 Hz.

(2) Accelerations are predicted at Structural Level '60 PENT' (712.42 ft above Structural Level '01 LOBB at a radial distance of 26 ft from the central axis of the tower (given in Figure 4).

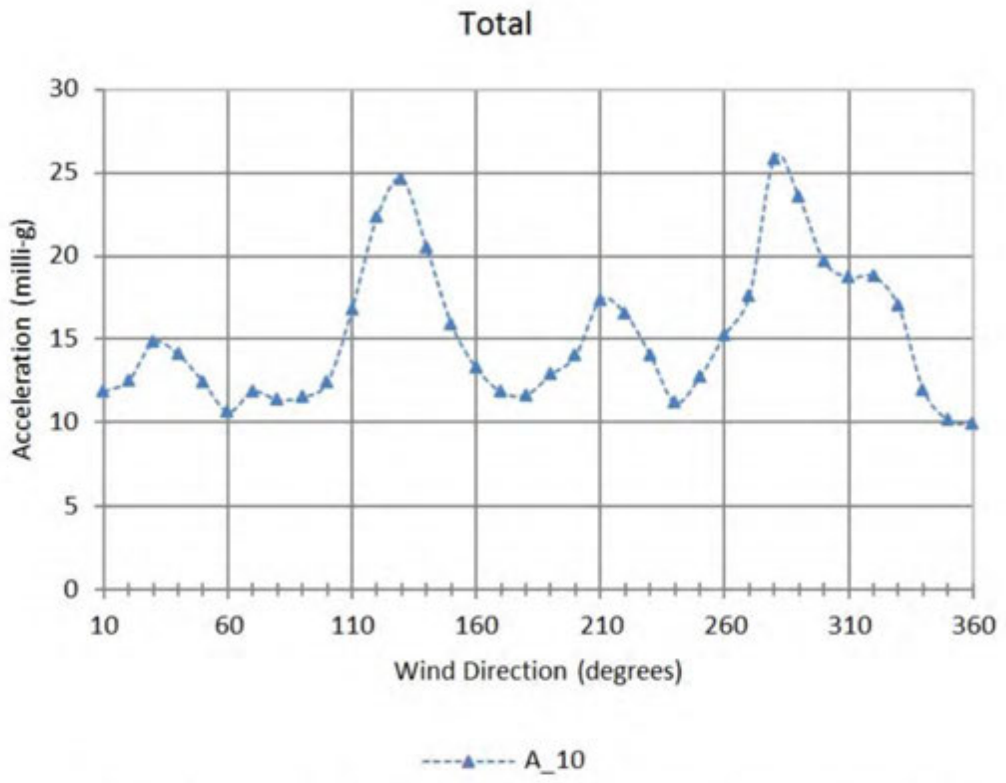
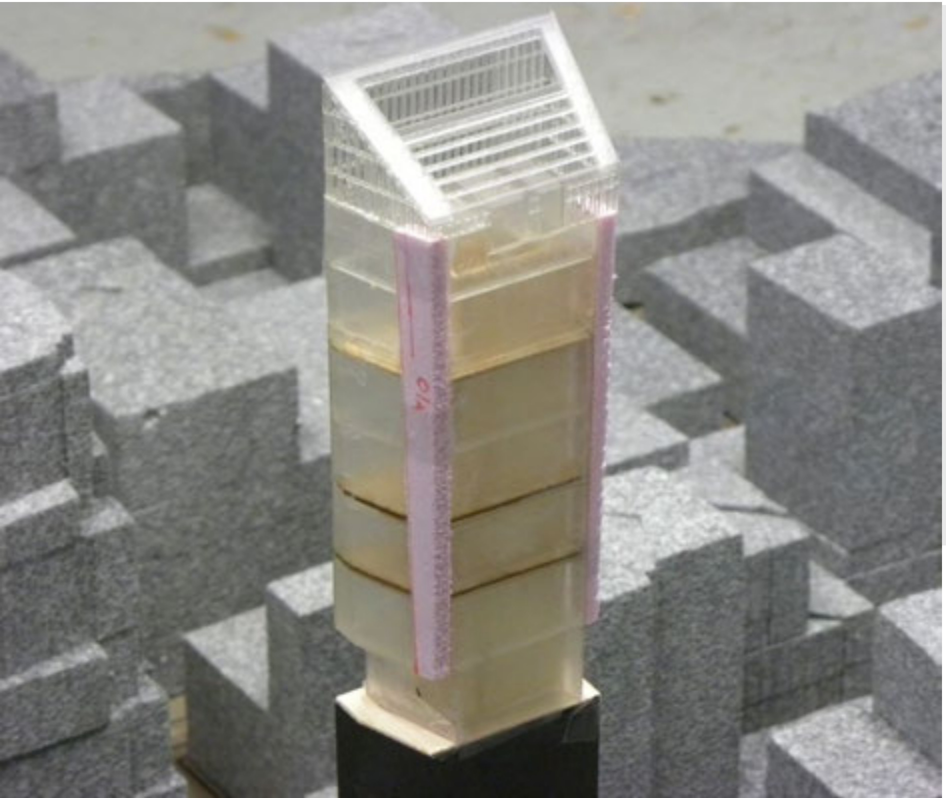


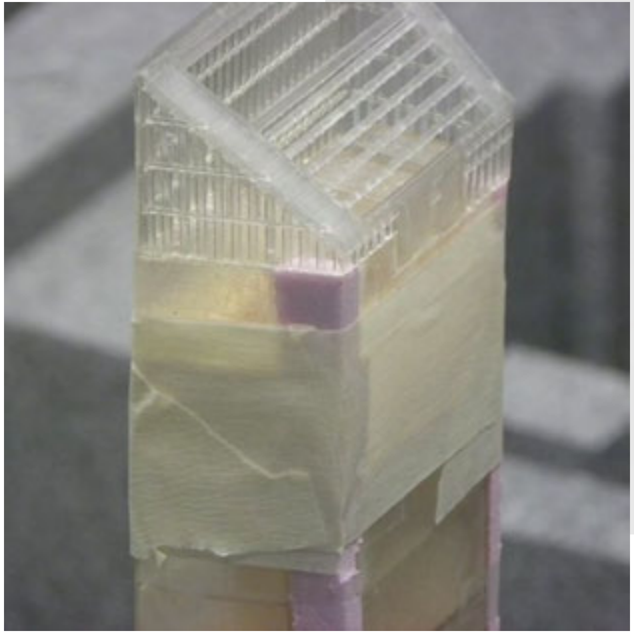
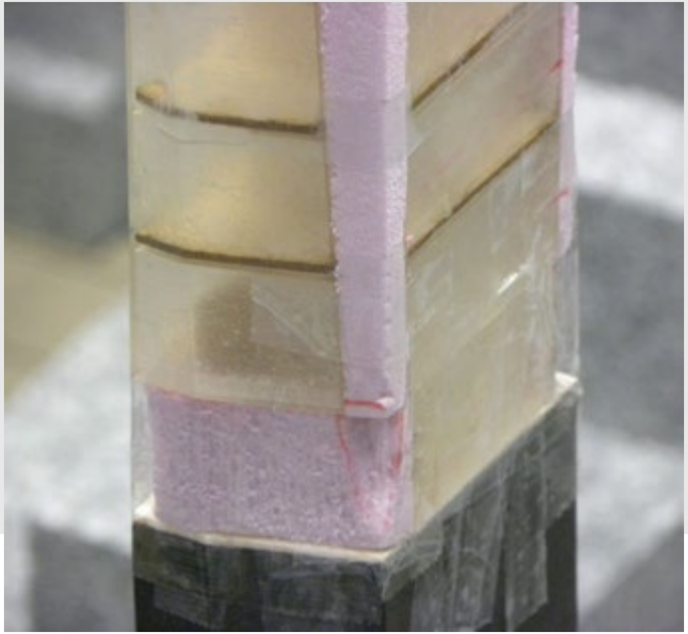
Figure 1: Extruded Tower Baseline Accelerations

Partial Corner Notches

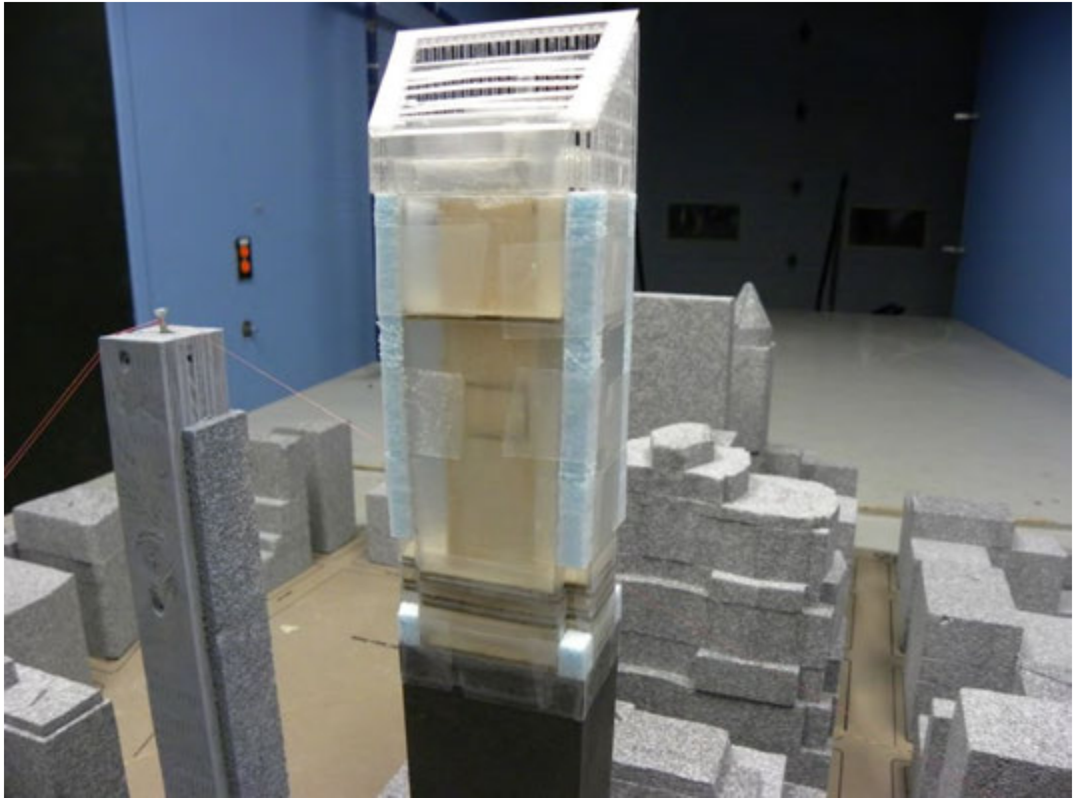
Trial 6 – Option 8 – Porous Top & Lower Refuge

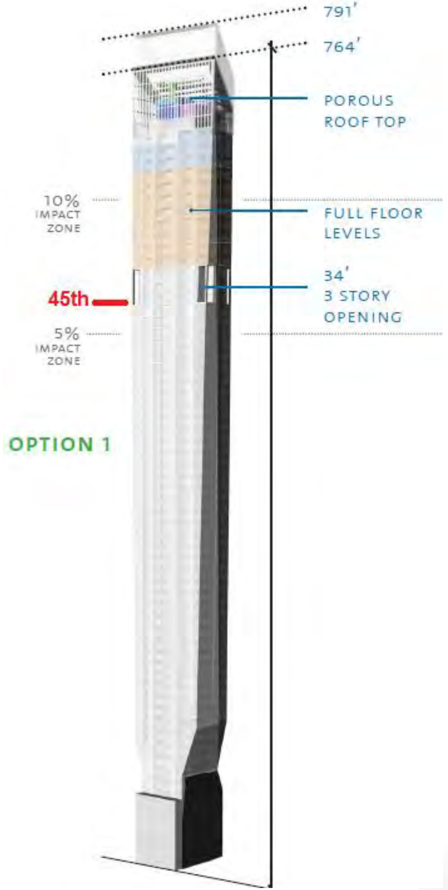


Trial 11 – Porous Top Only

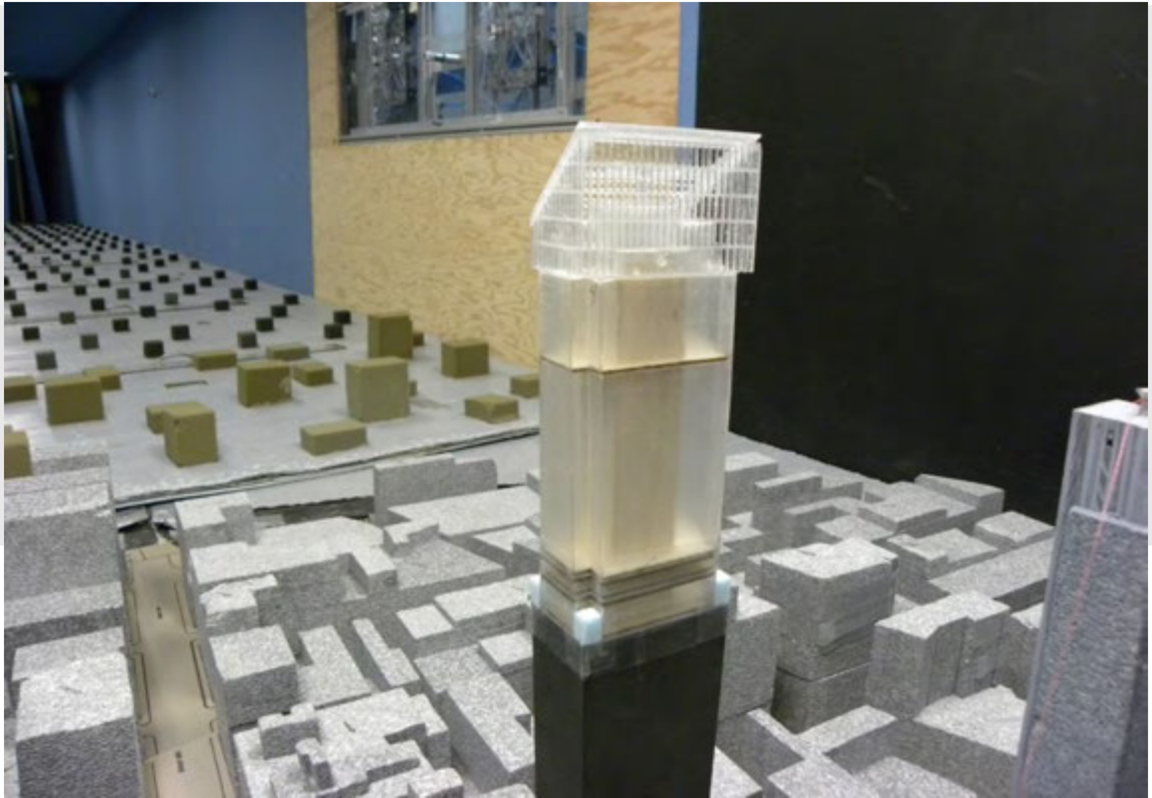




Trial 13 – KPF Option 1 764’

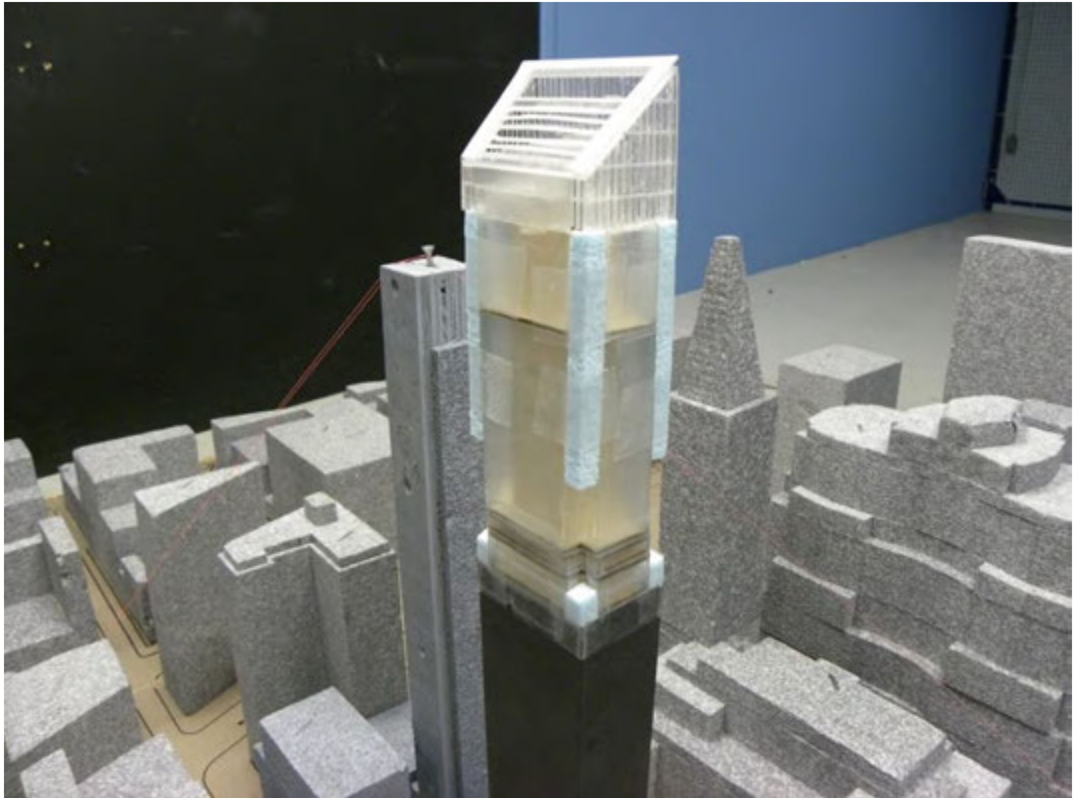


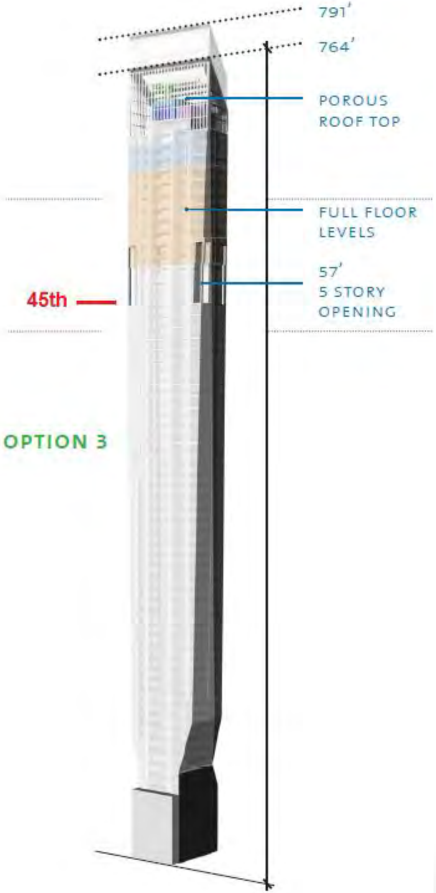


Trial 14 – 764’ 10 X 10 notches - 45th floor to top - all four sides

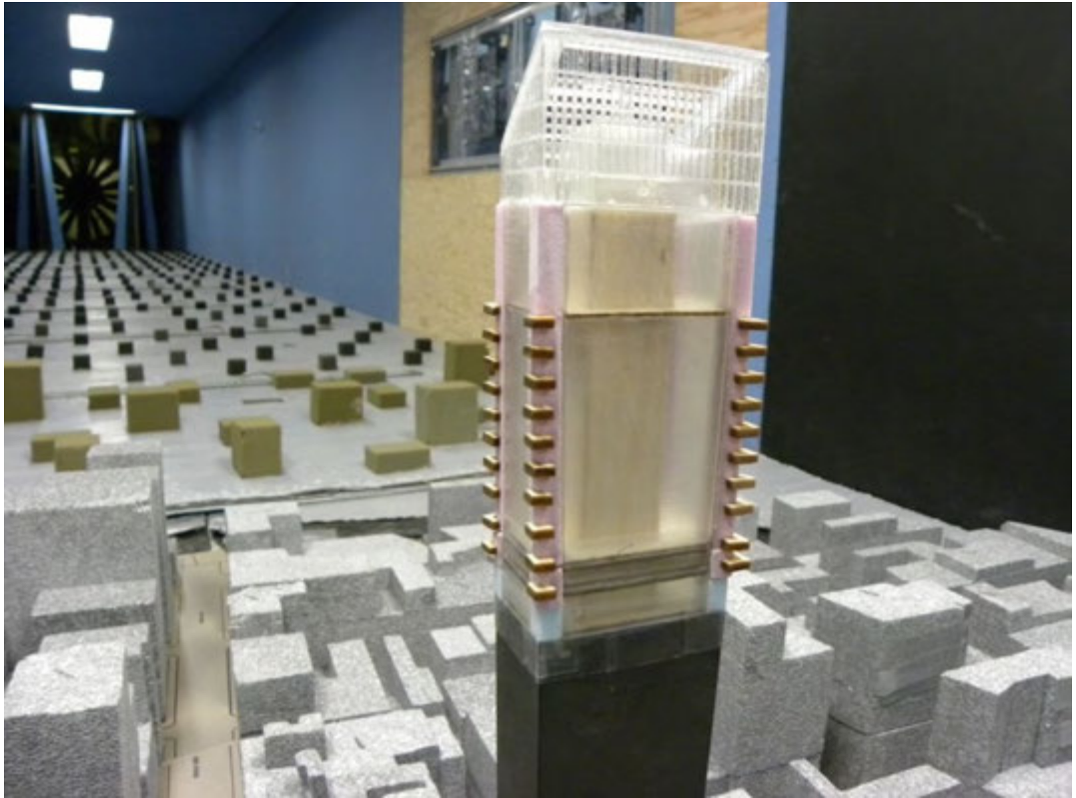


Trial 15 – KPF Option 3

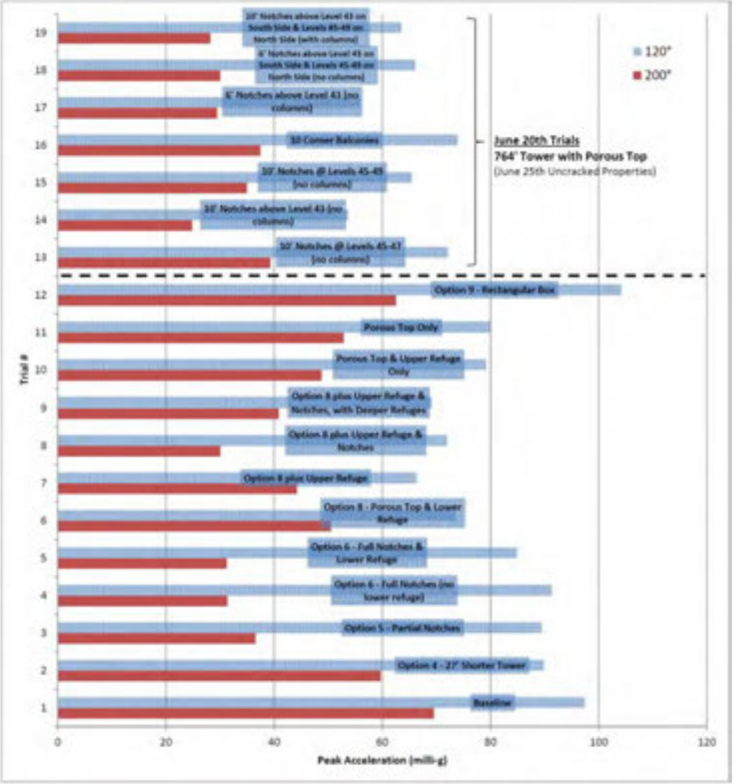




Trial 16 – KPF Option 2



Summary of 19 Options



Following the Shaping Workshop

- Following the aerodynamic workshop we identified a total of 6 shape changes that were acceptable to the architect and building developer. We were confident that with supplemental damping any combination of the 6 options would yield acceptable results.
- At this point we knew that the building needed supplemental damping to bring the total damping up to 6% of critical (3X a building's normal inherent damping)
- We then went back to the tunnel and performed a more detailed set of tests on the remaining 6 options.

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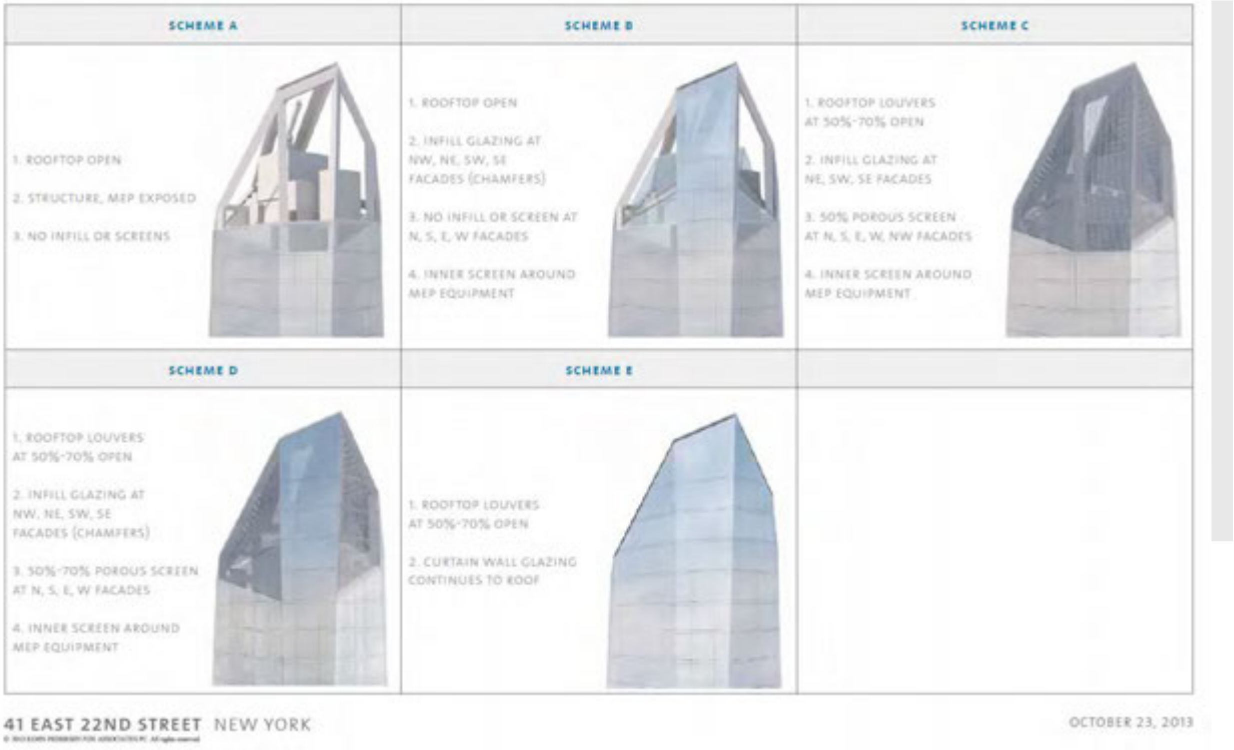
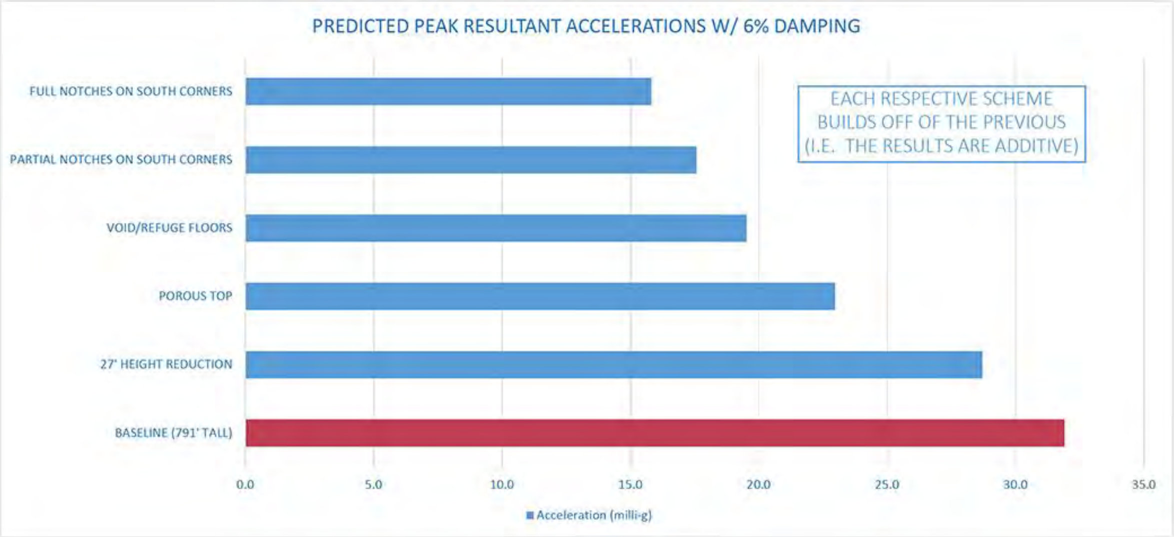
Updated Schemes from KPF

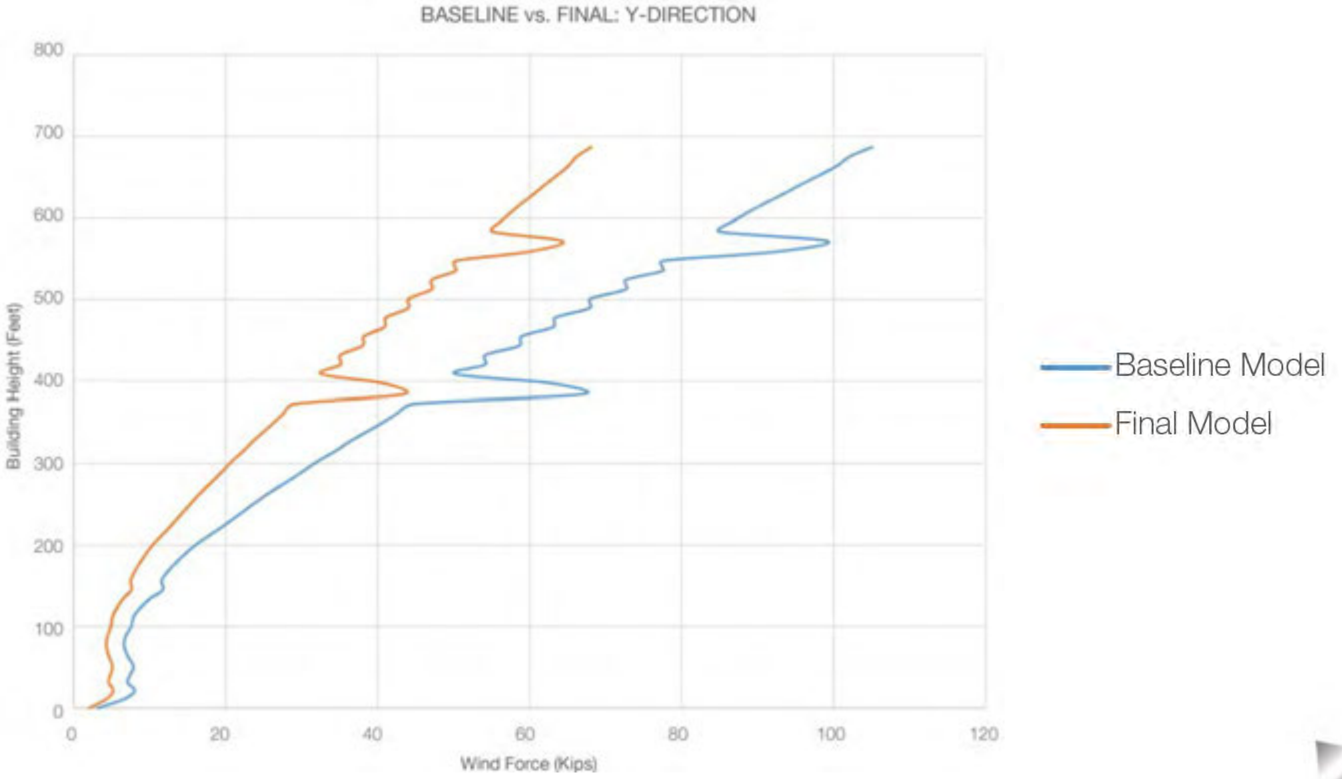


WIND TUNNEL ALTERNATIVES

ADDITIONAL STRATEGIES

DESCRIPTION OF CHANGE	ANTICIPATED REDUCTION	PREDICTED PEAK RESULTANT ACCELERTIONS W/ 6% DAMPING
BASELINE (791' TALL)	0%	31.9 milli-g
27' HEIGHT REDUCTION	10%	28.7 milli-g
POROUS TOP	20%	23.0 milli-g
VOID/REFUGE FLOORS	15%	19.5 milli-g
PARTIAL NOTCHES ON SOUTH CORNERS	10%	17.6 milli-g
FULL NOTCHES ON SOUTH CORNERS	10%	15.8 milli-g



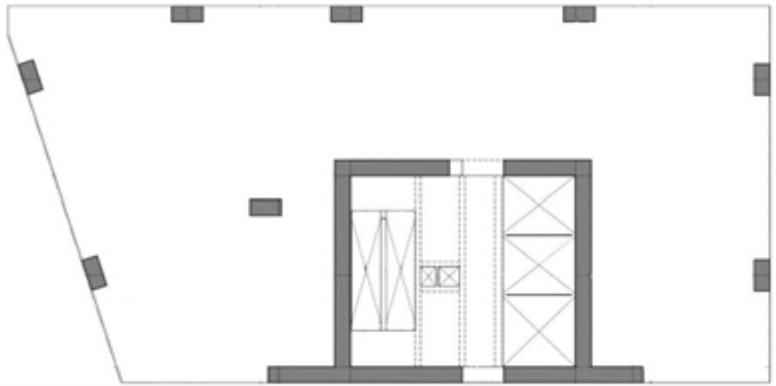


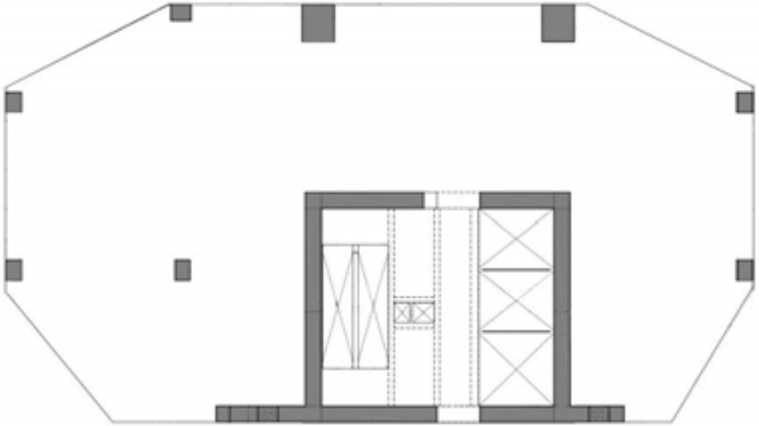
Baseline Model Base Shear: 1,904k
Final Model Base Shear: 1,234k

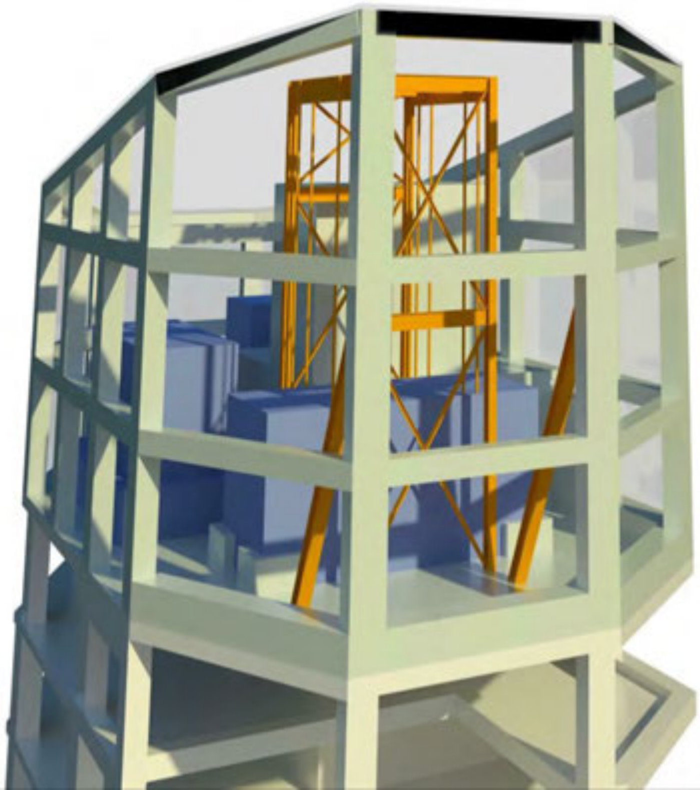
Summary of Wind Engineering

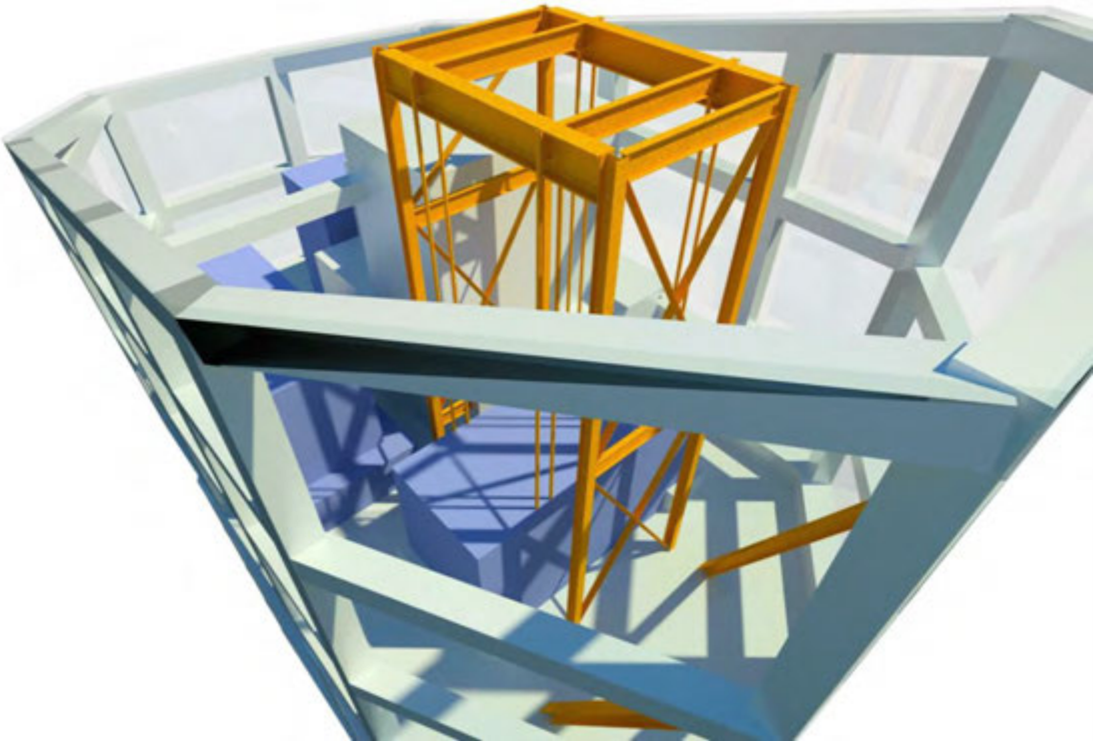
- Occupant comfort was the driving issue
  - Accelerations were reduced by ~50% through architecture changes
  - Reduced a further ~40% through damping

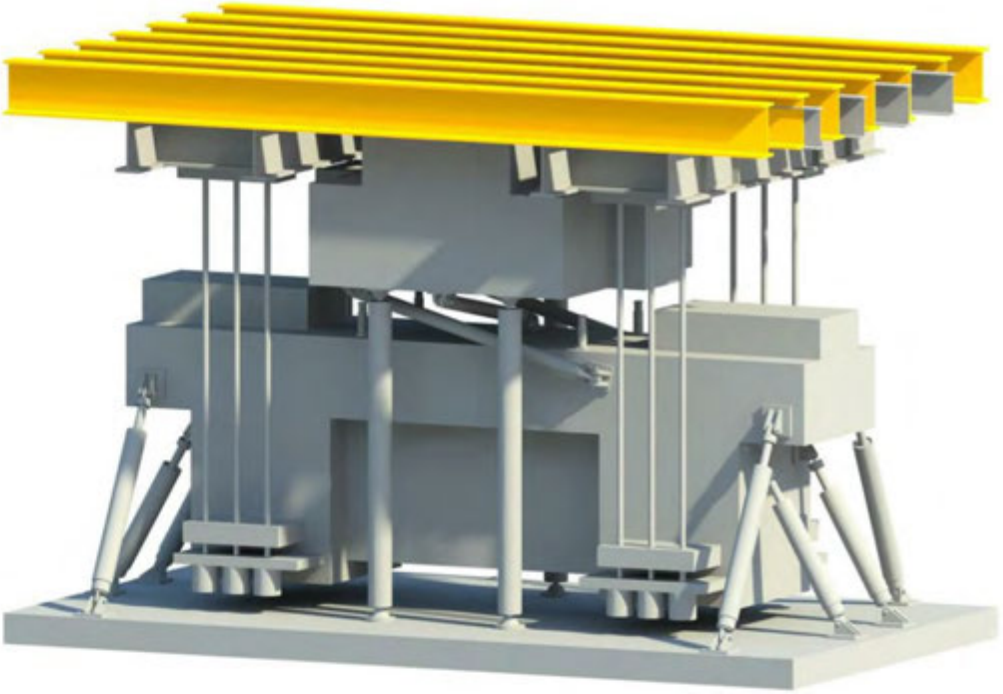
- To achieve the desired performance target, a 650 ton Tuned Mass Damper is needed on the building to get to a total damping of 6% of critical

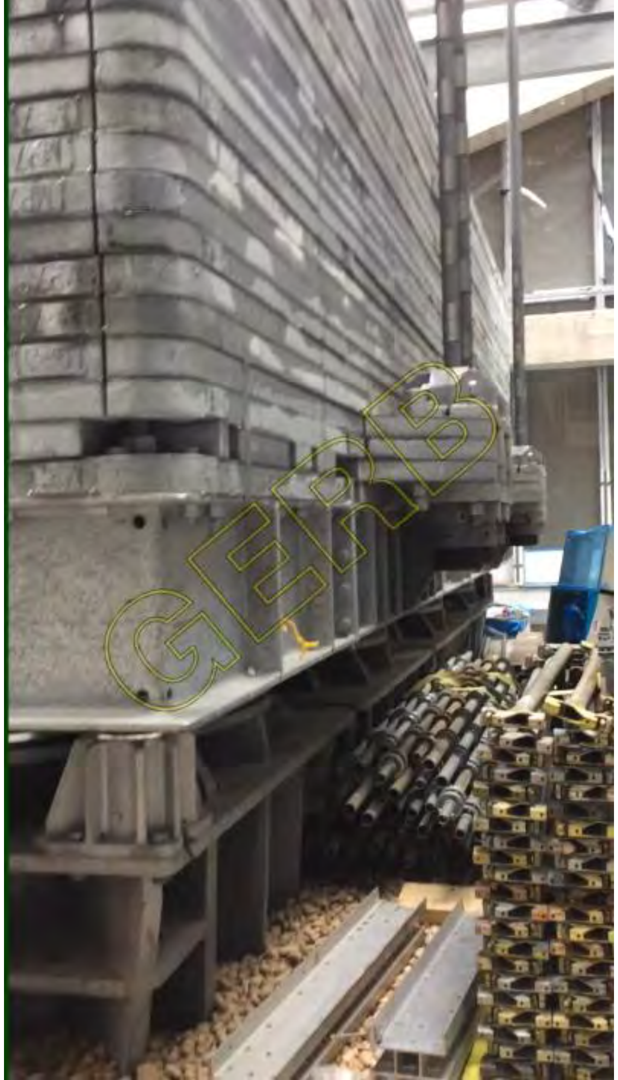










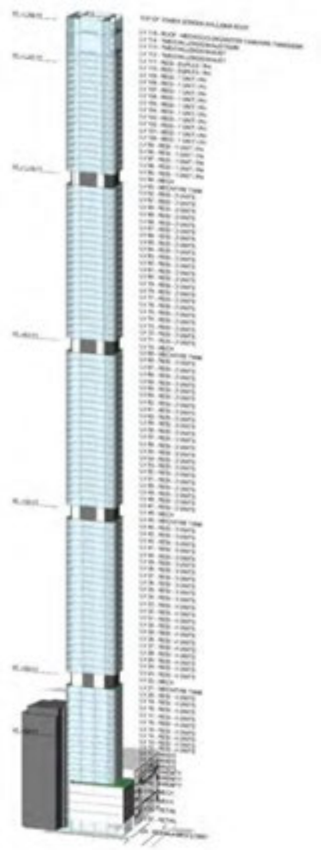

GERB


charles SCHWAB

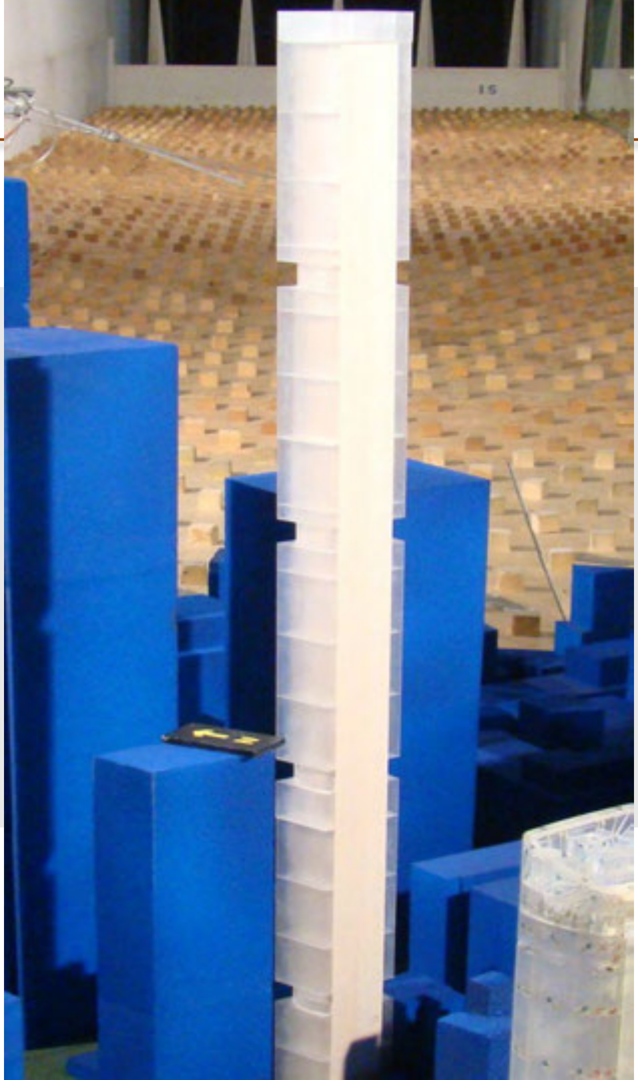
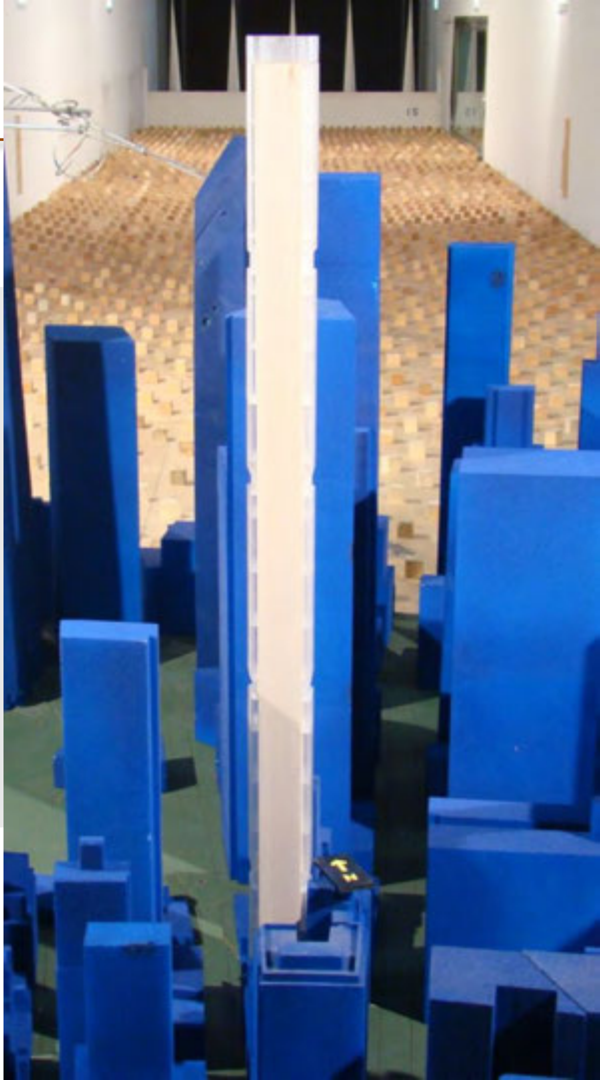
125 Greenwich Street

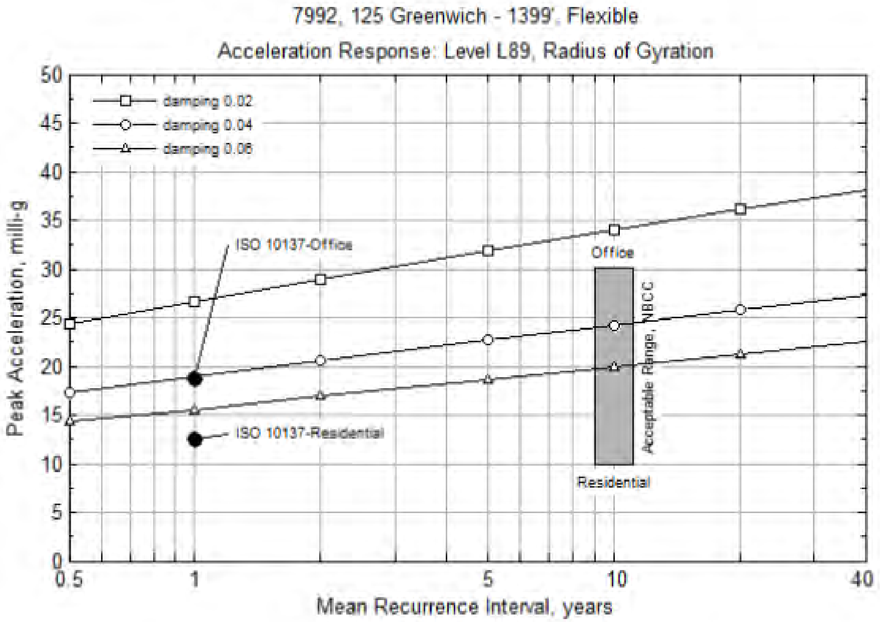
New York, New York

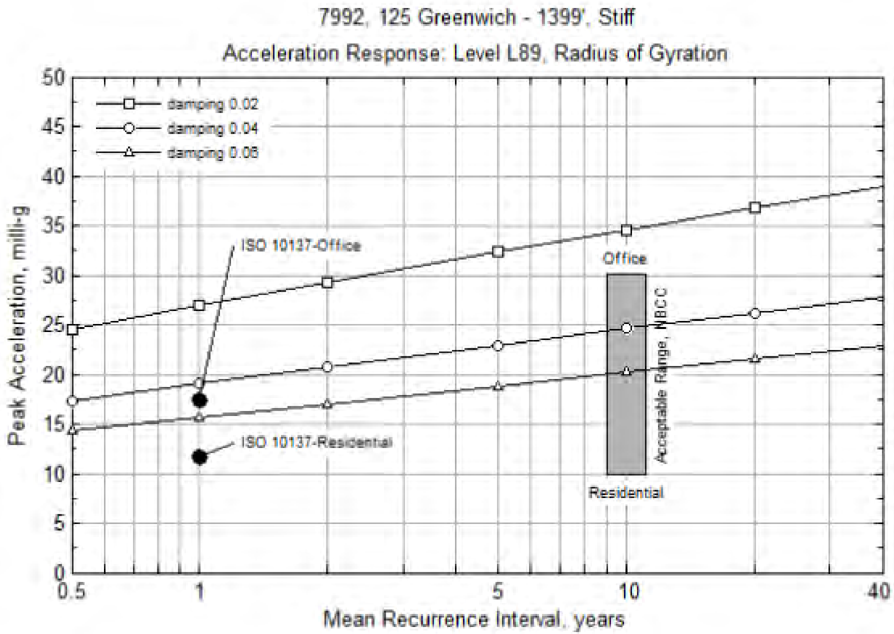
Performance Based Approach

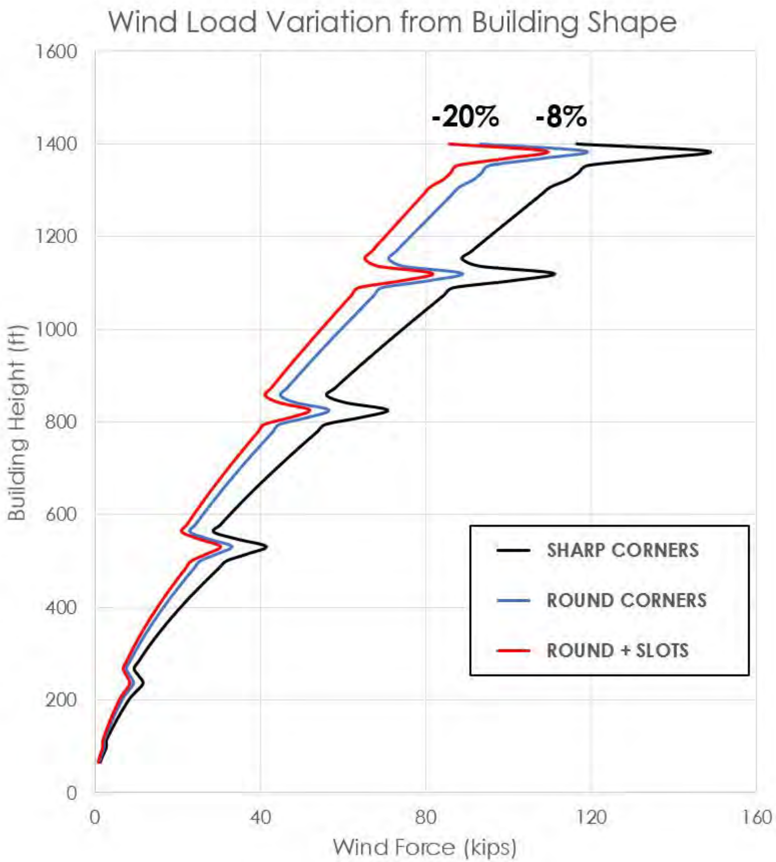


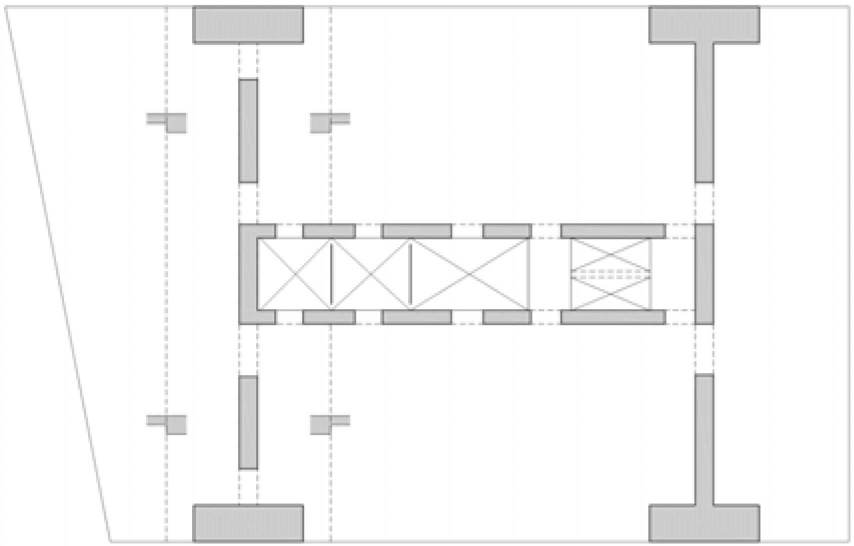

cpp
CERMAK
PETERKA
PETERSEN

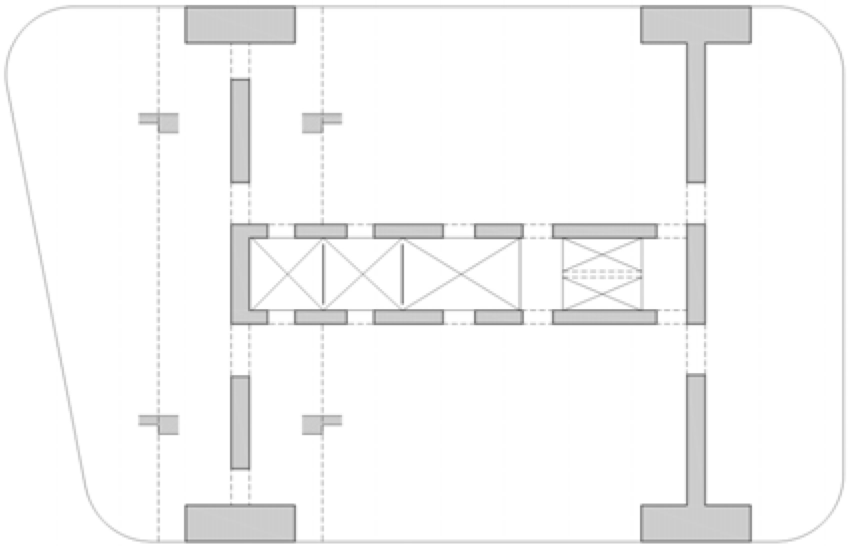





7992, 125 Greenwich - 1399', Flexible
Acceleration Response: Level L89, Radius of Gyration
damping 0.02
damping 0.04
damping 0.06
ISO 10137-Office
ISO 10137-Residential
Office
Residential
Acceptable Range, NBCC
Peak Acceleration, milli-g
Mean Recurrence Interval, years
0
5
10
15
20
25
30
35
40
45
50
0.5
1
5
10
40

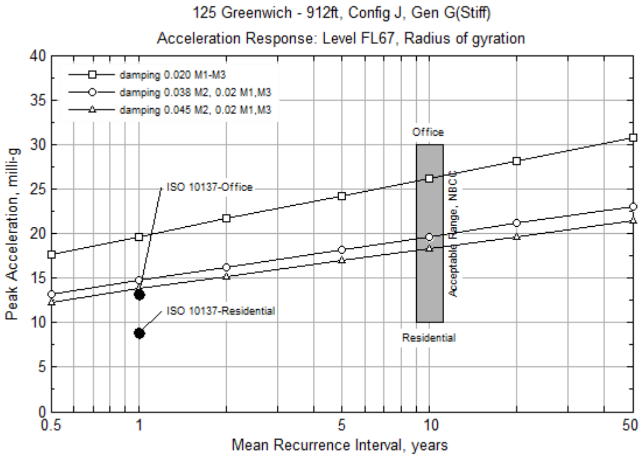

7992, 125 Greenwich - 1399', Stiff
Acceleration Response: Level L89, Radius of Gyration
damping 0.02
damping 0.04
damping 0.06
ISO 10137-Office
ISO 10137-Residential
Office
Residential
Acceptable Range, NBCC
Peak Acceleration, milli-g
Mean Recurrence Interval, years
0
5
10
15
20
25
30
35
40
45
50
0.5
1
5
10
40

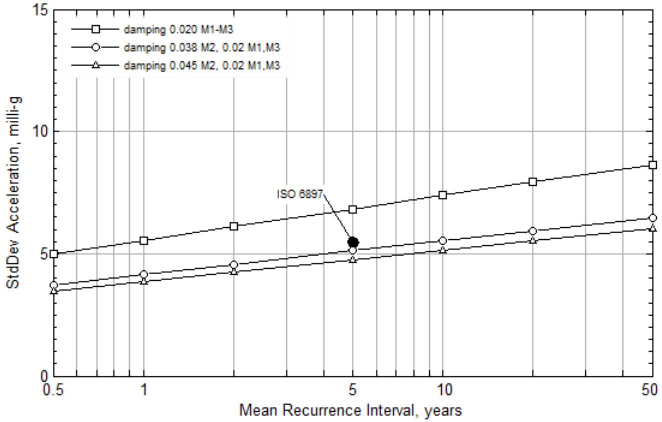

Wind Load Variation from Building Shape
-20%
-8%
SHARP CORNERS
ROUND CORNERS
ROUND + SLOTS
Building Height (ft)
Wind Force (kips)
0
200
400
600
800
1000
1200
1400
1600
0
40
80
120
160

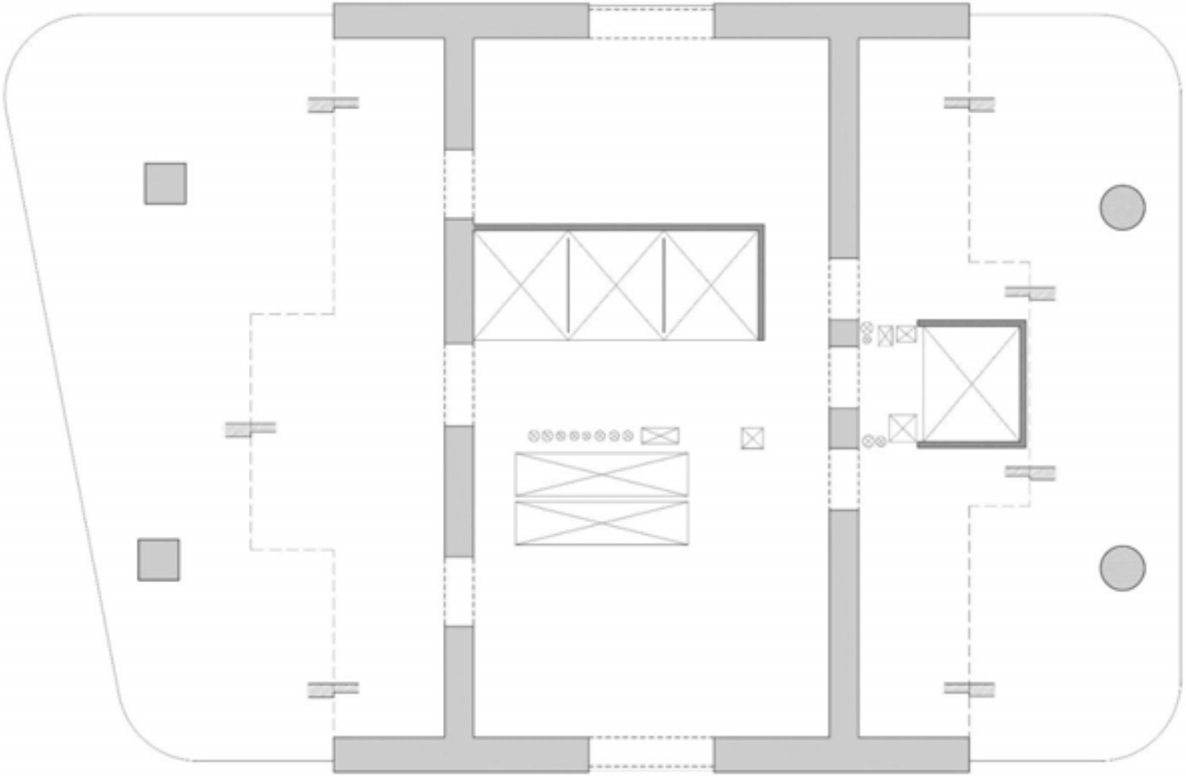




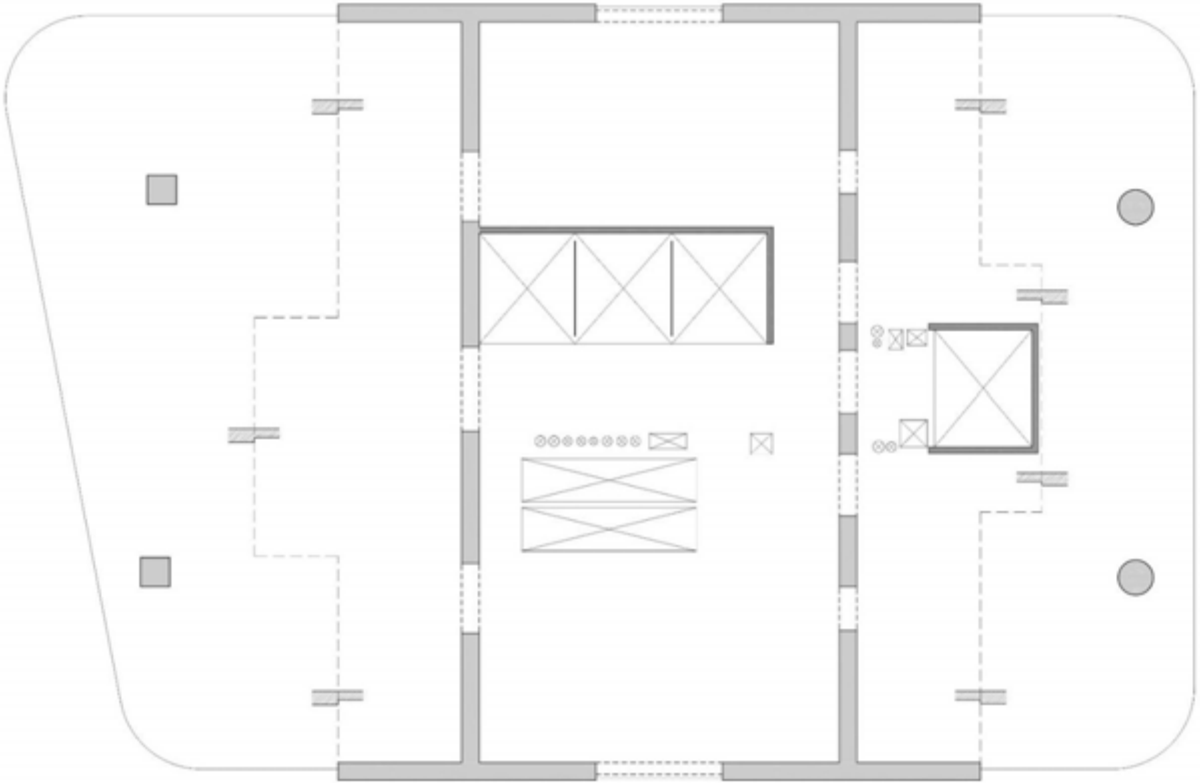

NI


125 Greenwich - 912ft, Config J, Gen G(Stiff)
Acceleration Response: Level FL67, Radius of gyration
damping 0.020 M1-M3
damping 0.038 M2, 0.02 M1,M3
damping 0.045 M2, 0.02 M1,M3
Office
ISO 10137-Office
Acceptable Range, NBCC
ISO 10137-Residential
Residential
Peak Acceleration, milli-g
Mean Recurrence Interval, years
0
5
10
15
20
25
30
35
40
0.5
1
5
10
50

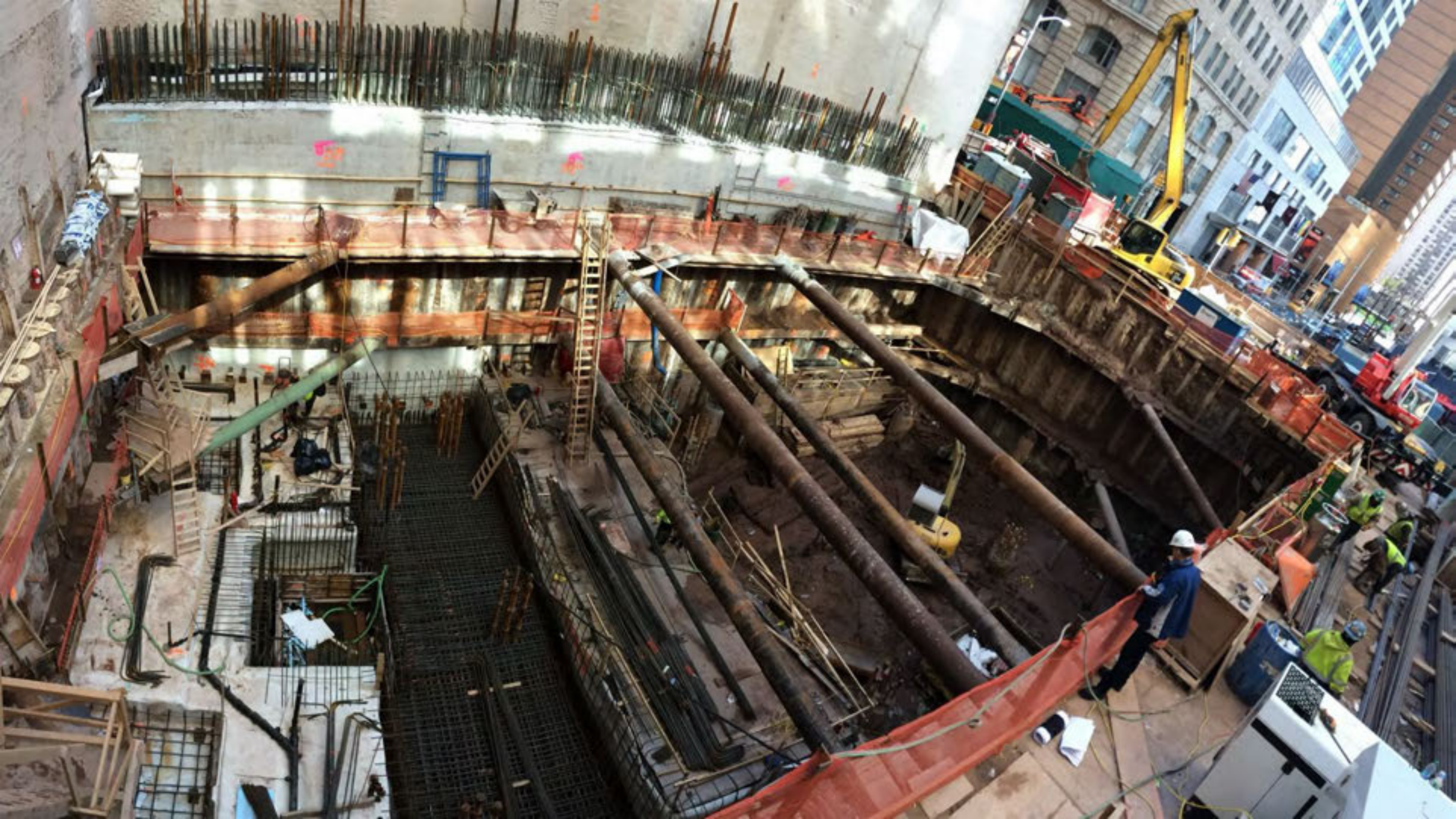

damping 0.020 M1-M3
damping 0.038 M2, 0.02 M1,M3
damping 0.045 M2, 0.02 M1,M3
ISO 6897
StdDev Acceleration, milli-g
Mean Recurrence Interval, years
0
5
10
15
0.5
1
5
10
50



15th – 23rd Floor Framing Plan



53rd – 62nd Floor Framing Plan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