UNIVERSITY SCIENCES BUILDING

Northeast USA

Senior Thesis 2011 Faculty Advisor: Andrés Lepage

Kathryn Gromowski | Structural Option

BUILDING INTRODUCTION

SITE MAP

- New Laboratory/Classroom building
- Located in Northeast USA
- 138,000 SF
- Maximum Height: 94'-3"
- Construction Cost: $50 Million
- August 2009-September 2011
- LEED Gold (version 2.2)

PROJECT TEAM

- **Owner:** Not Released
- **Architect:** Diamond & Schmitt Architects, Inc.
  - **Associate Architect:** H2L2 Architecture Planning Interior Design
- **General Contractor:** Turner Construction
- **Structural Engineer:** Halcrow Yolles
  - **Associate Structural Engineer:** Keast and Hood Co.
- **Mechanical Engineer:** CEL International, Inc.
- **Electrical Engineer:** CEL International, Inc.
- **Civil Engineer:** Stantec Consulting Services, Inc.

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- **Building Introduction**
- Existing Structural System
- Problem Statement
- Proposed Solution
- Moment Frame Designs
- Viscous Fluid Damper Design
- Comparison of Designs
- Sustainability Breadth: Viability Study
- Questions/Comments

ARCHITECTURAL FEATURES

- Departure from surrounding campus architecture
- Façade is unique
  - Stone/Aluminum Panels
  - Windows
- 5-story atrium with biowall

RENDERINGS

EXISTING STRUCTURAL SYSTEM

BAY SIZES

- Cast-in-place concrete pile foundations
- Bay sizes

UNIVERSITY SCIENCES BUILDING — EXISTING STRUCTURAL SYSTEM — FILIGREE SLAB DETAILS

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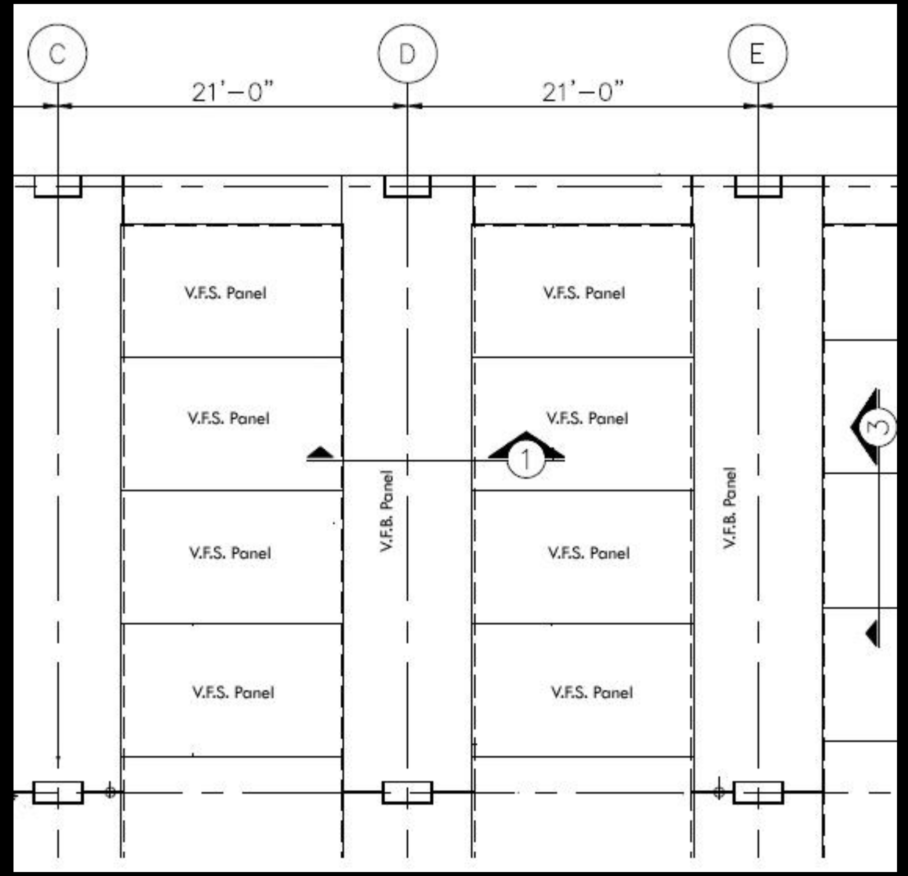
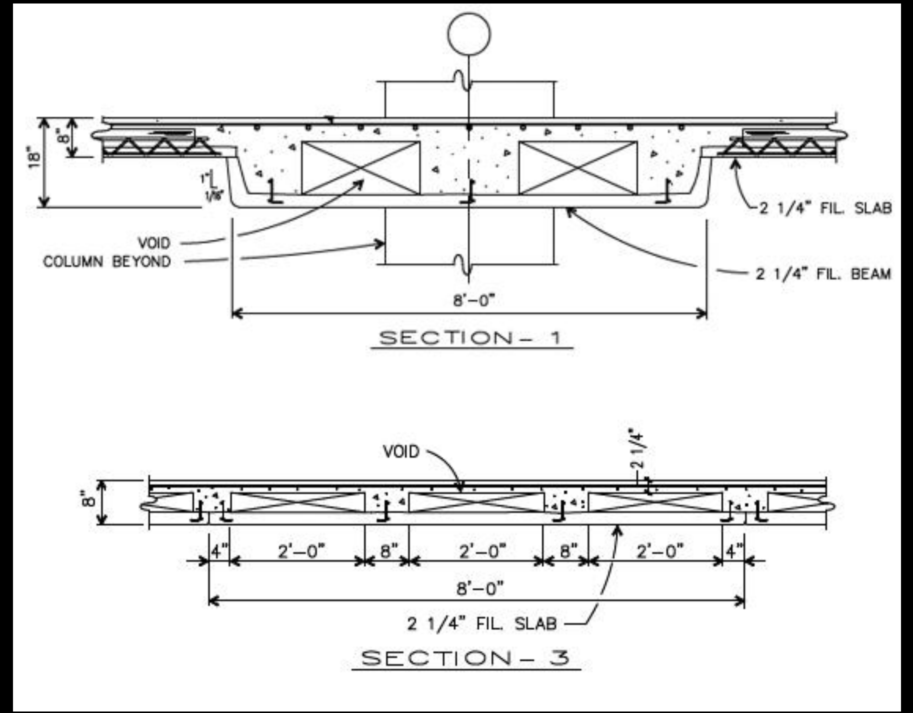
- Cast-in-place concrete pile foundations
- Bay sizes
- Filigree slab construction
- Structural steel mechanical levels





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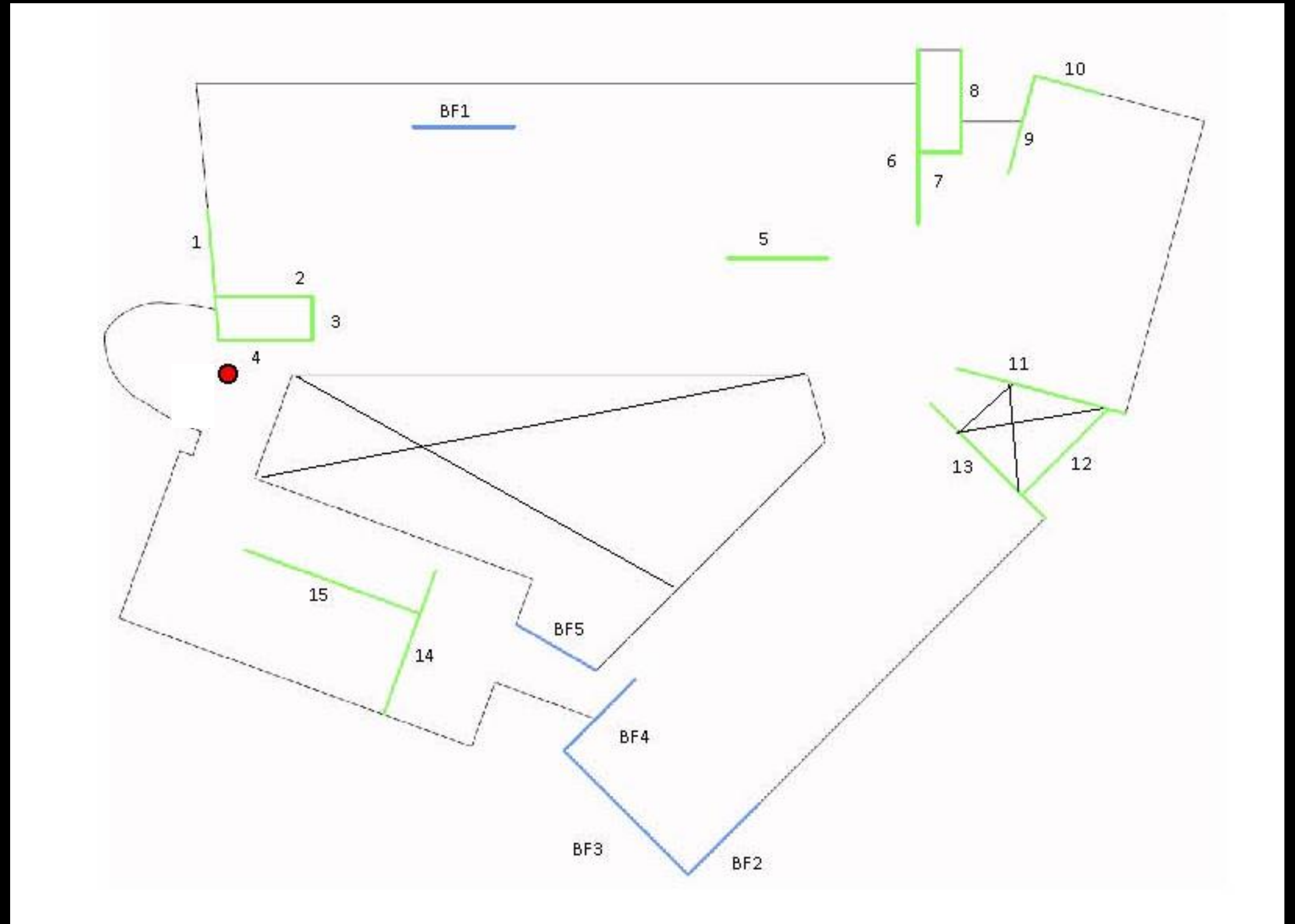
- Cast-in-place concrete pile foundations
- Bay sizes
- Filigree slab construction
- Structural steel mechanical levels
- Cast-in-Place Concrete Shear Walls
  - Braced frames at mechanical levels

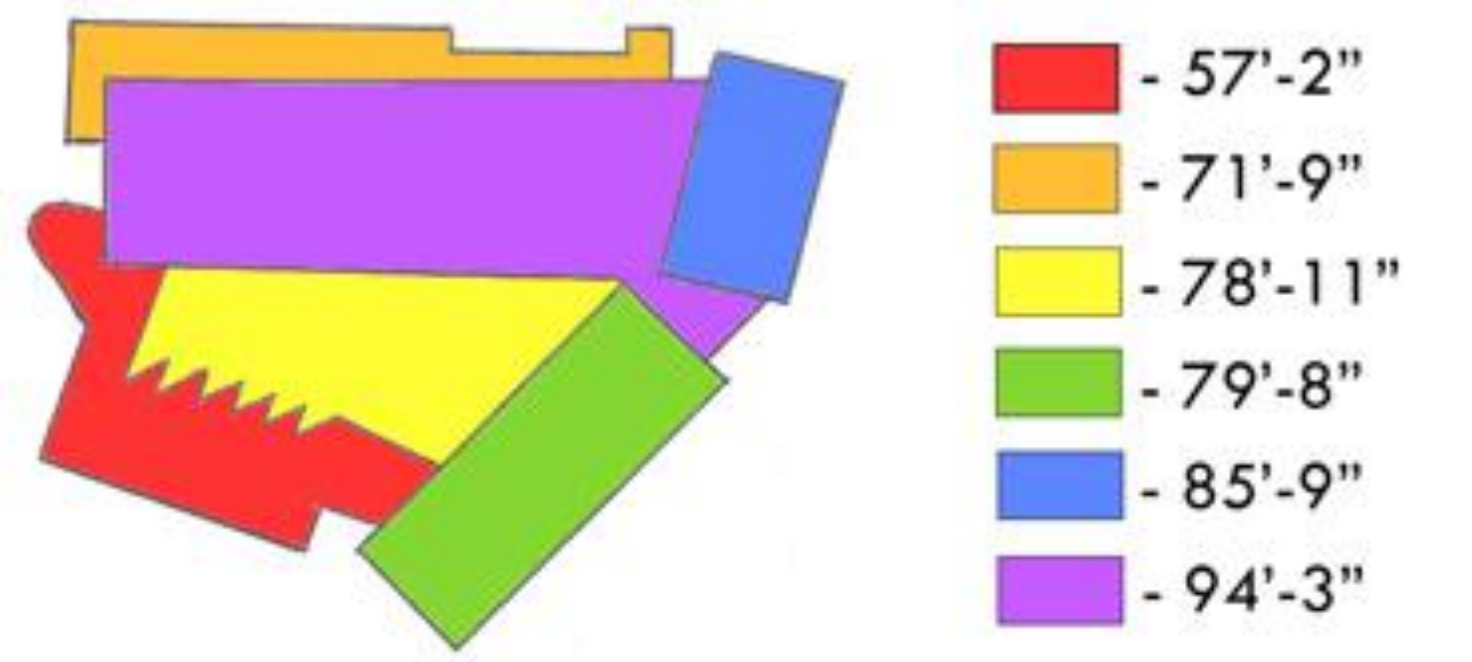
LATERAL SYSTEM



ROOF HEIGHTS

ROOF HEIGHTS PLAN

- 6 Roof Heights
  - Office Roof
  - "Ledge" Roof
  - Atrium Roof
  - 5^{th} Level Mech. Rm. Roof
  - Chiller Room Roof
  - AHU Mech. Rm. Roof



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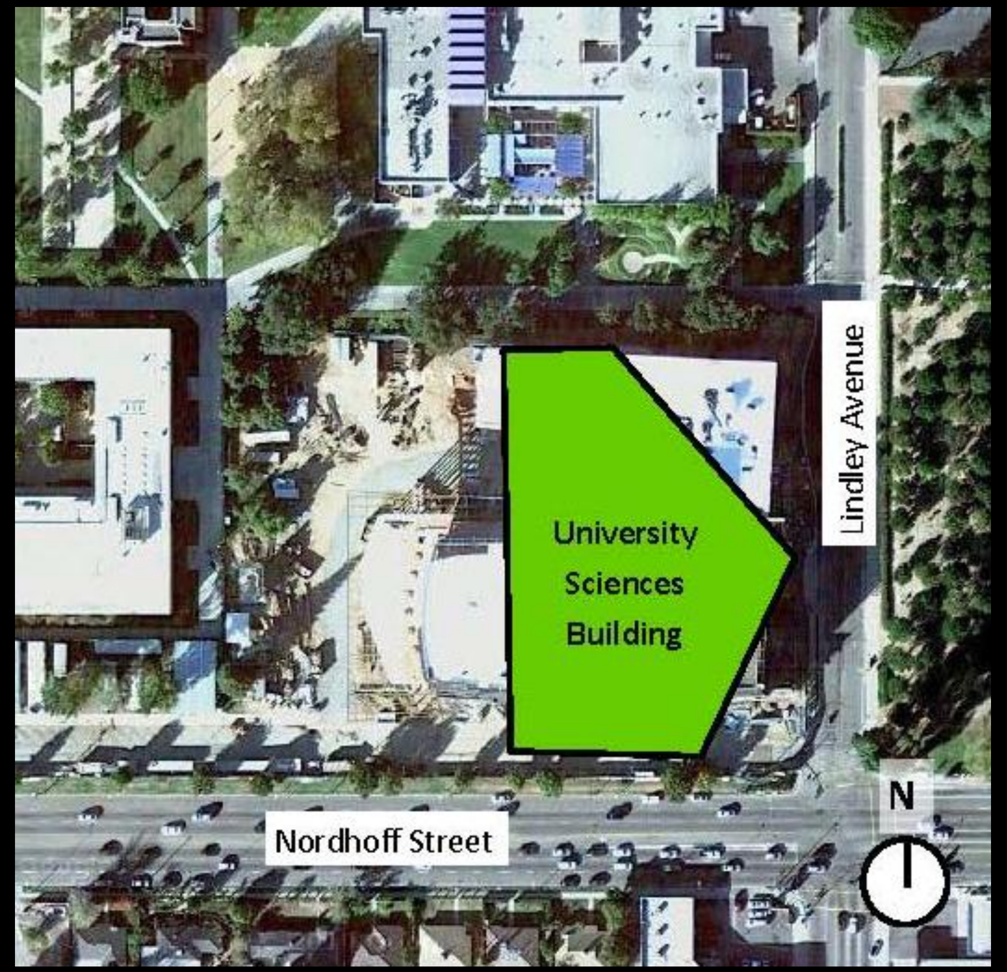
PROBLEM STATEMENT

- Interest in seismic design
- New scenario created
  - Building commissioned by California State University, Northridge (CSUN) instead
  - Very close to Northridge fault (Northridge Earthquake in 1994)
  - Geotechnical report found for site on the CSUN campus
    - Very similar to Northeast USA site

CALIFORNIA SITE



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PROPOSED SOLUTION

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- 4 Designs undertaken in steel
  - Code Minimum Moment Frame in Northeast USA (NE USA S-3)
  - Code Minimum Moment Frame in California (CA S-3)
  - Immediate Occupancy Moment Frame in California (CA S-1)
  - Code Minimum Moment Frame augmented with Viscous Fluid Dampers to achieve Immediate Occupancy in California (CA S-3 with VFD)

GOALS

- Comparison between different designs
  - Original to NE USA S-3 (Concrete vs. Steel in current location)
  - CA S-3 to NE USA S-3 (high seismic vs. low seismic)
  - CA S-1 to CA S-3 (high performance, traditional method vs. minimum performance)
  - CA S-3 with VFD vs. CA S-3 (high performance, high-tech method vs. minimum performance)
  - CA S-3 with VFD to CA S-1 (traditional vs. high-tech)

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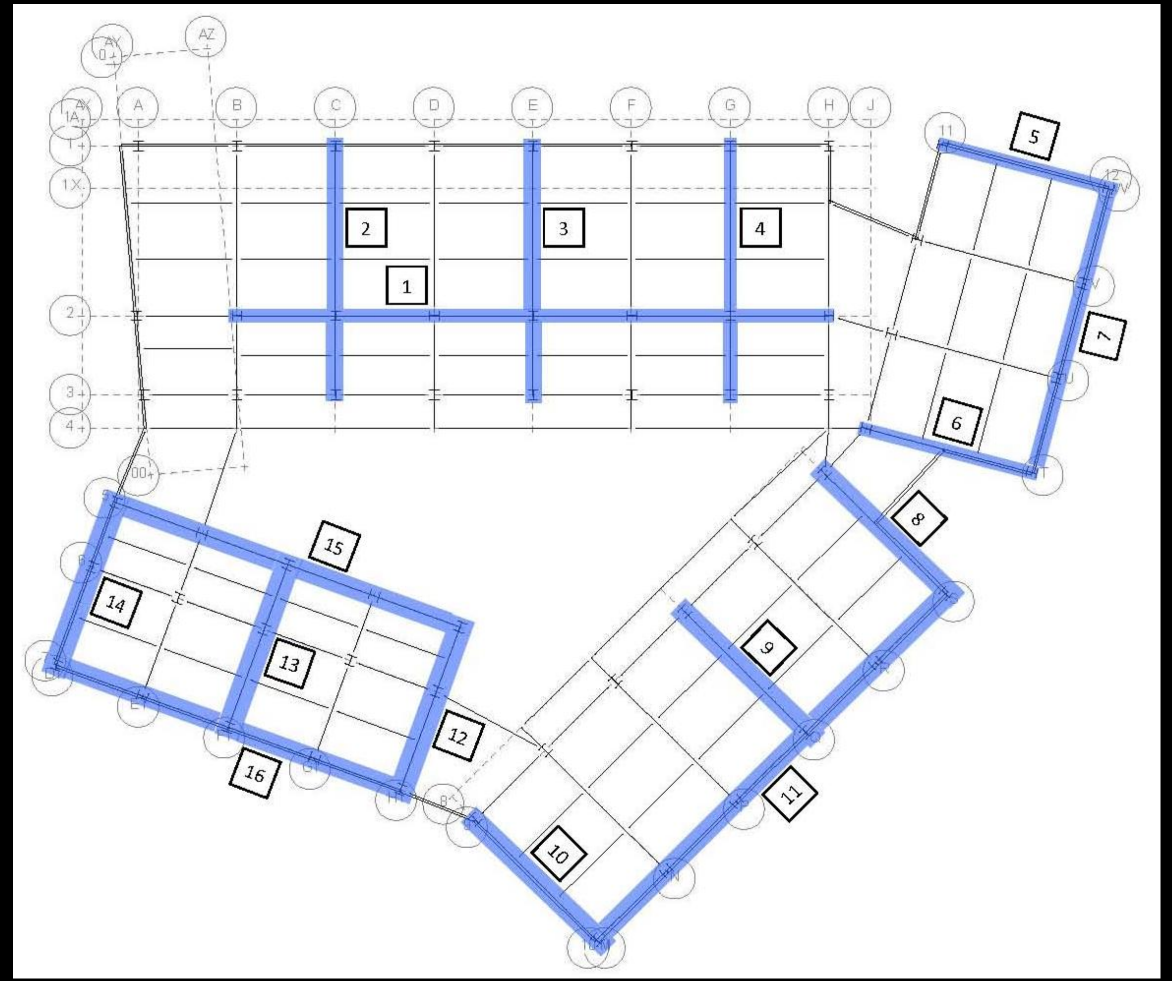
GRAVITY REDESIGN

MOMENT FRAME LAYOUT



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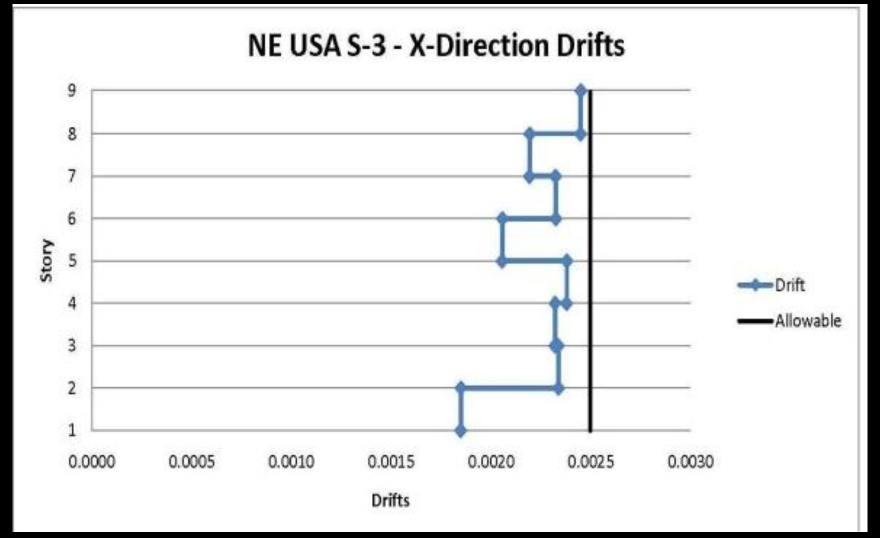
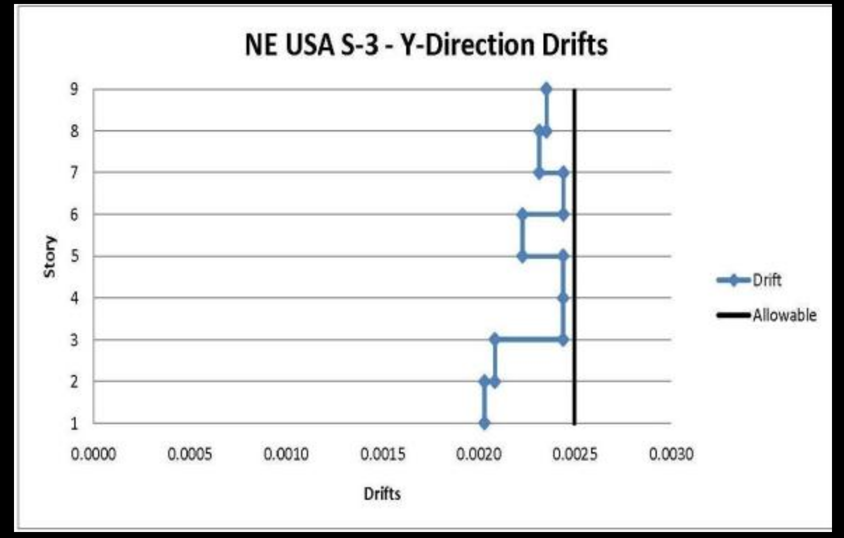
NE USA S-3 SUMMARY

- Weight – 11,800 k
- Wind Base Shears
  - N-S Direction – 450 k
  - E-W Direction – 652 k
- Seismic Base Shear
  - Both Directions – 456 k

STORY DRIFT RATIOS

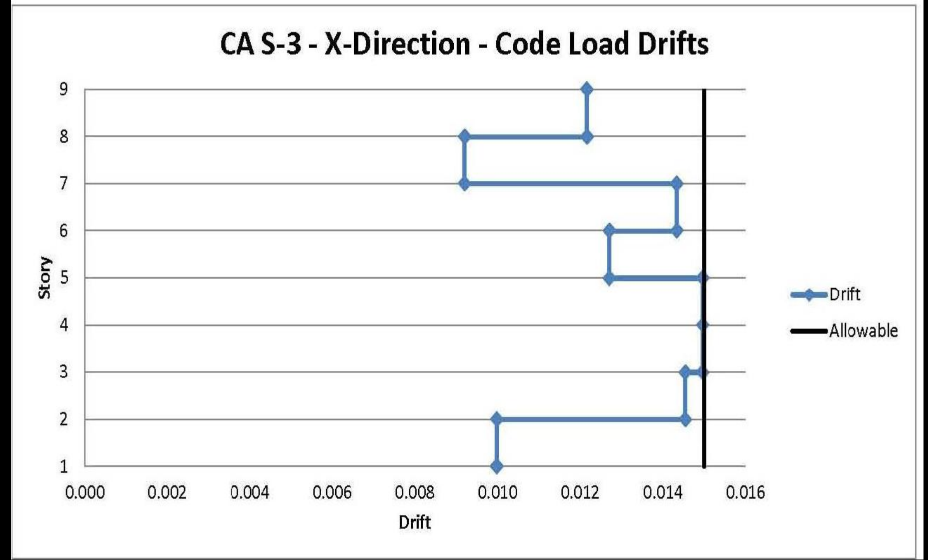


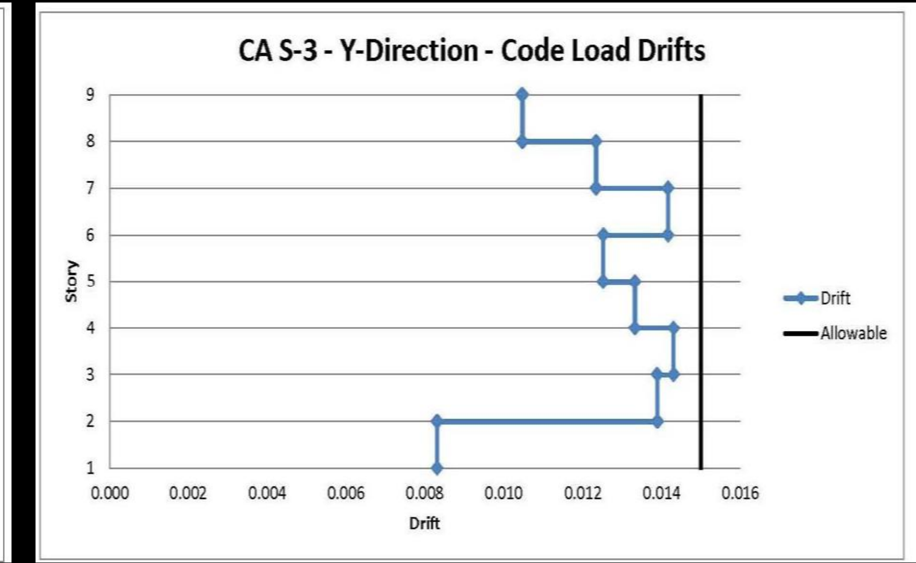


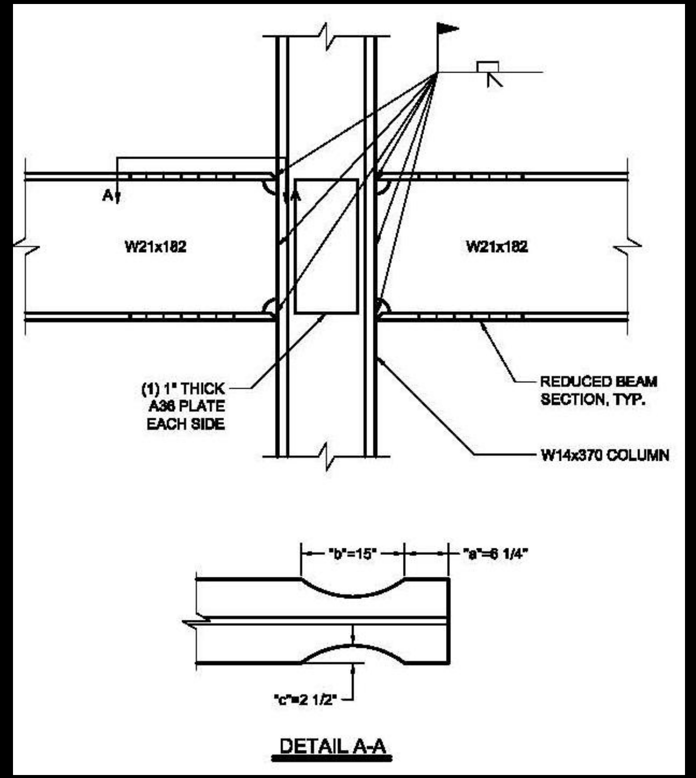
CA S-3 SUMMARY

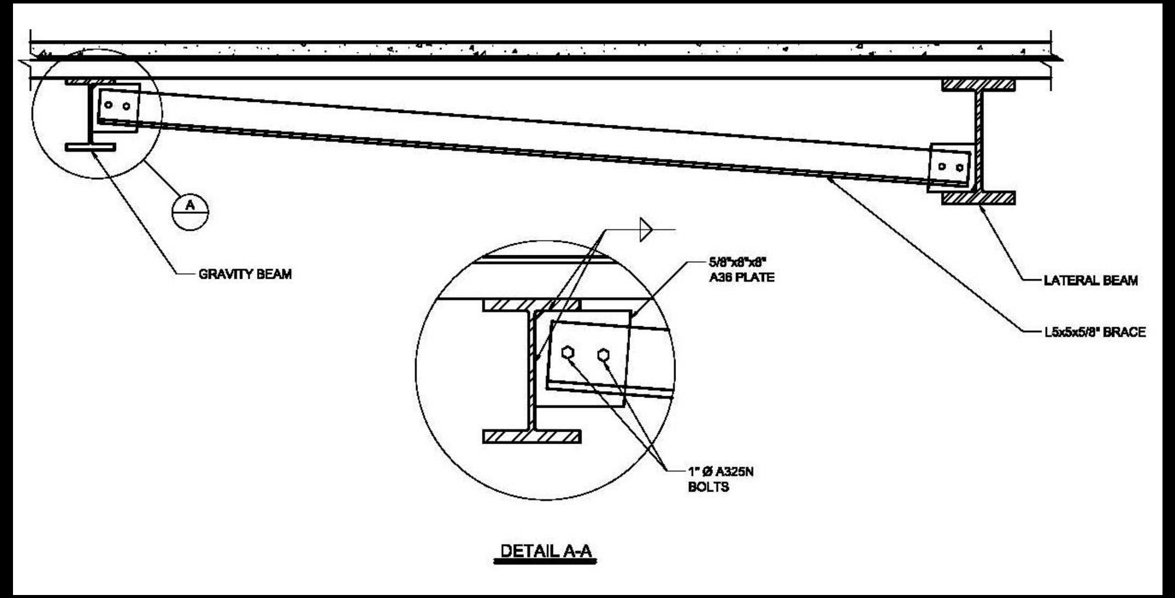
CA S-3 CONNECTIONS

- Weight – 12,300 k
- Seismic Base Shear
  - Both Directions – 815 k









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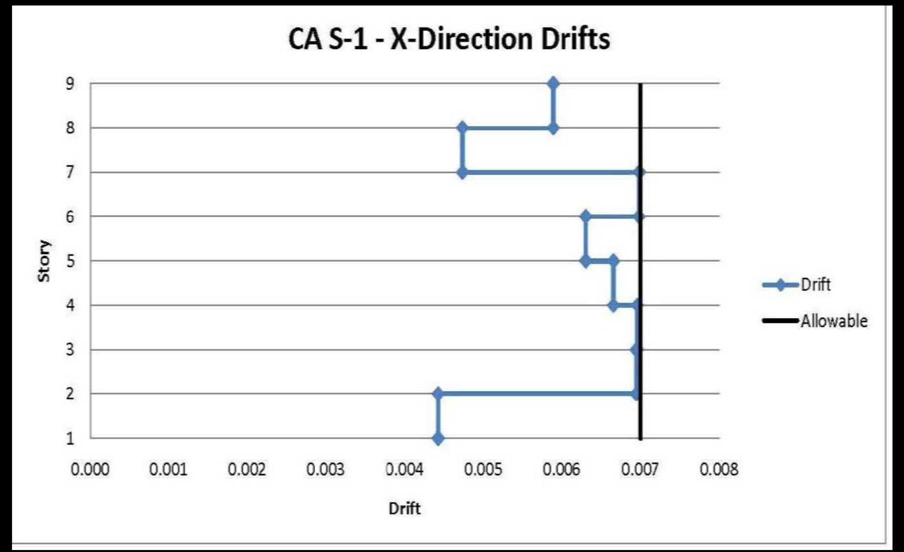
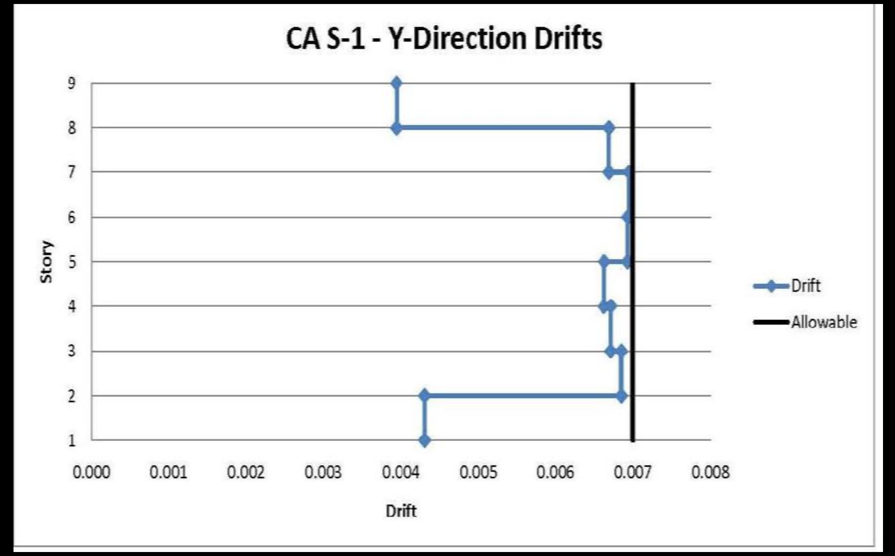
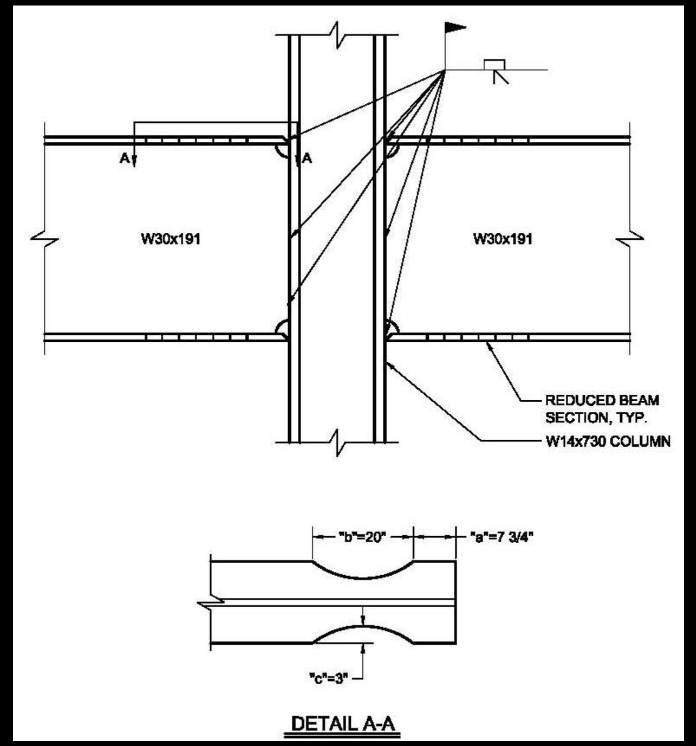
CA S-1 SUMMARY

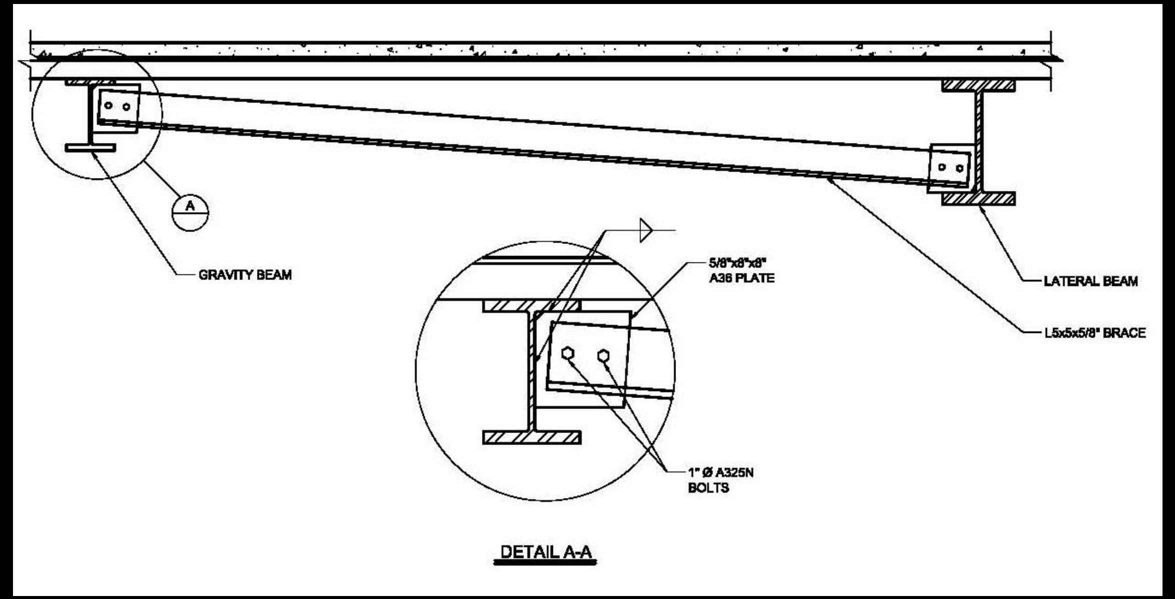
- Weight – 13,500 k
- Seismic Base Shear
  - Both Directions – 849 k





CA S-1 CONNECTIONS





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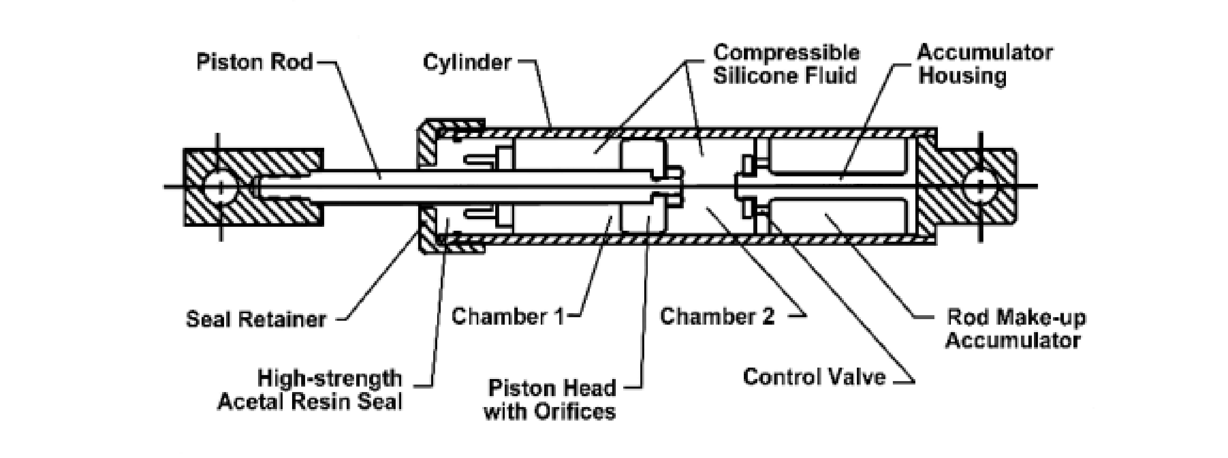
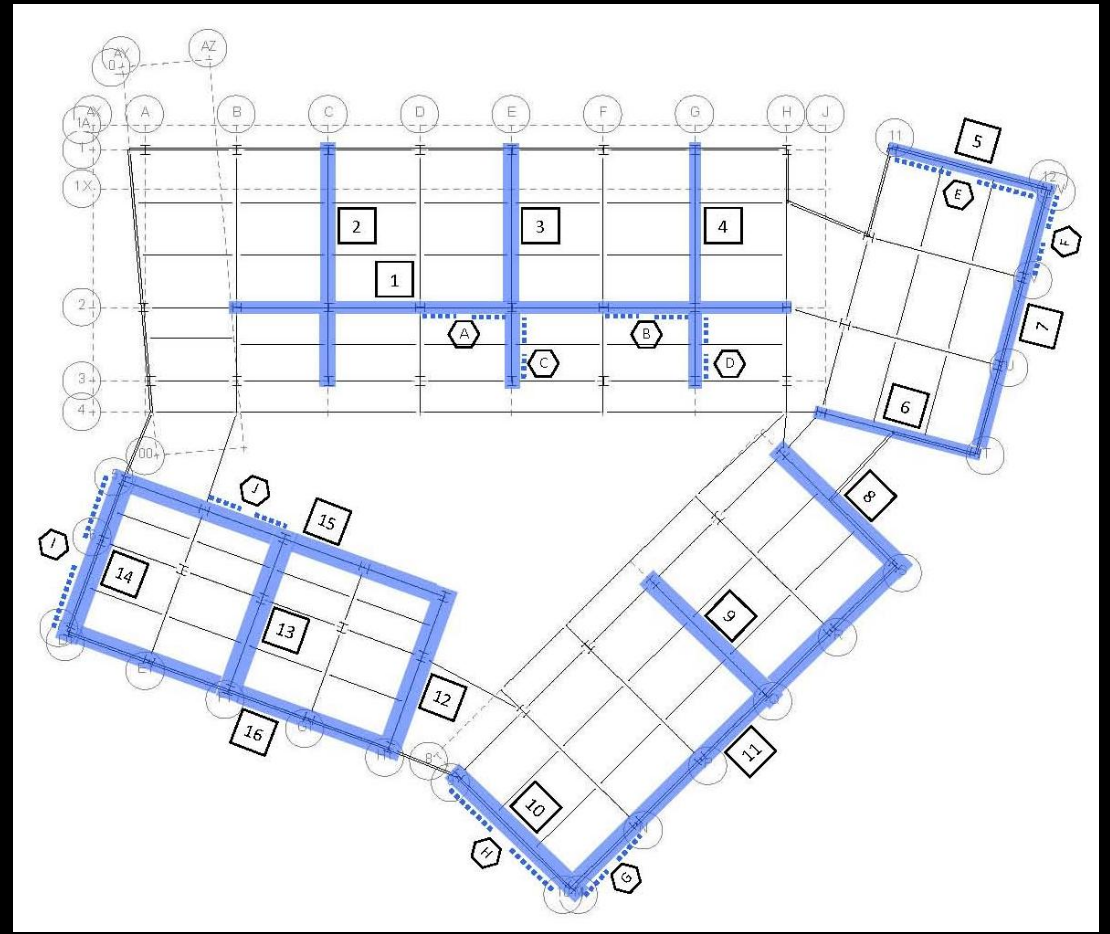
VFD INTRODUCTION



VFD LAYOUT



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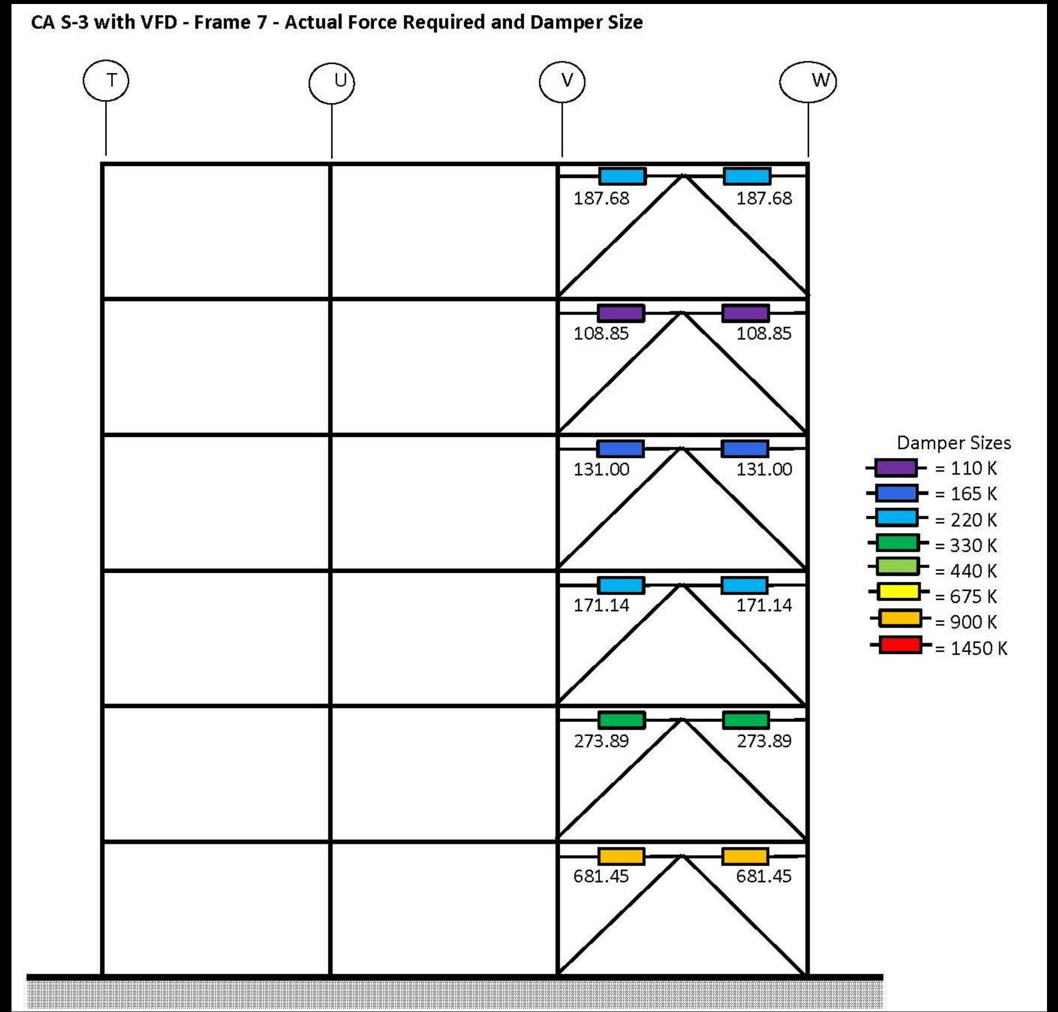
PRELIMINARY SIZING



MODELING PARAMETERS

$$F=Cv^{\alpha}$$

CA S-3 with VFD - Frame 7 - Required Damper Properties				
Level	Size (k)	Velocity (in/s)	α	C_{req}
AHU Roof	N/A	11.114	0.6	N/A
Chiller Roof	220	11.114	0.6	51.87
Atrium Roof	N/A	11.114	0.6	N/A
Penthouse	110	11.114	0.6	25.93
5th	165	11.114	0.6	38.90
4th	220	11.114	0.6	51.87
3rd	330	11.114	0.6	77.80
2nd	900	11.114	0.6	212.18

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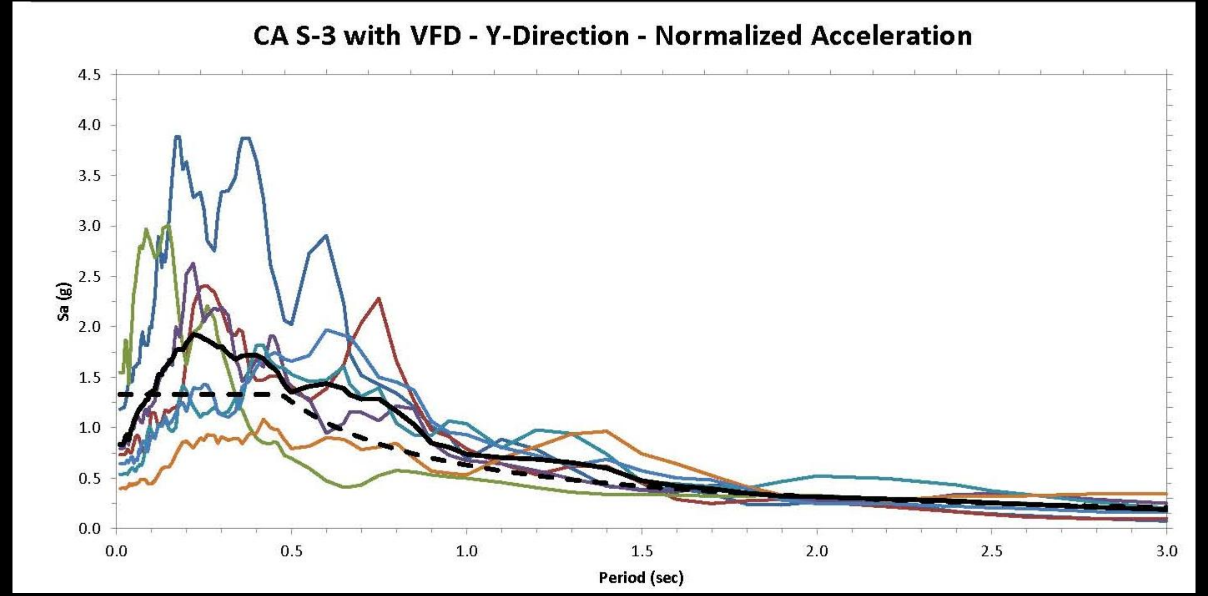
INITIAL SCALING

- Earthquake history records selected and scaled for nonlinear analysis
  - Records selected were recommended in FEMA P695
  - Scaling was done in a two-step process



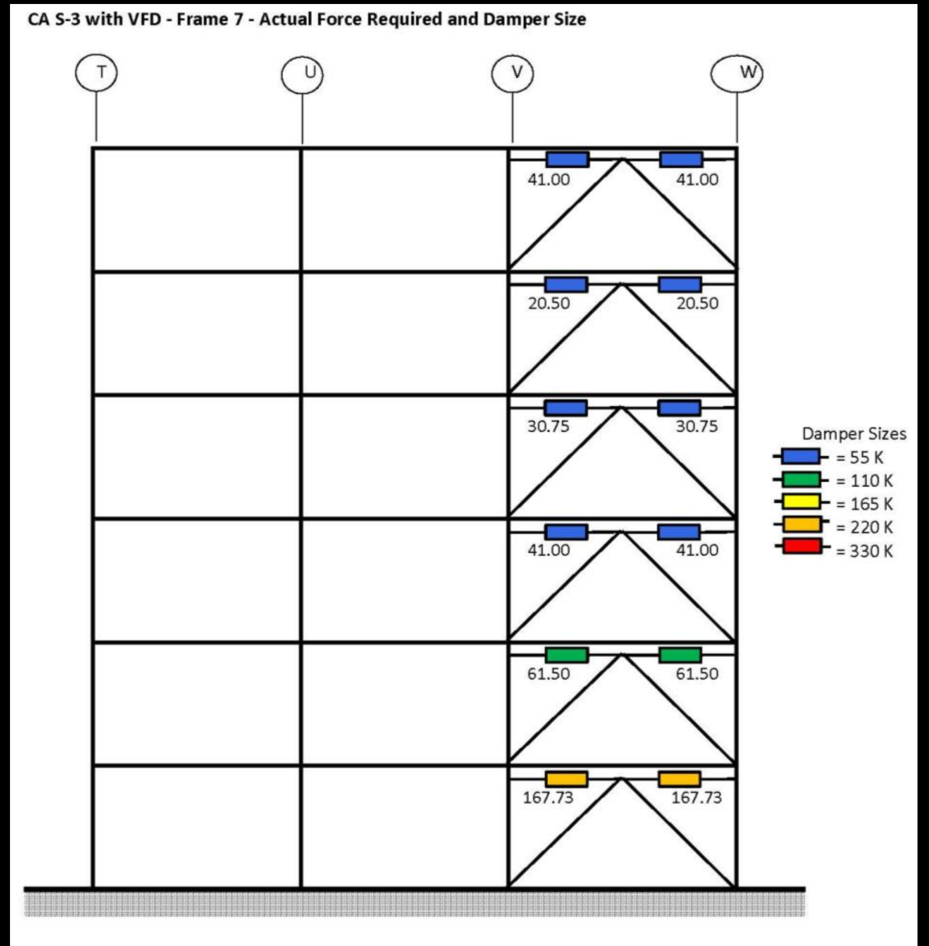
HISTORY APPLICATION

- Histories first applied to CA S-3 model as linear loads to verify earthquake selection
  - Records scaled for 1.5% drifts
- Histories applied to CA S-3 with VFD model
  - Dampers sized to achieve 0.7% drift

FINAL PARAMETERS

FINAL SIZES

CA S-3 with VFD - Frame 7 - Required Damper Properties					
Level	C	Velocity (in/s)	α	F_{req}	Size (k)
AHU Roof	N/A	31.370	0.6	N/A	N/A
Chiller Roof	5.19	31.370	0.6	41.00	55
Atrium Roof	N/A	31.370	0.6	N/A	N/A
Penthouse	2.59	31.370	0.6	20.50	55
5th	3.89	31.370	0.6	30.75	55
4th	5.19	31.370	0.6	41.00	55
3rd	7.78	31.370	0.6	61.50	110
2nd	21.22	31.370	0.6	167.73	220



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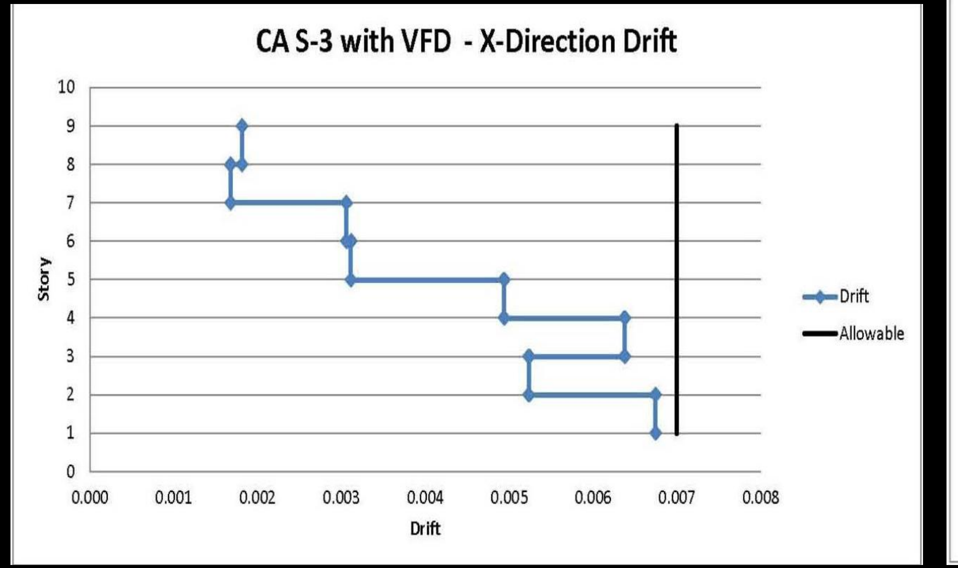
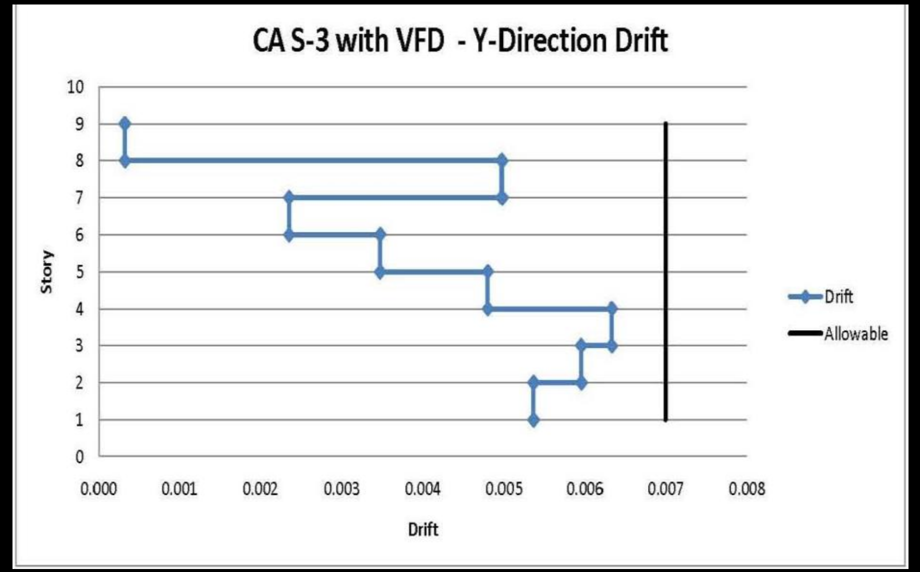
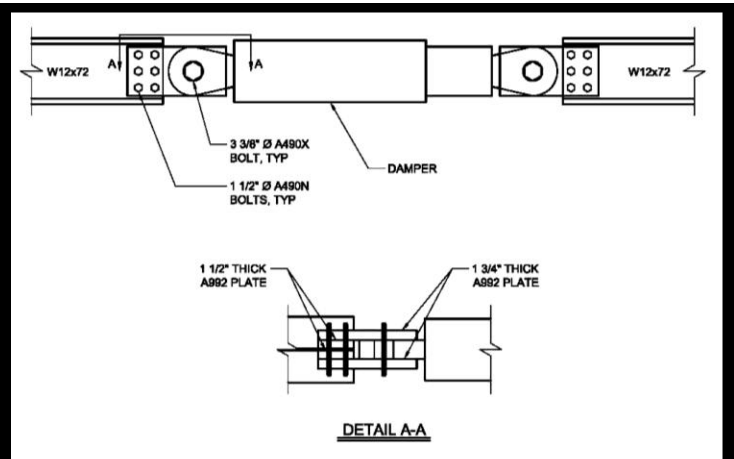
CA S-3 WITH VFD SUMMARY

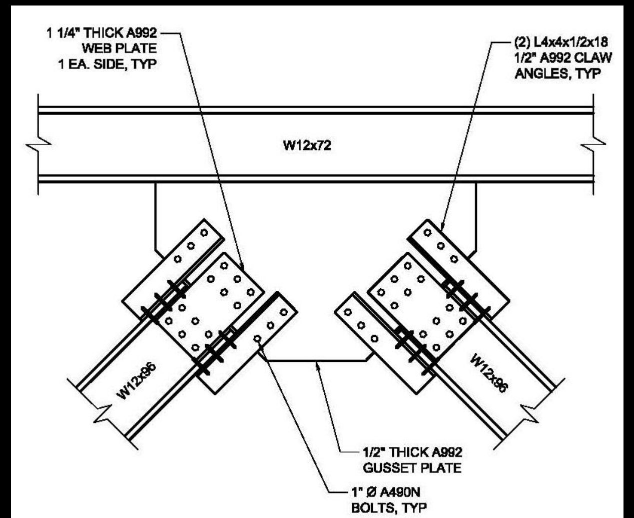
- Weight – 12,500 k
- Seismic Base Shear
  - Both Directions – 815 k

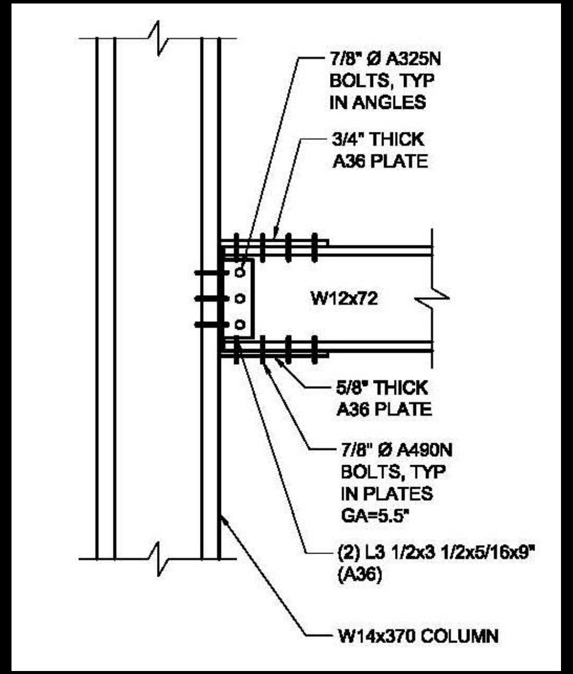




CA S-3 WITH VFD CONNECTIONS







CA S-3 VS. CA S-3 WITH VFD

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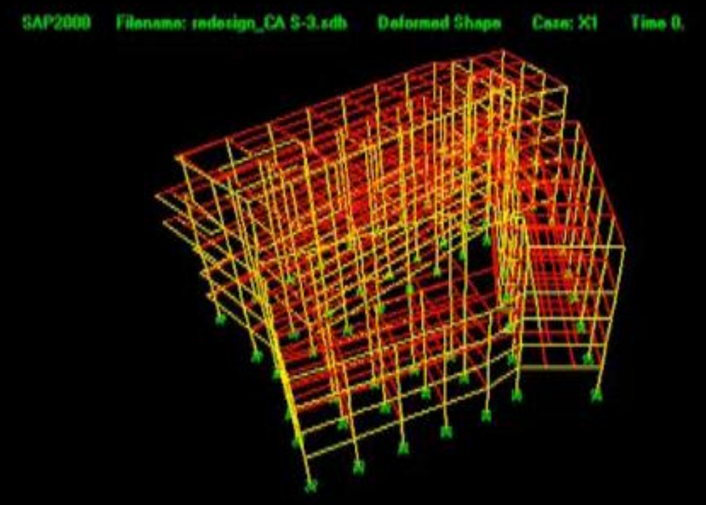
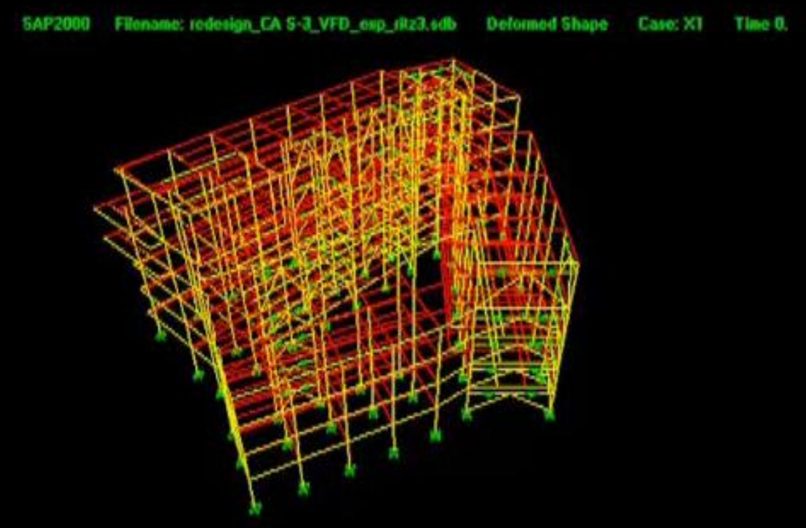


CA S-3



CA S-3 with VFD

CM BREADTH SUMMARY

COMPARISONS

CM Breadth Summary		
System	Cost	Schedule Duration (months)
Original	$39.4 million	22
NE USA S-3	$37.2 million	24
CA S-3	$37.8 million	24
CA S-1	$40.1 million	25
CA S-3 with VFD	$38.3 million	25

- NE USA S-3 structure 5.6% less expensive, 50% lighter than original
  - Longer duration unacceptable
- CA S-3 structure 1.6% more expensive, 4.5% heavier than NE USA S-3
  - Same duration as NE USA S-3
  - Cost associated with moving to a seismic region is small

COMPARISONS

- CA S-1 structure is 6% more expensive, 9.7% heavier than CA S-3 structure
  - Impractical method to achieve higher performance
- CA S-3 with VFD is 1.5% more expensive, 1.5% heavier than CA S-3 structure
  - Very efficient method of increasing performance
  - Cost minimal in comparison to cost of replacing damaged system following an earthquake
  - System very specialized and difficult to design

INTRODUCTION

- Building is now in California
- Feasibility of a solar photovoltaic system
  - Life Cycle Assessment
  - Payback Period
  - Carbon Footprint (net after one year)
  - Additional LEED points earned
- Feasibility of a green roof system
  - Life Cycle Assessment
  - Payback Period
  - Carbon Footprint (net after one year)
  - Additional LEED points earned

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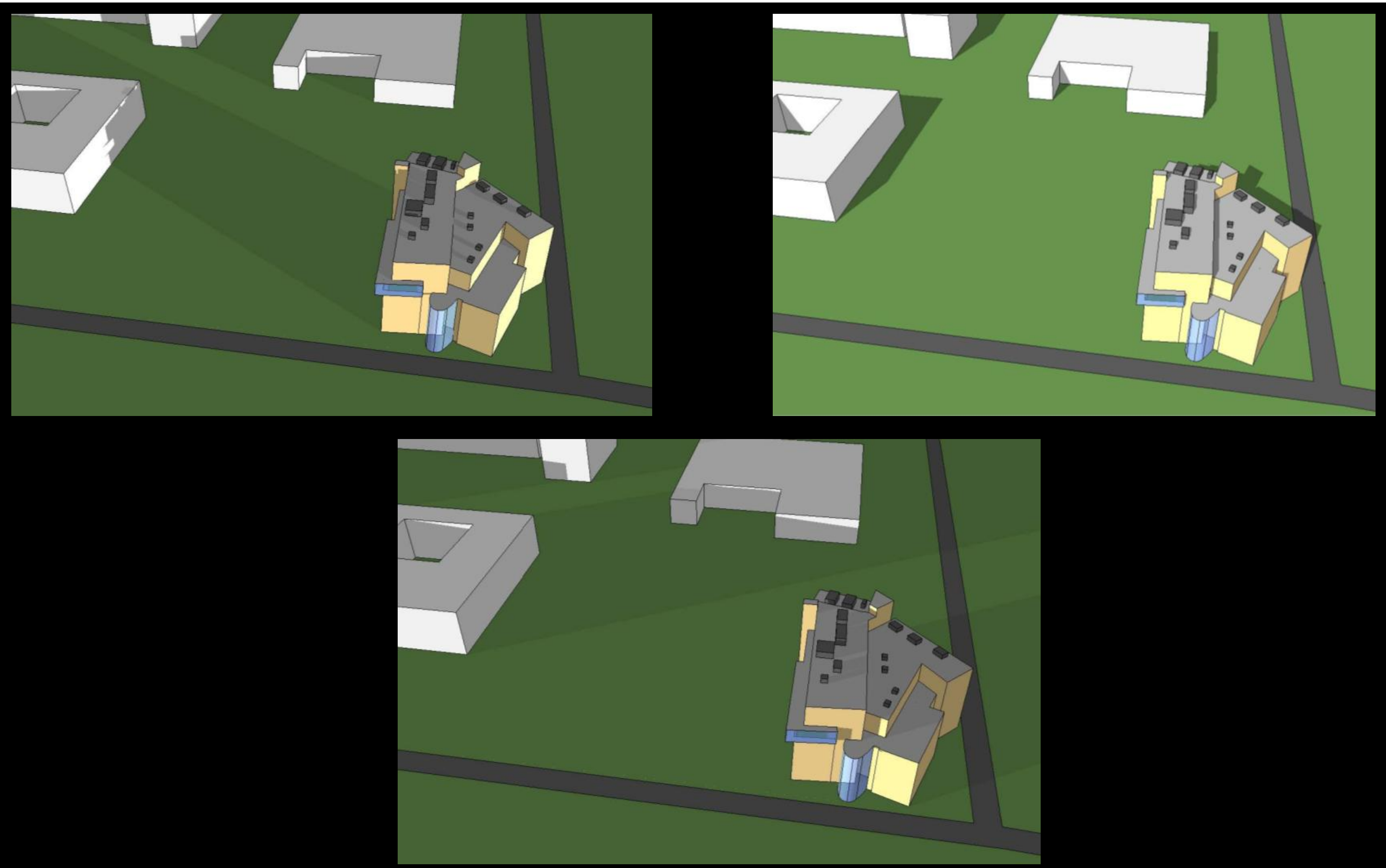
PV DESIGN – SOLAR STUDY

- Carried out using Google Sketchup
- Critical Days
  - Winter Solstice, Summer Solstice, and Equinox
- Critical Times
  - Sunrise, Sunset, and 1:00 PM (peak hour)
- Determined that Office Roof was the only suitable location

SHADING IMAGES



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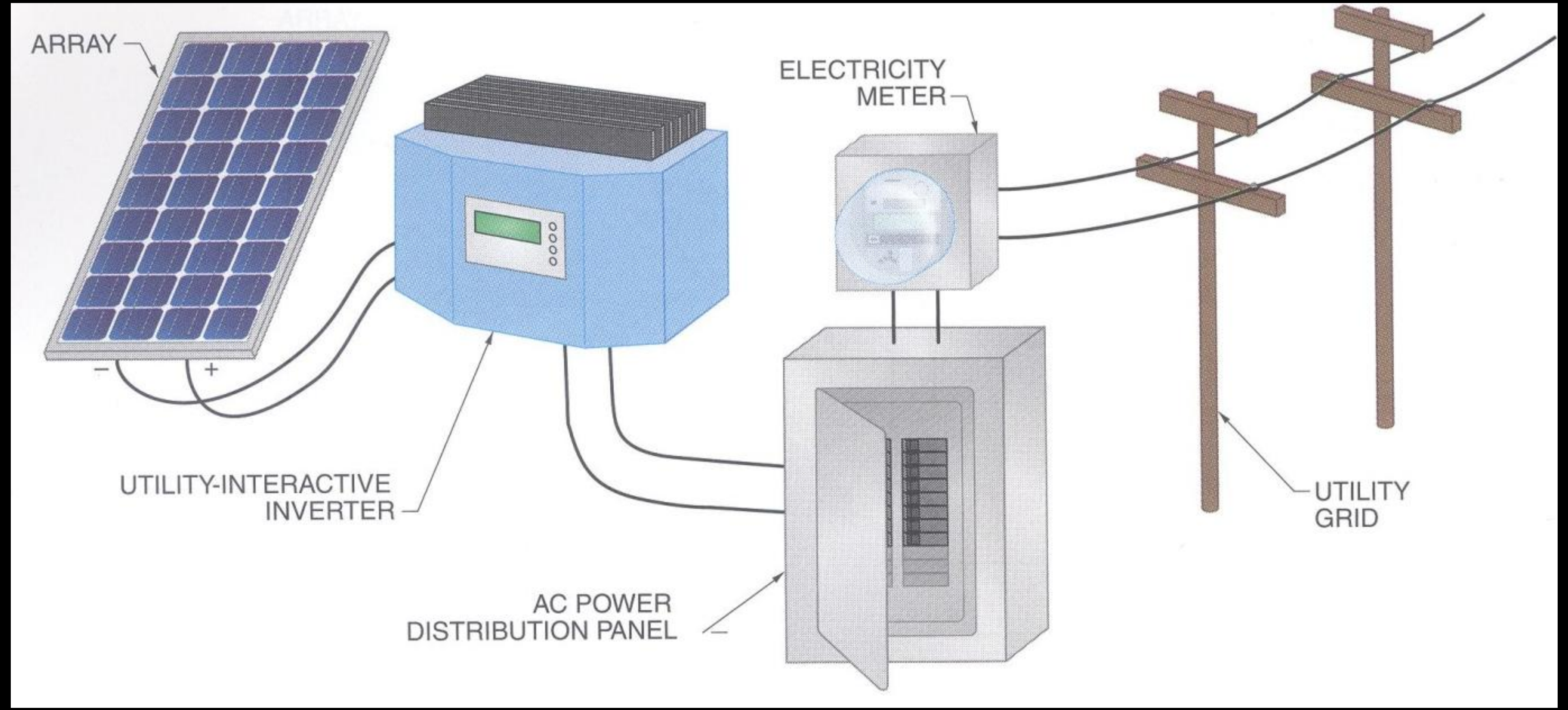
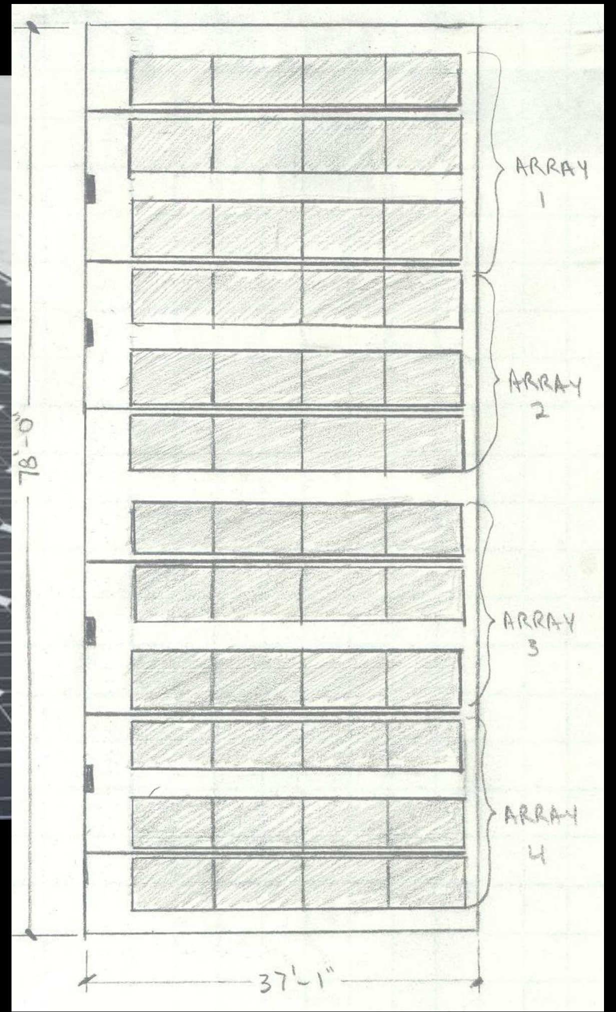
PV DESIGN – SYSTEM SELECTION



PV DESIGN – PANELS



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PV ANALYSIS – LIFE CYCLE COST

Life-Cycle Cost - PV System					
General Rate: 0.04					
Energy Rate: 0.03					
Cost Description	Cost/year	Single Cost Year	Recurring Cost Years	Present Value Factor	Present Value
Initial Costs					
System Purchase & Installation	$105,139.63	0		1.000	$105,139.63
Incentives	-$31,541.89	1		0.962	-$30,343.30
Maintenance Costs					
Inspections	$100.00		20	13.590	$1,359.00
Repair & Replacement Costs					
Inverter Replacement	$8,000.00	10		0.676	$5,408.00
Salvage Value					
Salvage	-$21,027.93	20		0.456	-$9,588.73
				Total:	$71,974.60

PV ANALYSIS – PAYBACK PERIOD

Payback Period - PV System		
Description	High Season	Low season
Total Power (kWh) *	8650	11456
High Peak Period Power (kWh) **	6920	9164.8
Low Peak Period Power (kWh) **	1730	2291.2
Value of High Peak Period Power	$927.33	$969.25
Value of Low Peak Period Power	$182.17	$226.70
Total Value of Power	$1,109.51	$1,195.95
Total Value per Year	$2,305.46	
Payback Period	31.22 years	

* = Found using PVWatts results
** = 80% of total power was assumed to be generated during the High Peak Period. The reamining 20% was assumed to be generated during the Low Peak Period.

PV ANALYSIS – OTHER ANALYSES

- Carbon Footprint
  - 2,570 lb CO_{2e}
- Additional LEED points earned
  - 1 credit – E&A Credit 2: On-Site Renewable Energy

GREEN ROOF DESIGN – SYSTEM

- Extensive system chosen
  - Shallower, lighter
  - Not accessible, no occupied floors above
- Modular system chosen
  - Ease of installation
  - Ease of maintenance (both green roof and roof below)
- GreenGrid Roof

SAMPLE INSTALLATION

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GREEN ROOF ANALYSIS – LCA

Life-Cycle Cost - Green Roof System					
General Rate: 0.04					
Energy Rate: 0.03					
Cost Description	Cost/year	Single Cost Year	Recurring Cost Years	Present Value Factor	Present Value
Initial Costs					
System Purchase & Installation	$60,742.50	0		1.000	$60,742.50
Maintenance Costs					
Inspections	$400.00		20	13.590	$5,436.00
Repair & Replacement Costs					
25% Module Replacement	$15,185.63	10		0.676	$10,265.48
Roof Membrane Non-Replacement	-$26,032.50	15		0.550	-$14,317.88
Salvage Value					
Salvage	-$12,148.50	20		0.456	-$5,539.72
				Total:	$56,586.39

GREEN ROOF ANALYSIS - PP

Payback Period - Green Roof		
Description	High Season	Low season
Power Saved	12000	24000
High Peak Period Power (kWh) *	9600	19200
Low Peak Period Power (kWh) *	2400	4800
Value of High Peak Period Power	$1,286.47	$2,030.55
Value of Low Peak Period Power	$252.73	$474.94
Total Value of Power	$1,539.20	$2,505.49
Total Value per Year	$4,044.69	
Carbon Saved (lb CO_{2e})	54,000	
Run-off Saved (CF)	4,810.00	
Cost of Run-Off ($/CF)	$0.038	
Value of Run-Off Saved per Year	$182.78	
Payback Period	13.39 years	

* = 80% of total power was assumed to be generated during the High Peak Period.
The reamining 20% was assumed to be generated during the Low Peak Period.

GREEN ROOF ANALYSIS – OTHER

- Carbon Footprint
  - 154,500 lb CO_{2e} to install
  - 54,000 lb CO_{2e} saved per year
  - 100,500 lb CO_{2e} net at 1 year
  - Will eventually go negative
- Additional LEED points earned
  - 1 credit – SS Credit 6.1: Stormwater Quantity Control

Sustainability Breadth Summary		
Description	PV System	Green Roof
Life Cycle Assesment	$71,974.60	$56,586.39
Net Carbon Footprint (lb CO_{2e})	2,570.92	100,459.50
Payback Period (years)	31.22	13.39
LEED Points (Version 2.2)	1	1
Weight (psf)	2.03	18-22
Structural Impact	Minimal	Moderate

- LEED – systems are the same
- All other analyses favor green roof

ACKNOWLEDGEMENTS

- Family and Friends
- Turner Construction
  - Amy Cavanaugh
  - Roger Gentry
  - Scott Frank
- HGA Architects and Engineers
  - Johanna Harris
  - Paul Asp
- All AE Faculty and Staff
  - Dr. Andrés Lepage

QUESTIONS?