De Young Museum Case Study

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Overview

- Structure Aspects:
  - Three-story steel structure 258,000 square feet
  - Nine-story twisting tower 33,000 square feet
  - Cantilever awning system

- Completion date: October 2005

- Location: San Francisco

- Privately funded
  - Total Cost: $202,000,000
  - Construction Cost: $135,000,000

Dimensions

- Longitudinal distance: 482 ft

- Width distance: 247 ft

- Tower height: 148 ft

- Basement height: 19 ft, 6 in

- First floor height: 19 ft

- Second floor height: 26 ft

Building Design

- Architectural design
  - Architects: Jacques Herzog and Pierre De Meuron

- Structural Engineering design:
  - Rutherford & Chekene

- Structural Challenges:
  - Highly irregular geometry
  - Long spans
  - Large floor openings
  - Cantilever and tower
  - Seismic Zone

Museum Features

- 4.7 miles from San Andreas Fault

- Previous structure damaged by Loma Prieta Earthquake in 1989

- Seismic Design:
  - Allows 3 ft of deflection

- Environmental friendly
  - Copper cladding
  - Gardens
  - Tree-ferns at the museum back entrance

Structural System – Main Building

- Composite Steel Braced Frame

- Metal Deck Floors with Concrete Fill

- Steel Joists

- Concrete Bearing/Shear Wall in Basement

Gravity System - Twisting Tower

- Concrete Structural System

- Two Bearing Shear Walls
  - Connected with Post-Tensioned Girders

- Steel Framed Roof

Loading

Dead Loads

- Structural Framing

- Cladding

- Flooring

- Mechanical Systems

- etc.

List of Live Loads - Based on ASCE 7-10

LIVE LOAD	WEIGHT, PSF
Offices	50
Café	100
Stores	100
Auditorium	100
Auditorium Seats	60
Light Storage	125
Landscaping (4'-0" soil)	400
Kitchen	150
Gallery	100
Lobby	100
Roof	20

Live Loading Plan

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Café	100
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Auditorium Seats	60
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Kitchen	150
Gallery	100
Lobby	100
Roof	20

Load Tracing
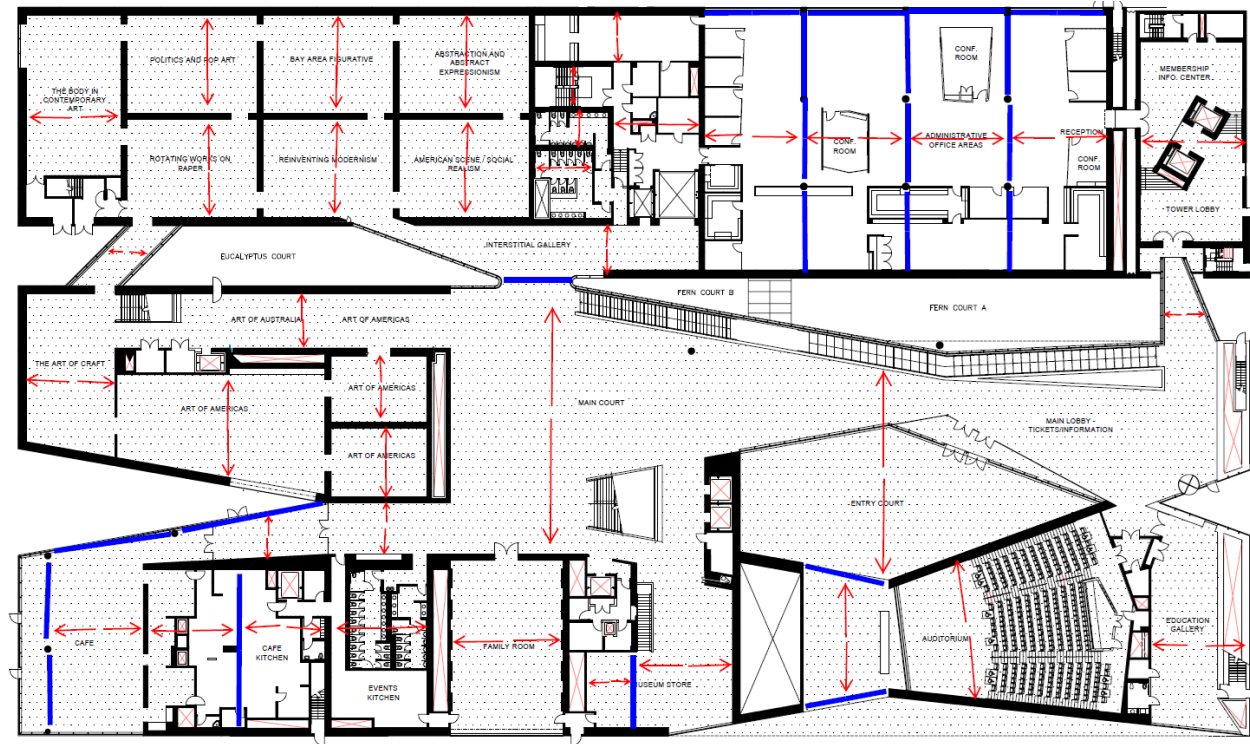
Load Tracing of Concourse Level

Connections

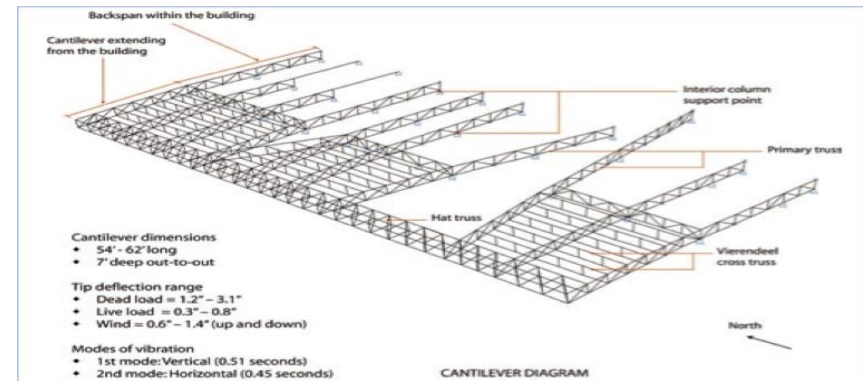Main Building Connections
- Simple Shear Tab

- Gusset Plates at Braces

Cantilever Connections
- Welded Wide Flange Connections

- Gusseted Connections

- Moment Connections
 - Between main and cross trusses

Cantilever System

- Perforated Copper Cladding

- Cantilever members are 62 feet long and 7 feet deep

- System Composed of :
  - Primary Trusses
  - Vierendeel Cross Trusses
  - Hat Trusses

- Wind and Seismic effects governed the design

Backspan within the building

Cantilever extending from the building

Interior column support point

Primary truss

Hat truss

Vierendeel cross truss

Cantilever dimensions
- 54'- 62' long
- 7' deep out-to-out

Tip deflection range
- Dead load = 1.2" – 3.1"
- Live load = 0.3" – 0.8"
- Wind = 0.6" – 1.4" (up and down)

Modes of vibration
- 1st mode: Vertical (0.51 seconds)
- 2nd mode: Horizontal (0.45 seconds)

North

CANTILEVER DIAGRAM

Structural Analysis- Cantilever System

- Structure modeled using SAP2000 software

- Fixed support connections

- All chords modeled as continuous

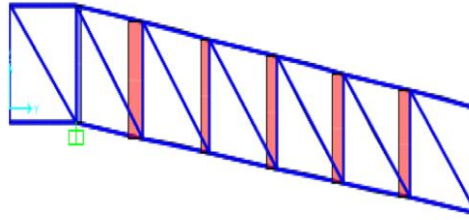| Type Of Load	Magnitude (psf)
Dead (Perforated Copper)	2
Roof Live	5
Wind	19.6
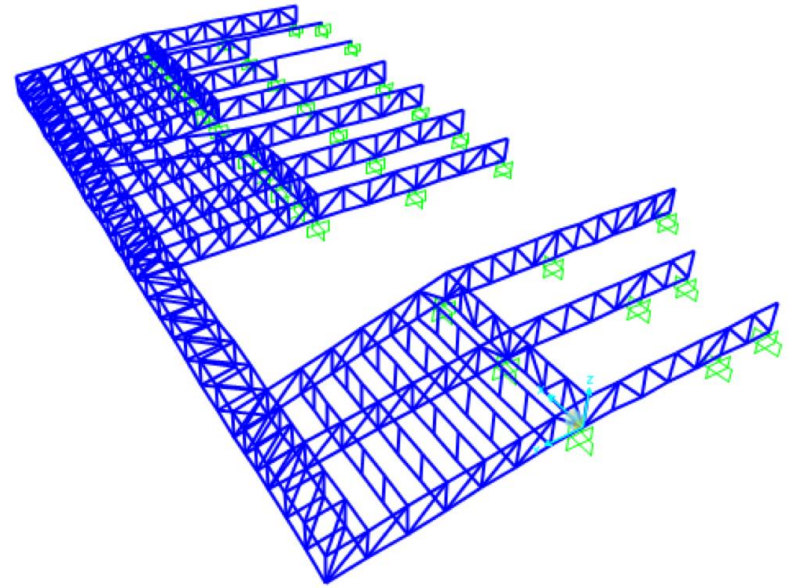
Structural Analysis (Gravity)

- A572 GR50 Steel

- Wide Flange Top and Bottom Chords

- Double Angle Braces

- Load combinations considered:
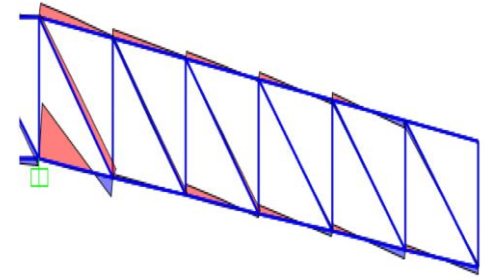 - 1.4D
  - 1.2D + 1.6Lr + 0.5W
  - 1.2D + 1.0W + 0.5Lr
  - 0.9D + 1.0W

Δ max = 3"

Deflected Shape
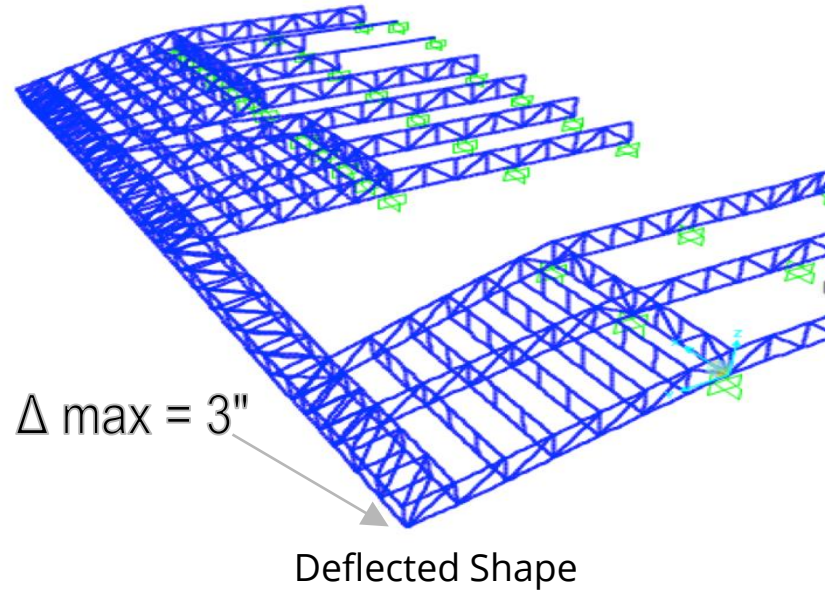
Structural Analysis (Gravity)
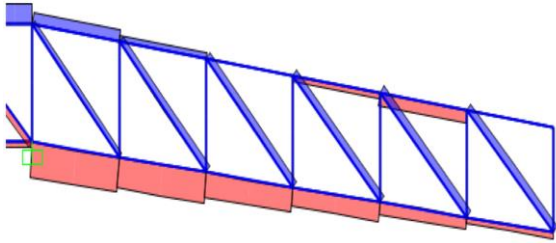
Axial Diagram

Shear Diagram

Moment Diagram

Lateral System – Wind Response
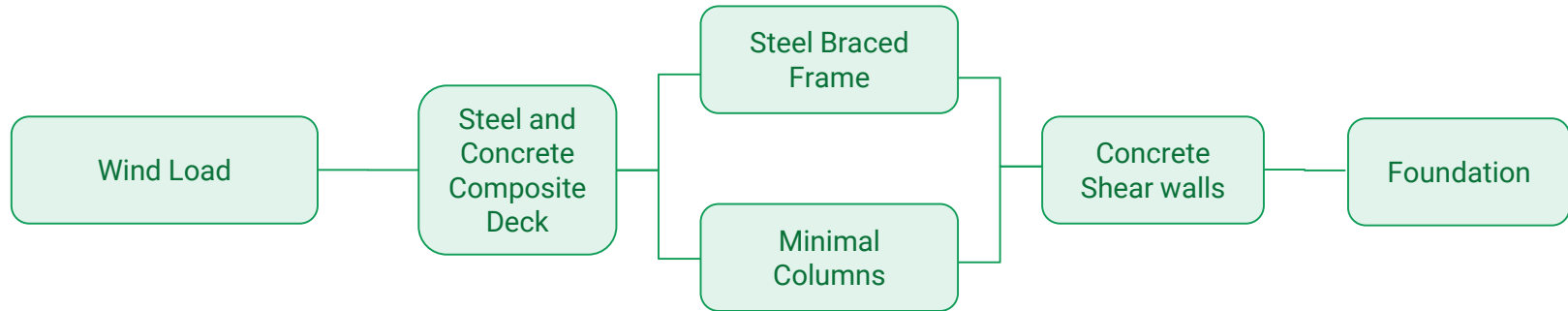
Lateral System – Main Building Wind Pressure

Wind in the East-West Direction

	z (ft)	Net Pressure (psf)
Windward	15	14.0
	20	14.9
	25	15.6
	30	16.3
	35	16.8
	40	17.3
	45	17.8

Leeward	All	-10.1
Side	All	-16.1

Roof	0 to h/2	-19.6
	h/2 to h	-19.6
	h to 2h	-12.5
	> 2h	-9.0

Wind in the North-South Direction

	z (ft)	Net Pressure (psf)
Windward	15	14.0
	20	14.9
	25	15.6
	30	16.3
	35	16.8
	40	17.3
	45	17.8

Leeward	All	-12.5
Side	All	-16.1

Roof	0 to h/2	-19.6
	h/2 to h	-19.6
	h to 2h	-12.5
	> 2h	-9.01

Wind Load Information

Wind Speed	110 mph
Exposure Category	B
Internal Pressure Coefficient, C_{pi}	±0.18
Gust Effect Factor, G	0.85
Mean Roof Height Main Building, h_m	45 ft
Mean Roof Height Tower, h_t	193 ft
Wind Directionality Factor, K_d	0.85
Velocity Pressure Exposure Coefficient, K_z	Varies
Topographic Factor, K_{zt}	1
Elevation Factor, K_e	1

Lateral System – Tower Wind Pressure

Wind in the East-West Direction		
	z (ft)	Net Pressure (psf)
Windward	65	21.3
	85	22.5
	105	23.6
	125	24.5
	145	25.3
	165	26.1
	185	26.7
	193	27.0

Leeward	All	-19.0
Side	All	-24.3

Roof	0 to h/2	-33.4
	> h/2	-24.3

Wind in the North-South Direction		
	z (ft)	Net Pressure (psf)
Windward	65	21.3
	85	22.5
	105	23.6
	125	24.5
	145	25.3
	165	26.1
	185	26.7
	193	27.0

Leeward	All	-13.2
Side	All	-24.3

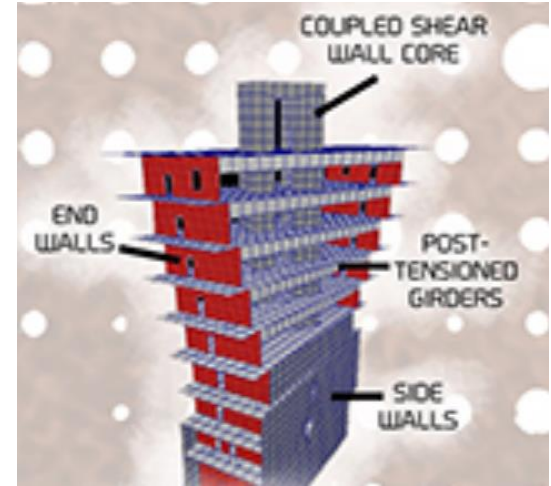| Roof	0 to h/2	-33.4
	> h/2	-24.3

Lateral System: Transfer of Seismic Loads
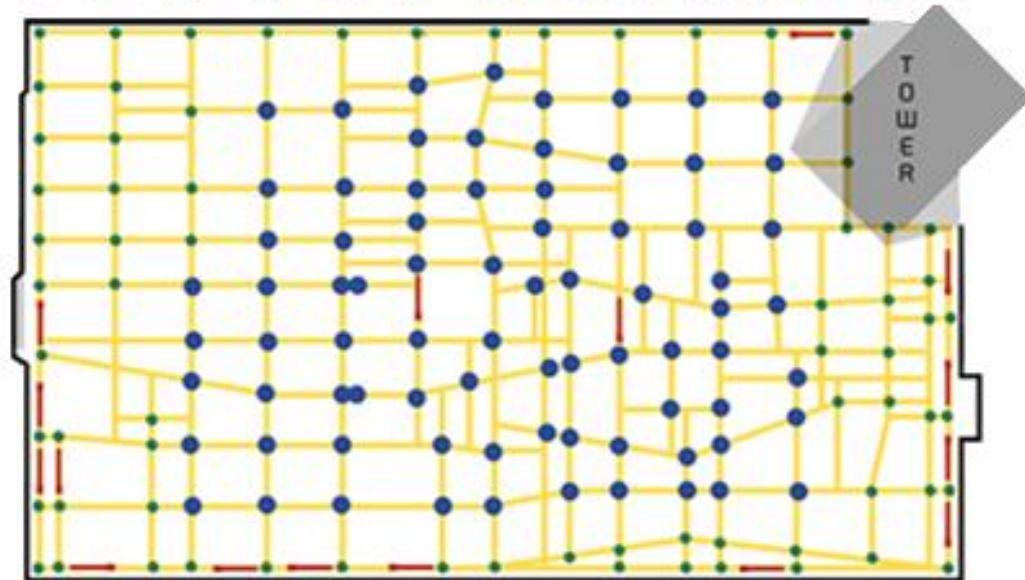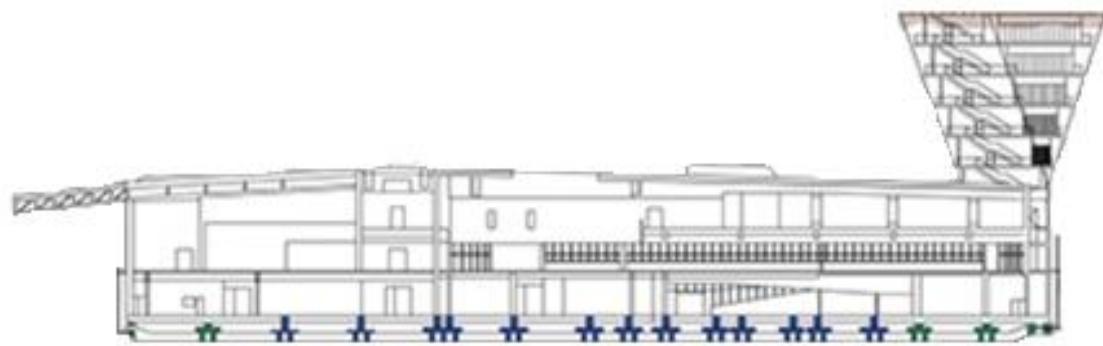
Main Building

- 76 High-Damping Rubber Bearing
- 76 Flat Sliding Bearings
- 24 Fluid Viscous Dampers

Tower

- Coupled shear wall system connected to concrete core
- End-walls function as both bearing and shear walls
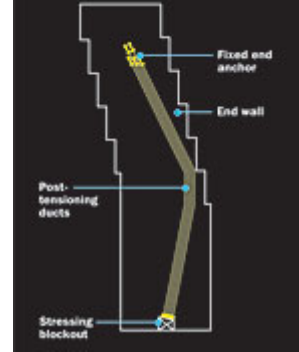- Torsion Box
- Fixed base, seismic joint

- Rubber Bearing
- Sliding Bearing
- Fluid Viscous Dampers
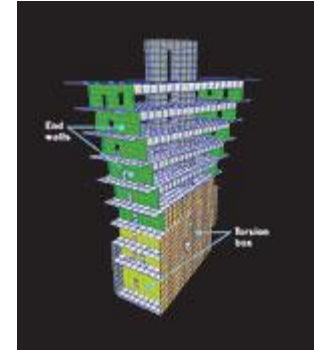- Grade Beams

Lateral System - Seismic Response

Main Building

- Sidesway displacement
- Twisting/Rotation
- Overturning

Tower

- Ratcheting/Bunny Effect

Lateral System – ASCE 7-10 Seismic Forces

Seismic Loads	
Site Classification	C

Spectral Response Acceleration Parameters	
S_S	1.5
S_1	0.6
S_{D1}	0.56
S_{DS}	1.2

| Period Parameters	
Approximate Fundamental Period, T_a	0.486 s
Initial Period, T_0	0.093 s
Short Period, T_s	0.467 s
Long Period, T_L	12 s

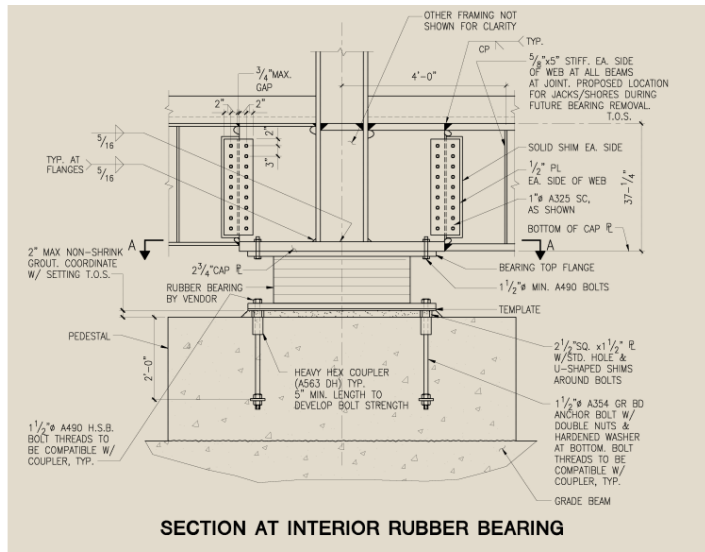| Equivalent Lateral Force	
Importance Factor, I_e	1
Response Modification Factor, R	5
Seismic Response Coefficent, C_s	0.0528
Seismic Weight, W	23010 k
Base Shear, V	1215 k

Foundation

- Soil Type
  - 131: Urban Land
  - 129: Sirdark Sand, 5 - 50 percent slopes
- Allowable Foundation Pressure, IBC - 2,000 psf
- Concrete grade beams with isolation system bearings placed on concrete pedestals at the intersection of a grid
- Lowest base shear, lowest floor acceleration, lowest cost
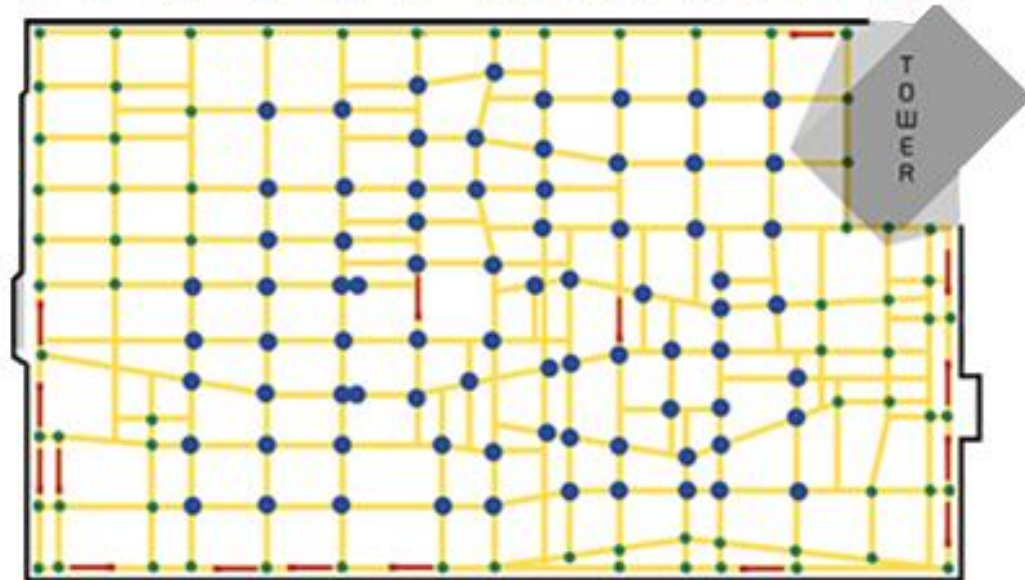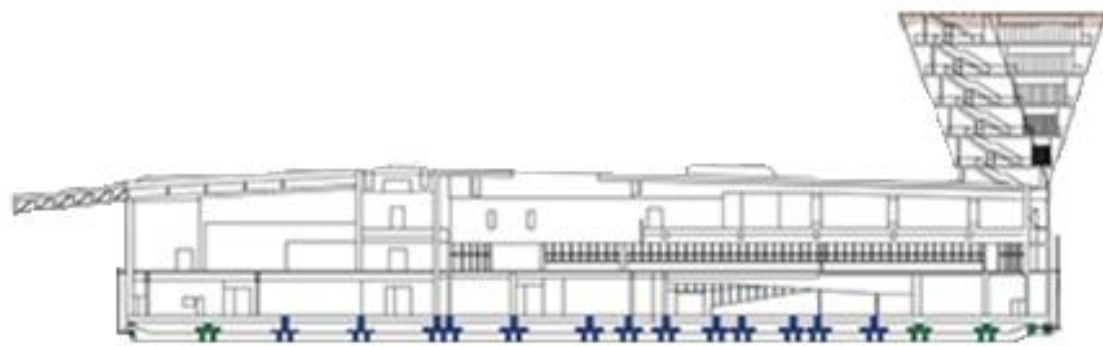
De Young Museum

- Rubber Bearing
- Sliding Bearing
- Fluid Viscous Dampers
- Grade Beams

SECTION AT INTERIOR RUBBER BEARING

Structural Animation

https://www.youtube.com/watch?v=vdtsTbPBeoM

References

- https://www.aisc.org/globalassets/modern-steel/archives/2006/08/2006v08_forever_de_young.pdf

- https://en.wikiarquitectura.com/building/de-young-museum/

- https://deyoung.famsf.org/about/rentals/de-young-floorplans

- https://sites.google.com/site/deyoungmuseumbuidingsystems/

- https://sites.google.com/site/deyoungmuseumbuidingsystems/home/architectural-system

- http://www.ruthchek.com/our_projects/8/9/de-young-museum