Collapse Assessment of the ACC Building Part I:

ASCE 41 Evaluation Utilizing Nonlinear Response History Analyses of a 1965 Reinforced Concrete Building

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SEAOC
STRUCTURAL ENGINEERS ASSOCIATION OF CALIFORNIA

San Diego SEAOC 2025 CONVENTION

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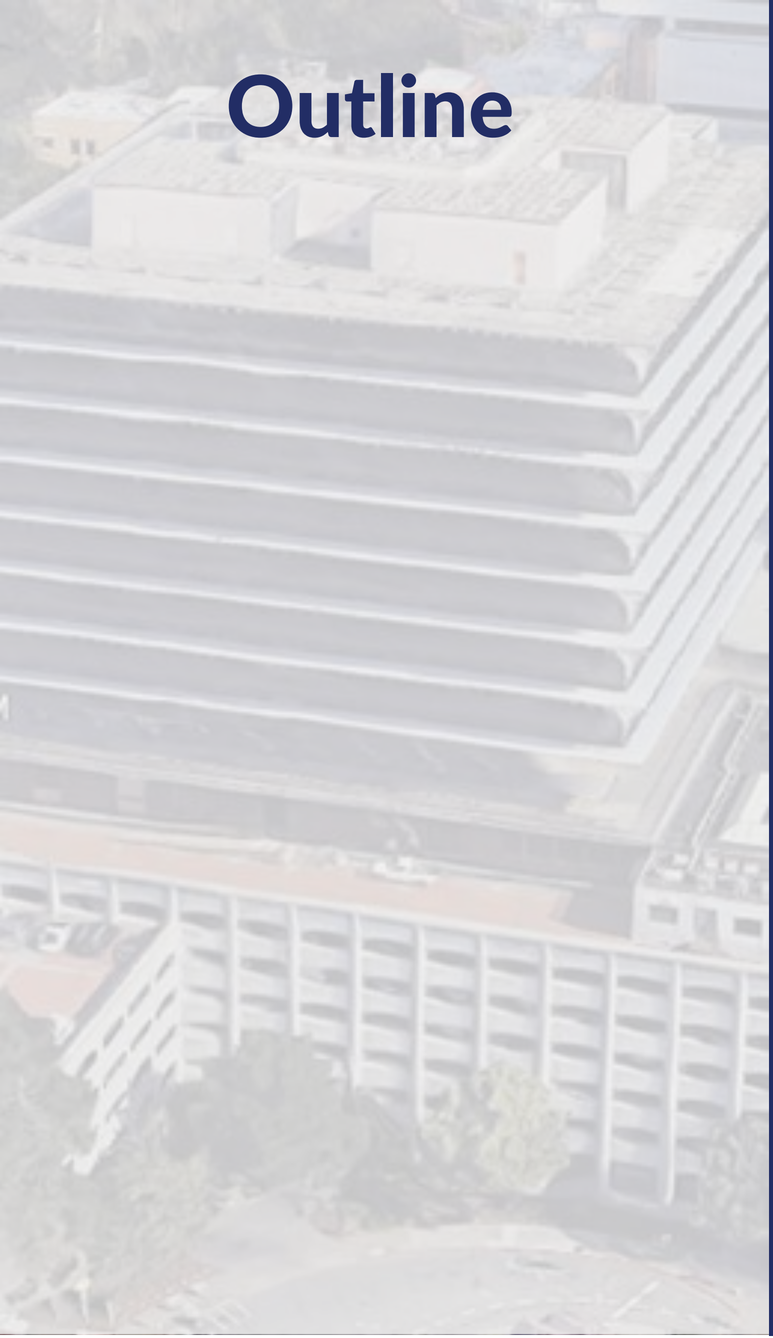
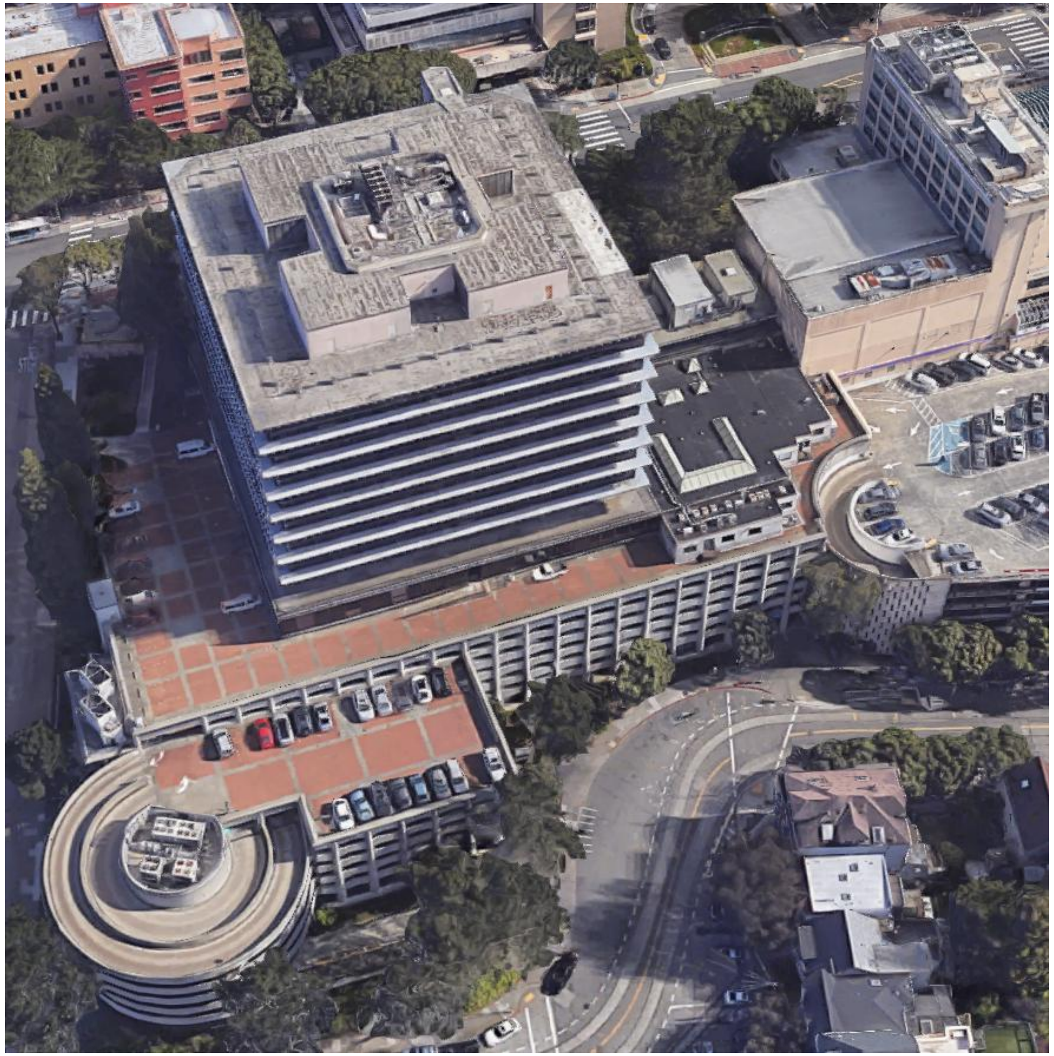
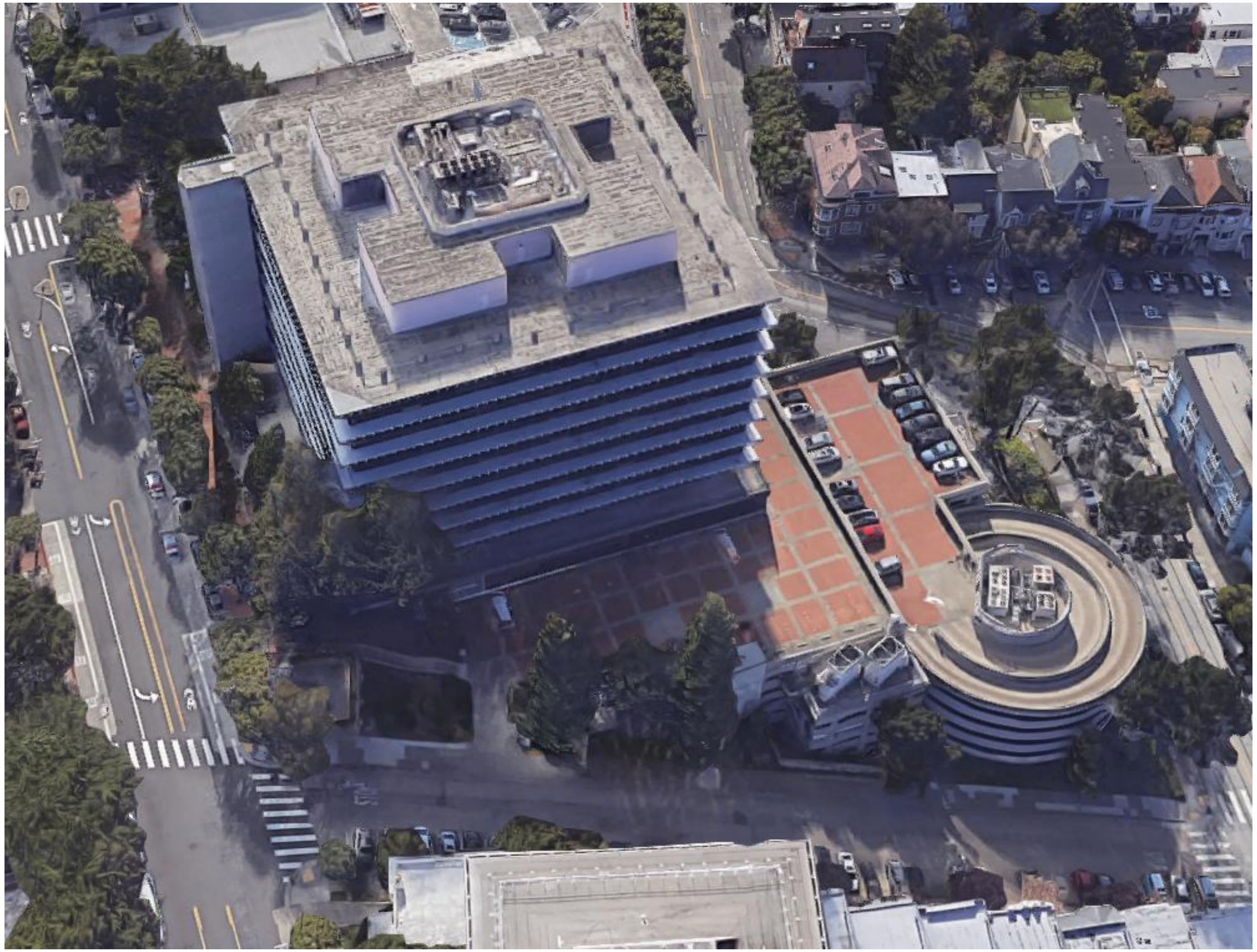
Outline



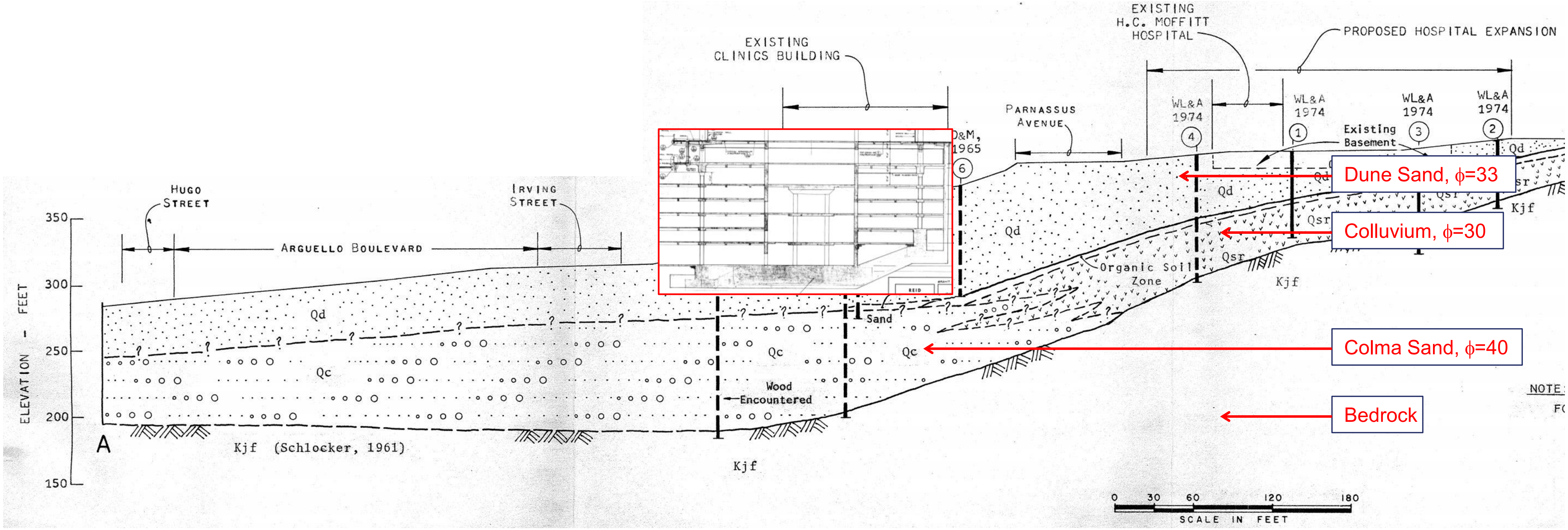
- Building Overview
- Project Description
- ASCE 41 Analyses
- Retrofit Schemes
- Conclusions

Building Overview

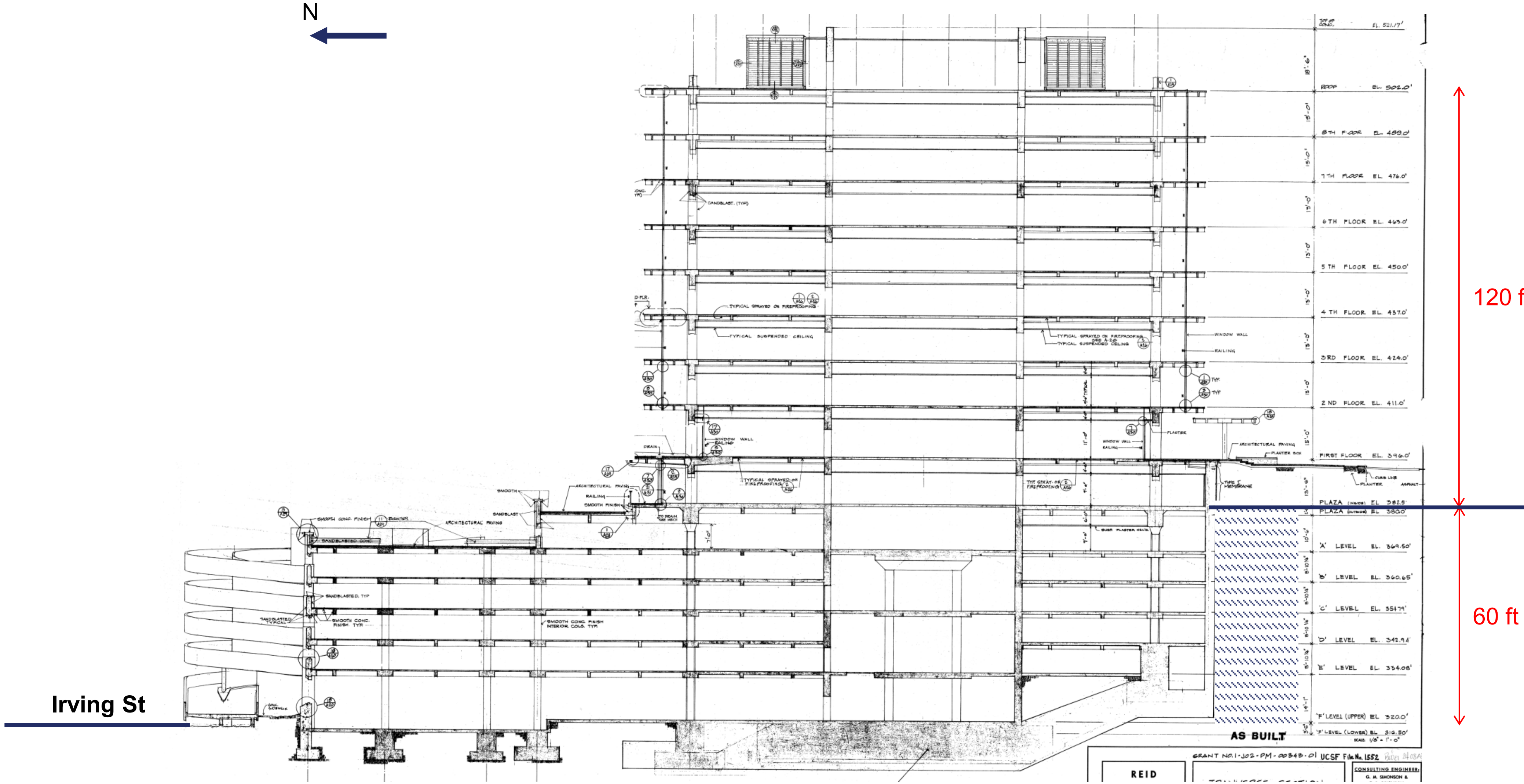


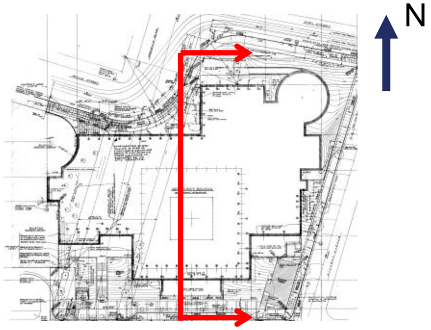


Geologic Cross-Section

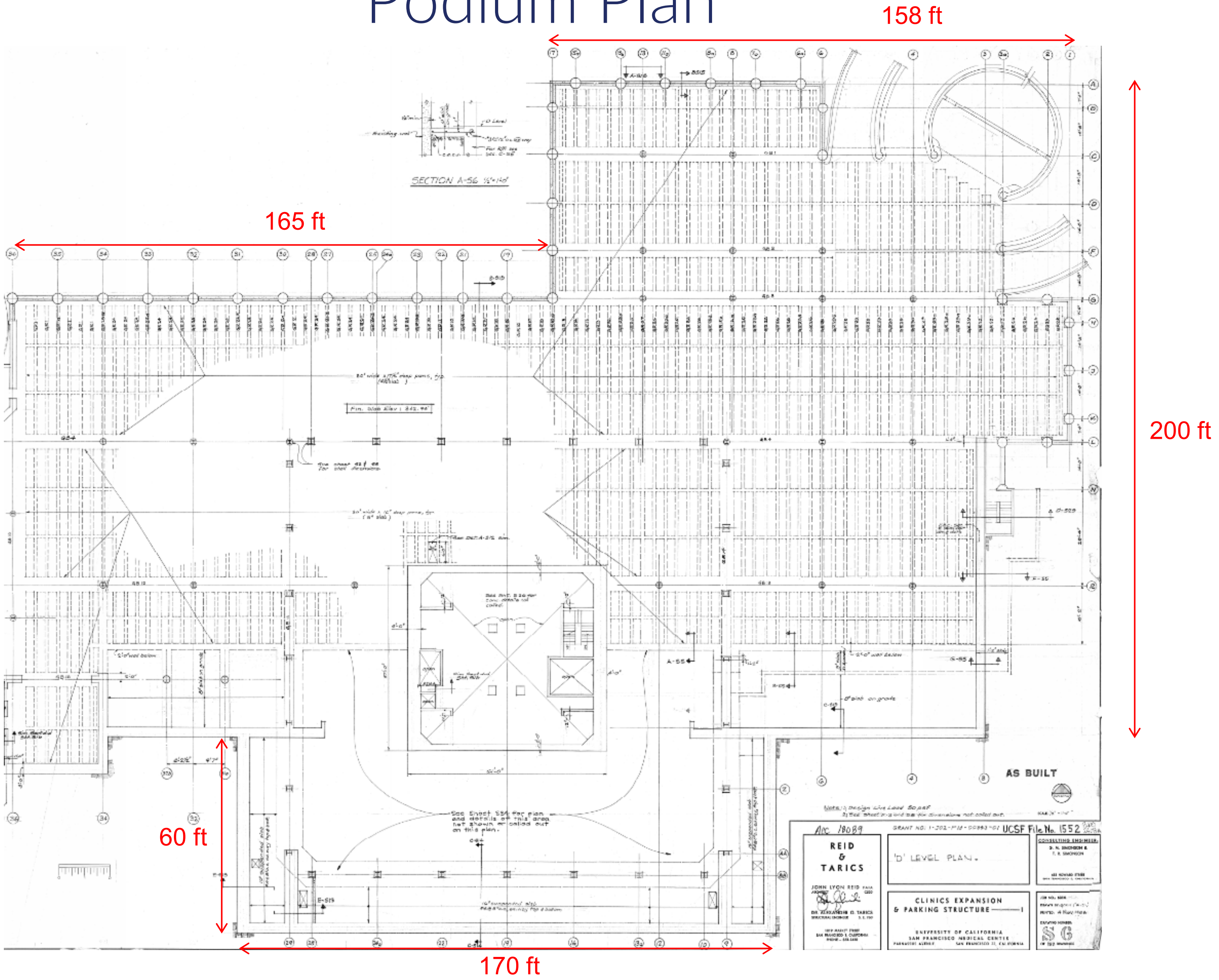


Full Building Section – Looking East





Podium Plan



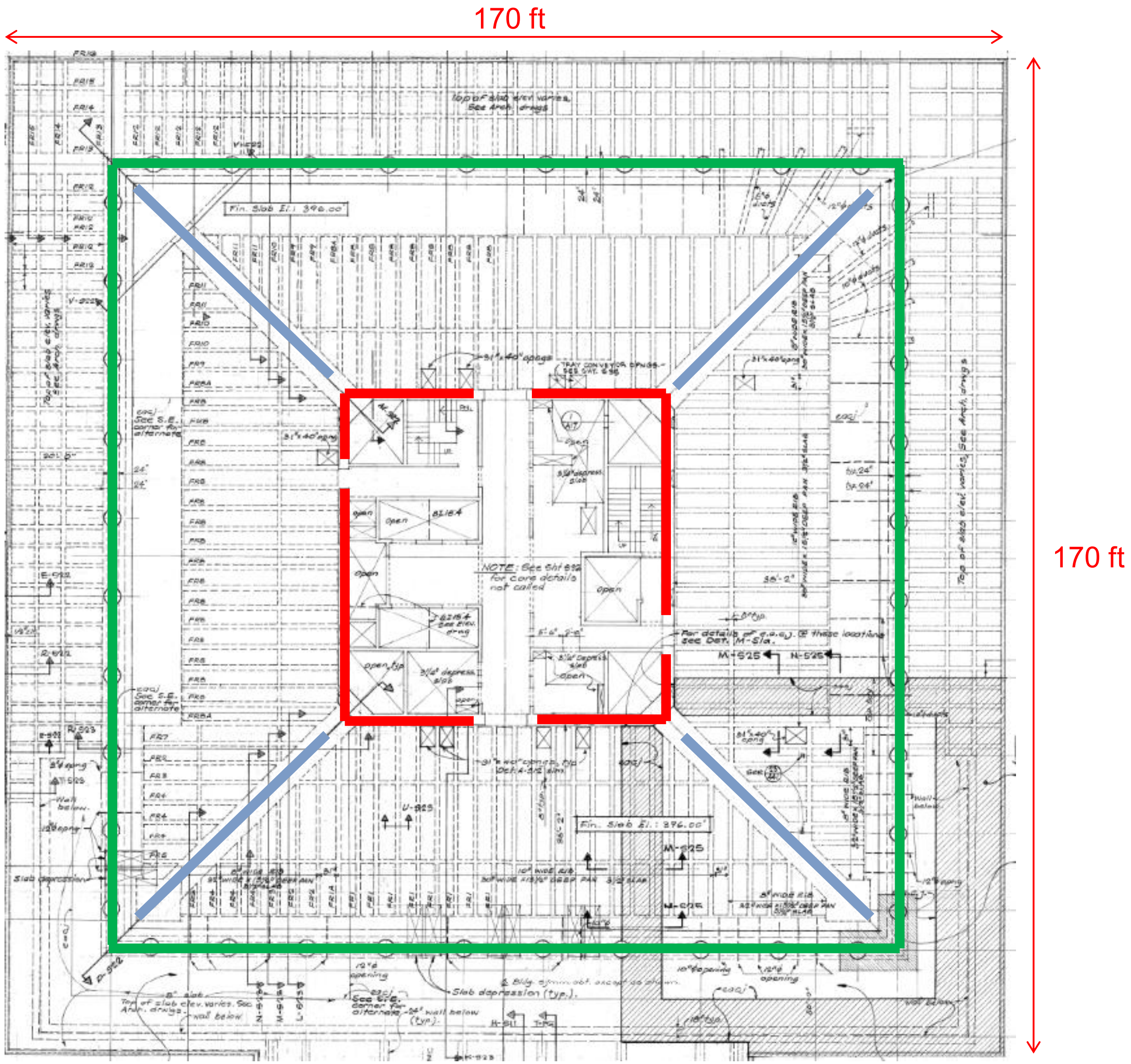
158 ft
165 ft
200 ft
60 ft
170 ft
SECTION A-56
AS BUILT
REID & TARICS
'D' LEVEL PLAN.
CLINICS EXPANSION & PARKING STRUCTURE
UNIVERSITY OF CALIFORNIA SAN FRANCISCO MEDICAL CENTER
UCSF File No. 1552

Typical Tower Plan

Tower Frame Lines

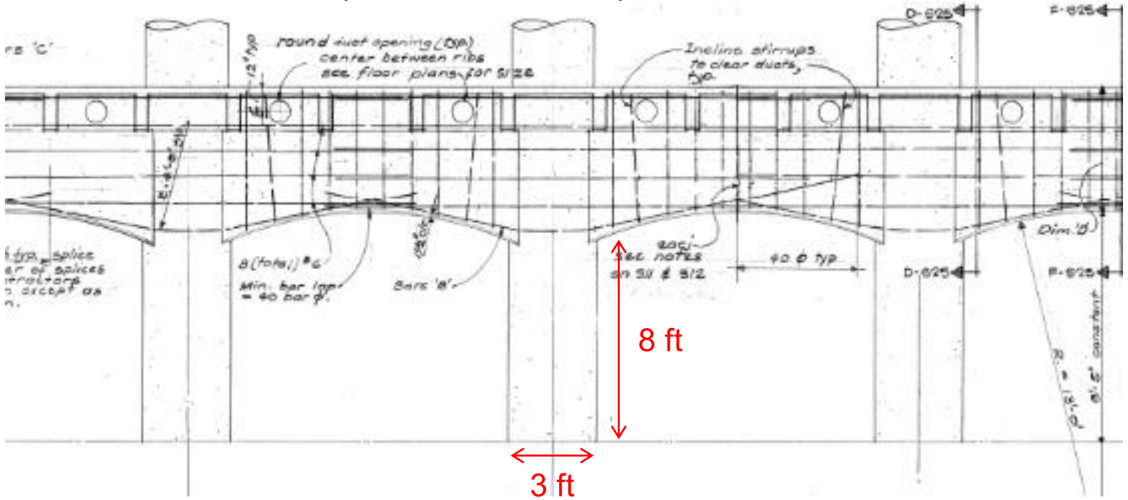
Post-Tensioned Beams

Core Walls

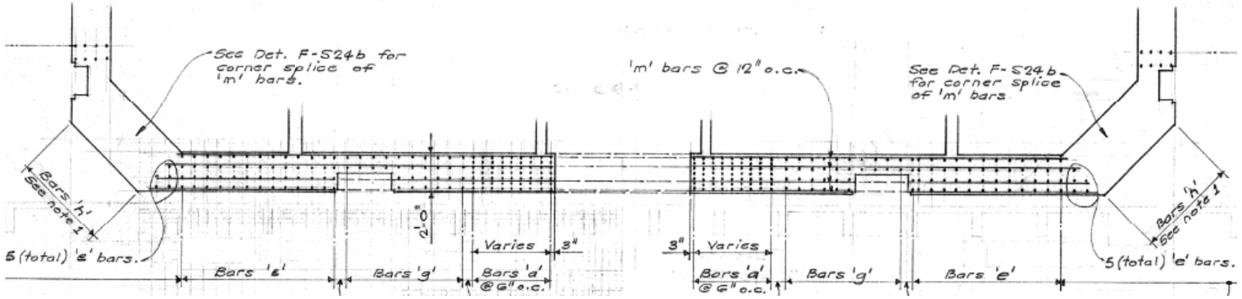


Important Structural Details

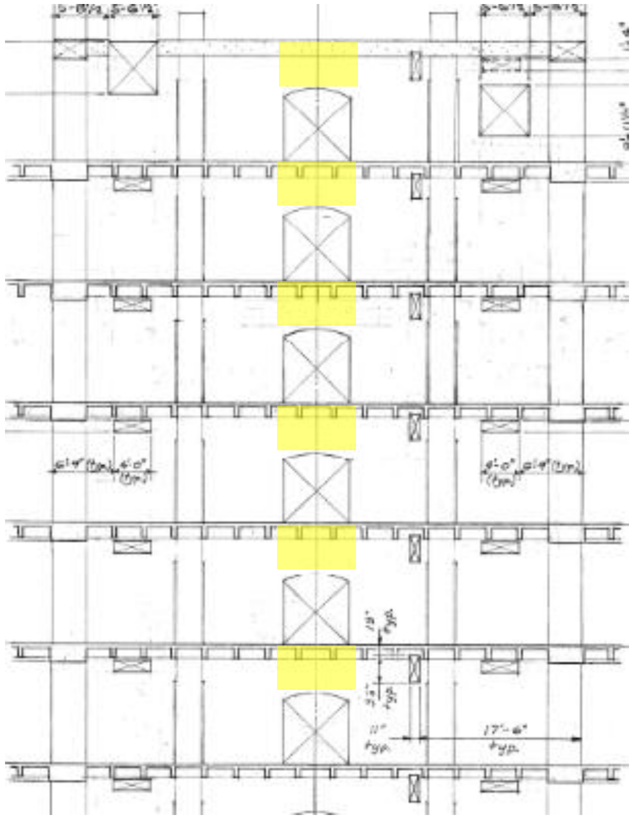
Columns short, stiff (shear-controlled)



Core wall heavily reinforced, but incredibly thick (2 ft)

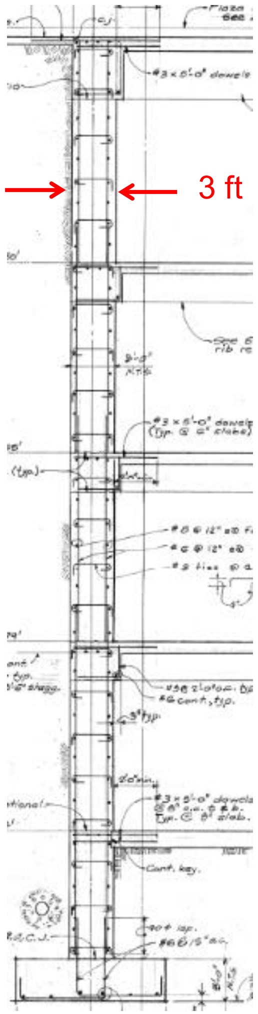


Tower core wall with large openings

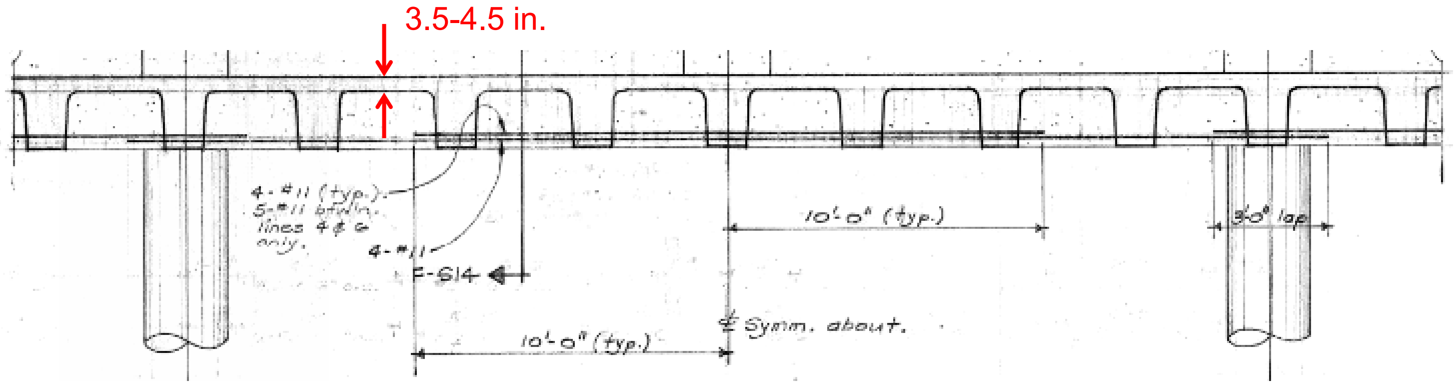


Important Structural Details

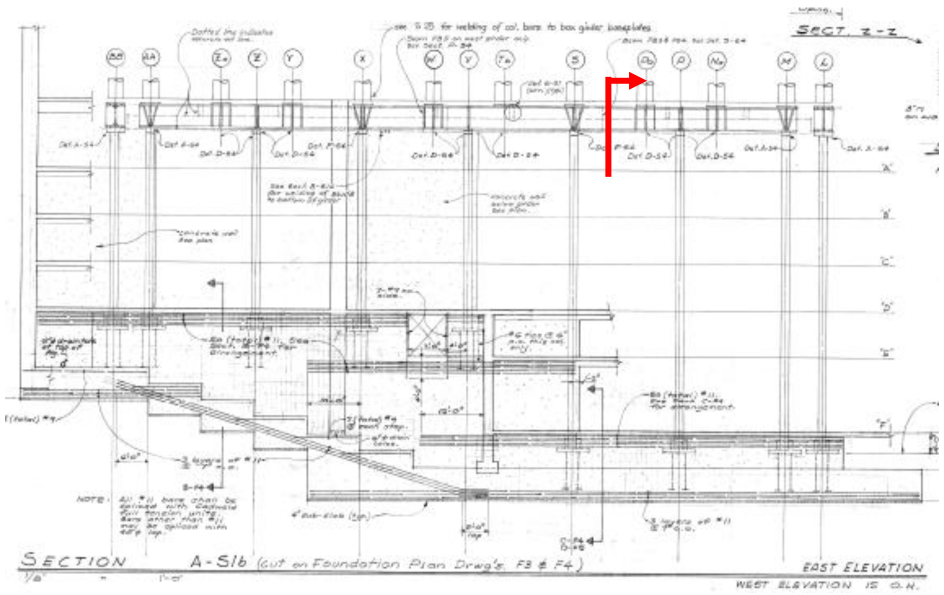
Thick perimeter walls in garage levels

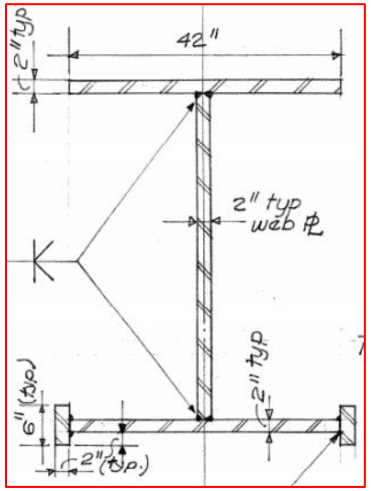


Thin diaphragm slab part of cast joist floor framing/system



Support at bottom of tower columns close to capacity.





Outline

- Building Overview
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Project Description

- Evaluate Building per UC Policy
  - Establish Seismic Performance Rating (I-VII)
  - If greater than IV, how to get to IV?

- Complete ASCE 41-17 Tier 1 evaluation (2018)
  - SPR V
- Explore advanced analysis influence (2019)
  - Soil-structure analysis (nonlinear)
  - Partial nonlinear time history analysis
  - Improved material property assumptions
  - SPR V
- Evaluate Seismic Retrofit (2023)
  - Various schemes
  - Include necessary code upgrades
  - Establish ROM costs

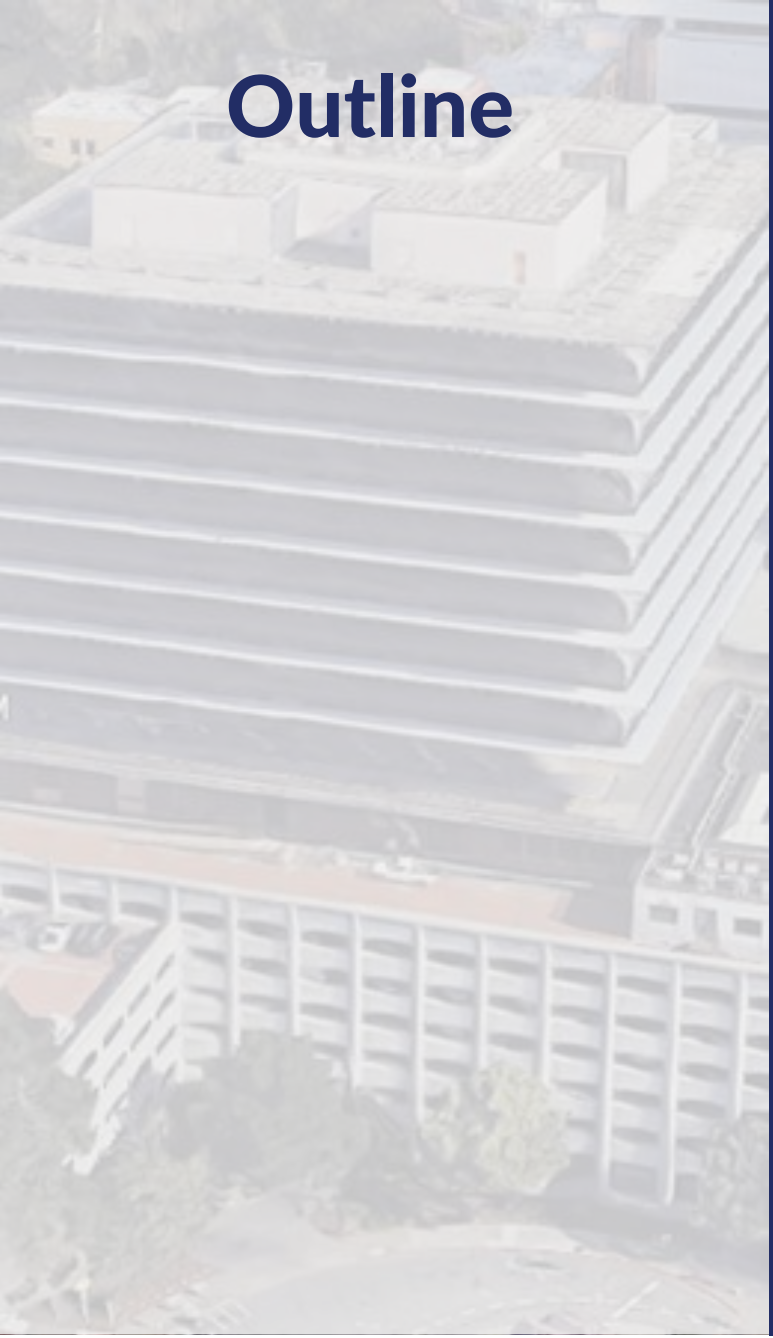
Table 1 - Expected Seismic Performance Ratings [1]

Definition [2], [3]	Expected Seismic Performance Rating [1]
A building evaluated as meeting or exceeding the requirements of CEBC Part 10 Chapter 3 for Risk Category IV performance criteria with BSE-1N and BSE-2N hazard levels replacing BSE-R and BSE-C as given in Chapter 3.	I
A building evaluated as meeting or exceeding the requirements of CEBC Part 10 Chapter 3 for Risk Category IV performance criteria.	II
A building evaluated as meeting or exceeding the requirements of CEBC Part 10 Chapter 3 for Risk Category I-III performance criteria with BSE- 1N and BSE-2N hazard levels replacing BSE-R and BSE-C respectively as given in Chapter 3; alternatively, a building meeting CBC requirements for a new building.	III
A building evaluated as meeting or exceeding the requirements of CEBC Part 10 Chapter 3 for Risk Category I-III performance criteria.	IV
A building evaluated as meeting or exceeding the requirements of CEBC Part 10 Chapter 3 for Risk Category I-III performance criteria only if the BSE-R and BSE-C values are reduced to 2/3 of those specified for the site.	V
A building evaluated as not meeting the minimum requirements for Rating V designation and not requiring a Rating VII designation.	VI
A building evaluated as posing an immediate life-safety hazard to its occupants under gravity loads. The building should be evacuated and posted as dangerous until remedial actions are taken to assure the building can support CBC prescribed dead and live loads.	VII

Project Description

- Assessment for ACC Building in 2023:
  - ASCE 41-17 Tier 3 retains SPR V
  - Seismic Retrofit is Untenable

- Perform ASCE 41-23 “Tier 3” Analysis (Part II):
  - Use pertinent results from previous analyses (soil/structure)
  - Use concrete wall fragilities from testing/literature
  - FEMP P695 direct collapse analysis (975-year ground motion)
  - Nonlinear static pushover
  - Nonlinear response history analysis
  - Detailed peer review



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ASCE 41-17 Tier 1 Deficiencies

- Core walls
  - Shear capacity in bottom six stories of tower and podium
  - Large openings (forming coupling beams) hurt performance
- Perimeter walls in garage
  - Possibly affected by torsional irregularity
- Columns
  - Brittle (shear-controlled)
  - Short and stiff, may attract high shear demand and fail
  - Half discontinuous at Plaza Level
  - Steel transfer girder
- Diaphragm
  - Relatively thin, load transfer between vertical elements

Component	Evaluation
	Tier 1
Tower Core Walls	DCR = 2 near base
Podium Core Walls	DCR = 0.7 - 1.3
Coupling Beams	Potential issue
Podium Perimeter Walls	DCR = 0.7 - 1.3
Tower Frame	Expected to fail
North Frame	Expected to fail
Transfer Girder	Potential issue
Diaphragms	May not transfer load
Embedment Soil	Further evaluation required

UC Seismic Performance Rating – Analysis Context

UC Seismic Performance Level	Performance Criteria[1]	
	Life Safety (LS)	Collapse Prevention (CP)
IV	BSE-R	BSE-C
V	2/3 * BSE-R	2/3 * BSE-C

[1] Per UC Seismic Safety Policy and California Building Code

Table C2-1. Probability of Exceedance and Mean Return Period

Probability of Exceedance		Mean Return Period (years)
50%/30 years		43
50%/50 years		72
20%/50 years	BSE-1E, BSE-R	225
10%/50 years	BSE-1N	475
5%/50 years	BSE-2E, BSE-C	975
2%/50 years	BSE-2N	2,475

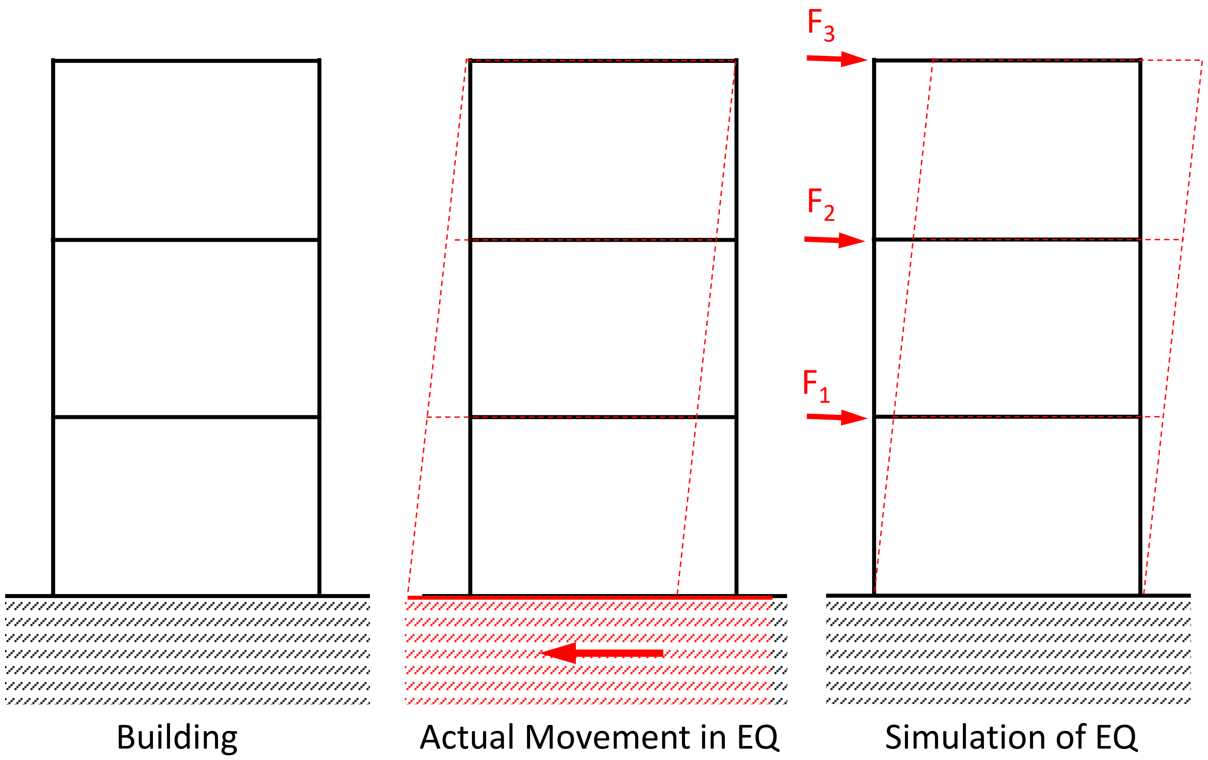
Term	Definition[1]
Life Safety (LS)	Structure has damaged components but retains a margin of safety against collapse
Collapse Prevention (CP)	Structure has damaged components and continues to support gravity loads but retains no margin against collapse
BSE-R	20% chance of occurrence in 50 years, 250-yr return period
BSE-C	5% chance of occurrence in 50 years, 1,000-yr return period

[1] Per California Building Code

Why ASCE 41 Tier 3?

Source	Base Shear (k)	Notes
UBC 1967	6,400	Used for original design
BSE-1N	21,000	ASCE 7-16, includes R=5
BSE-R	43,000	CBC, ASCE 41-17, includes m=2
BSE-C	53,000	CBC, ASCE 41-17, includes m=3

- BSE-R demand over 6 times greater than original design.
- BSE-C demand over 8 times greater than original design.



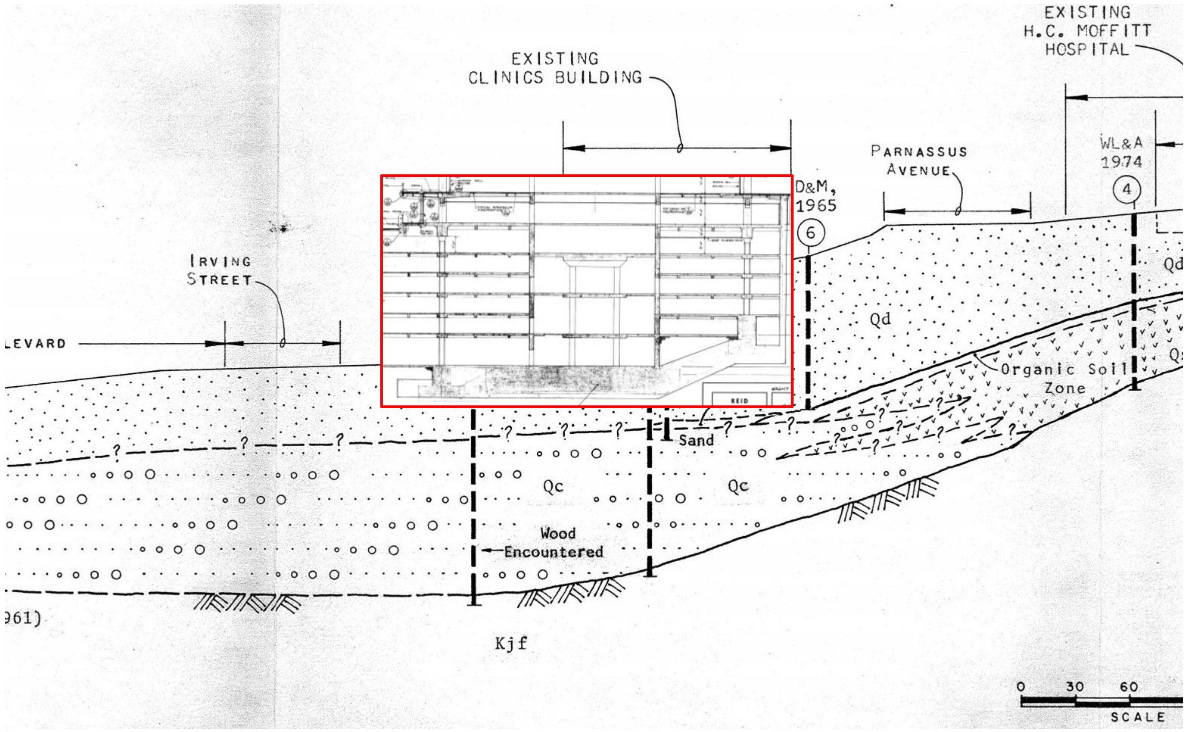
Base Shear = $F_1 + F_2 + F_3$

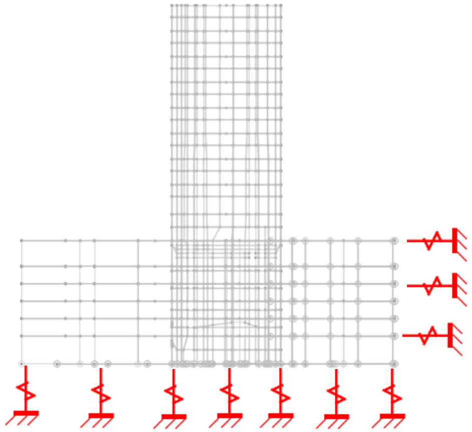
$F = C_s * W$

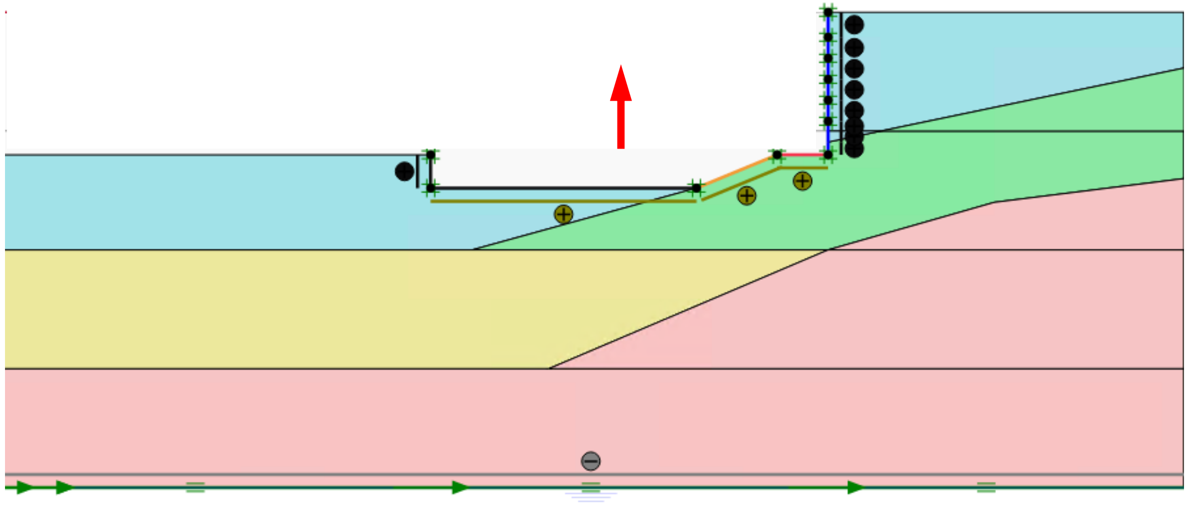
W = 150,000 kips

Soil-Structure Interaction Analysis

Modeling Approach

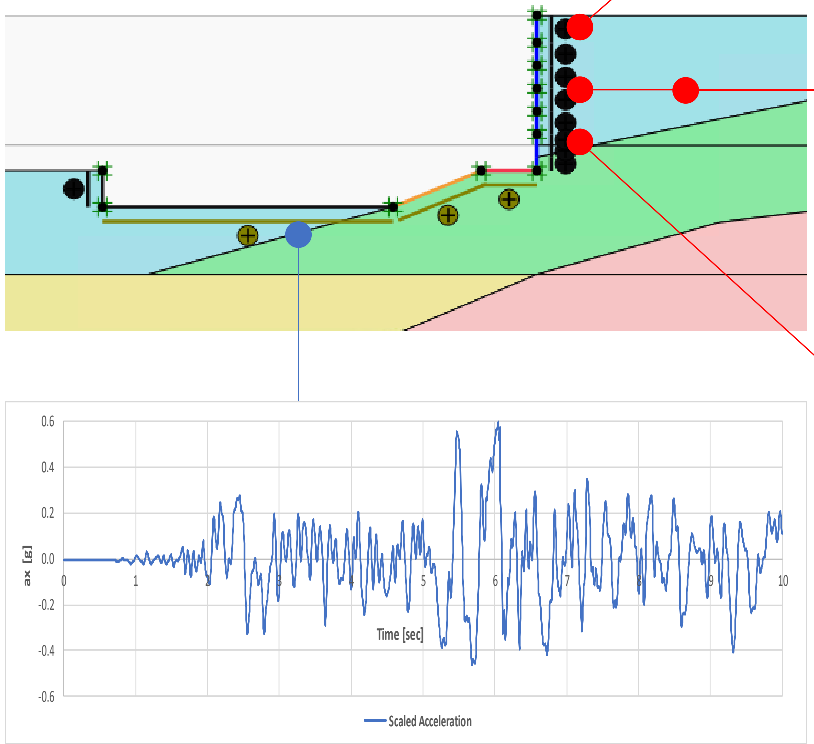


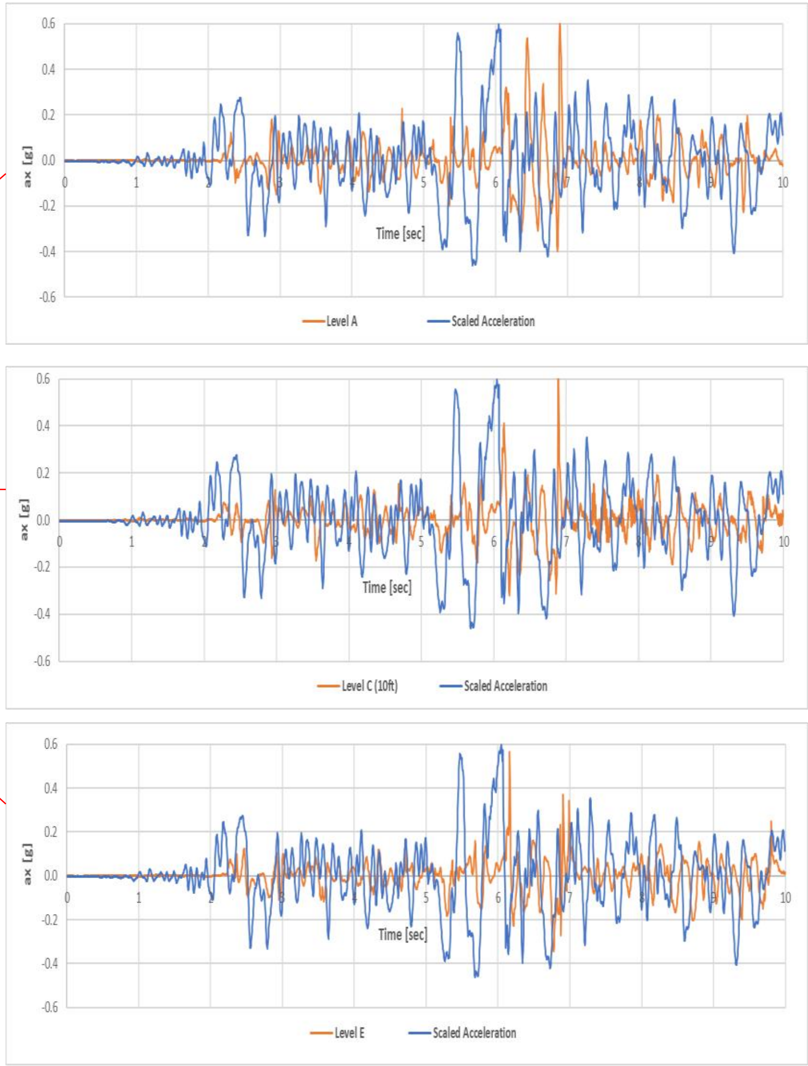




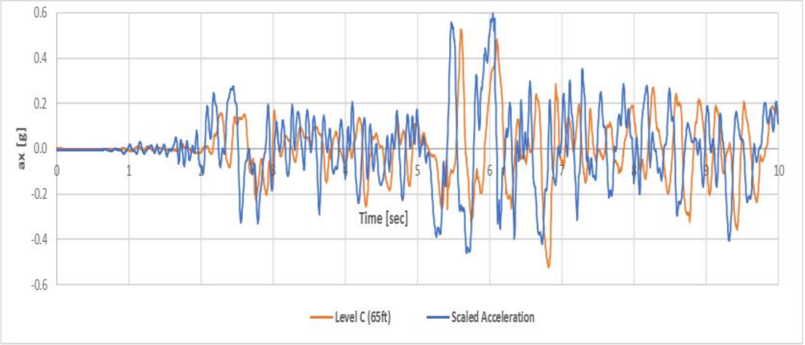
Soil-Structure Interaction Analysis

Variation in Ground Motion



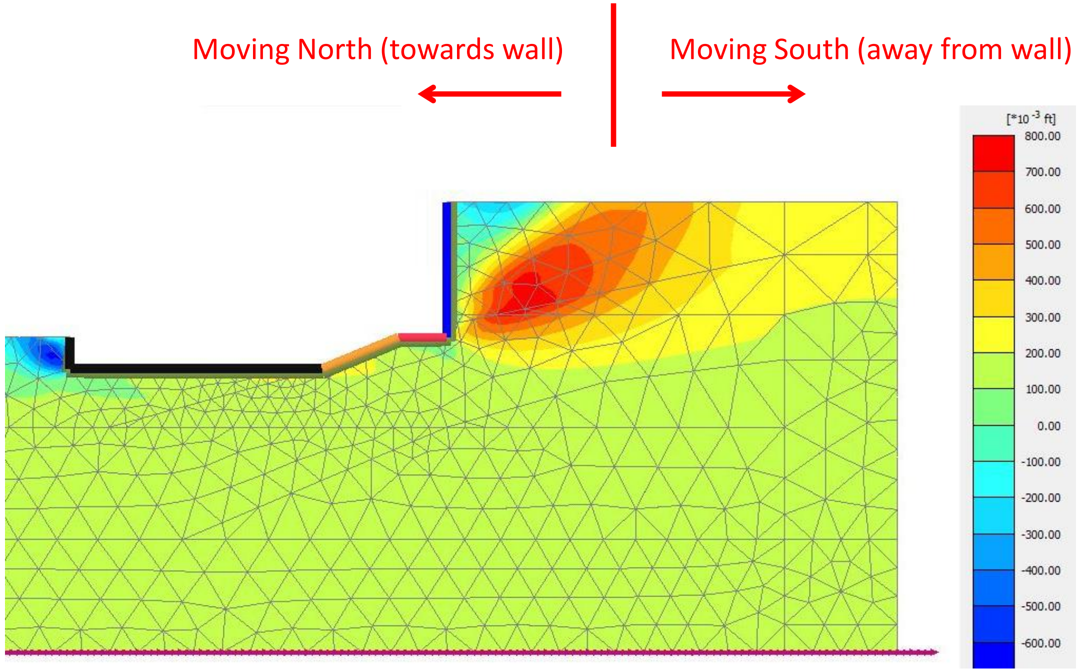


- Decreases close to wall
  - May reduce demand on building
- Increases up height
- Phase shift away from wall



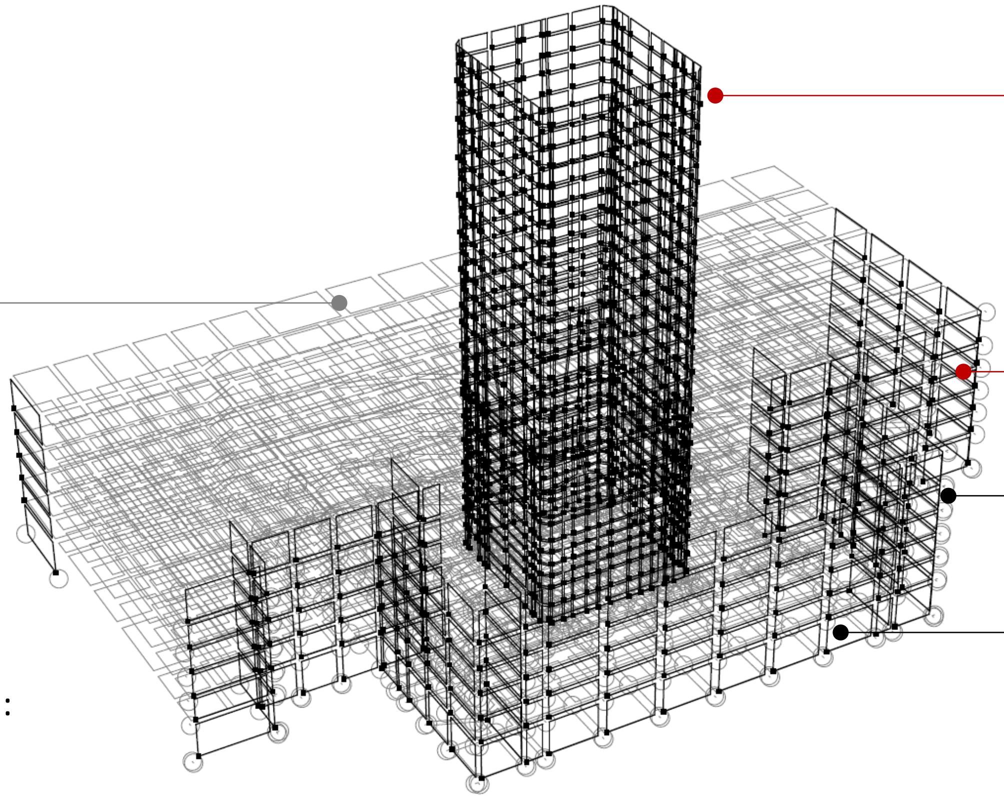
Soil-Structure Interaction Effects

- Ground motion reduced near wall
  - Apply varying ground motions from SSI model to nonlinear structural model to capture benefit of reduced demand.
- Soil behind wall expected to form failure plane during seismic event.
  - Potential to fill into gap formed as wall moves North (away from soil).
  - May cause ratcheting displacements.
  - Need to evaluate time history response of wall to assess ratcheting.



Nonlinear Response History Analysis

Perform3D Nonlinear Model

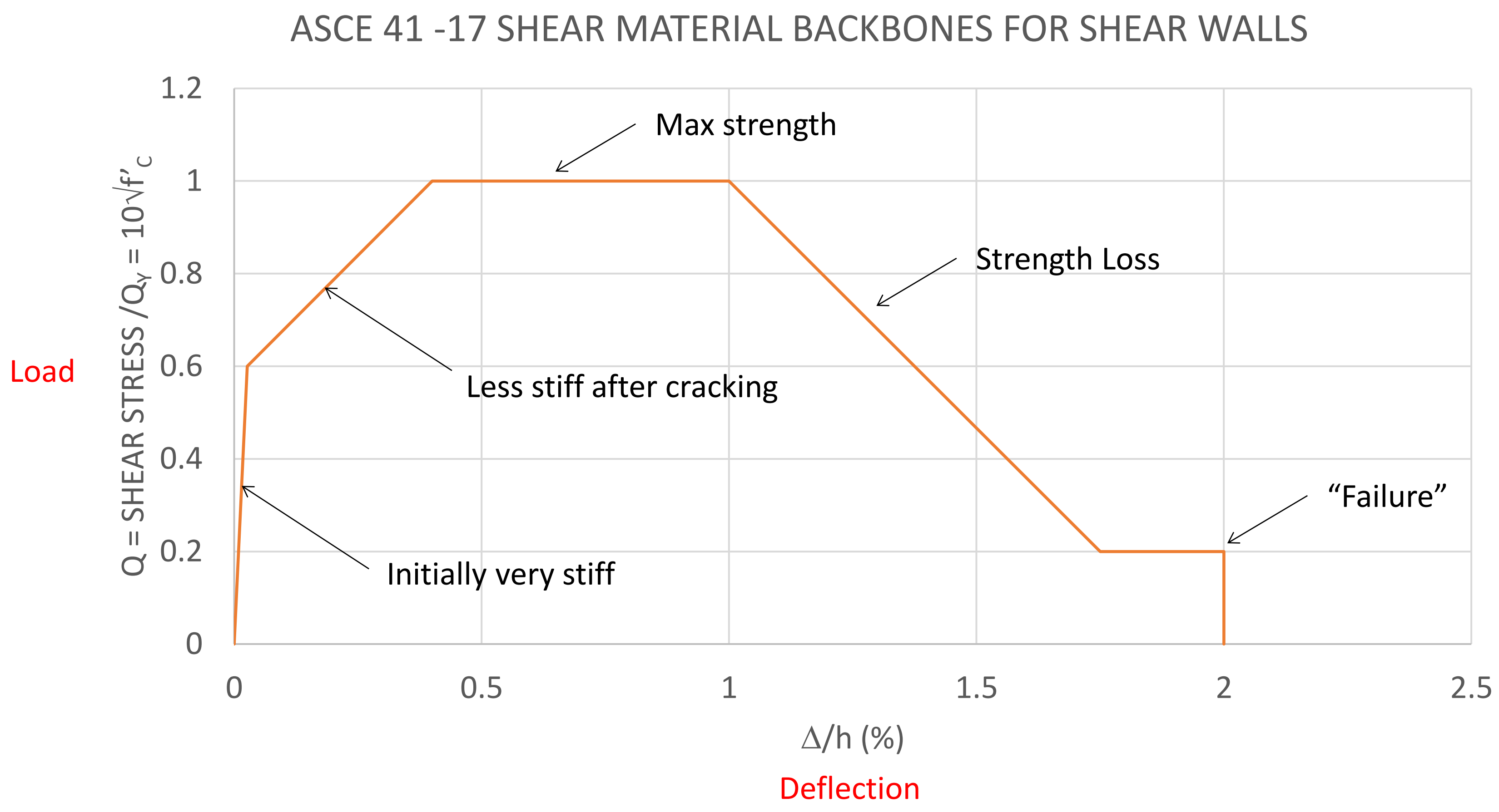


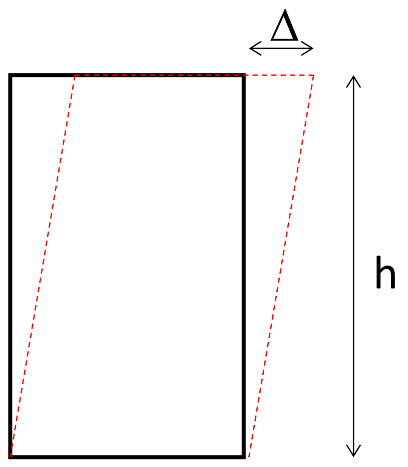
Structural elements excluded from model:

- Tower perimeter frames
- Podium frames on north elevation
- Tower floor slabs
- Gravity framing at garage levels
- Garage ramp

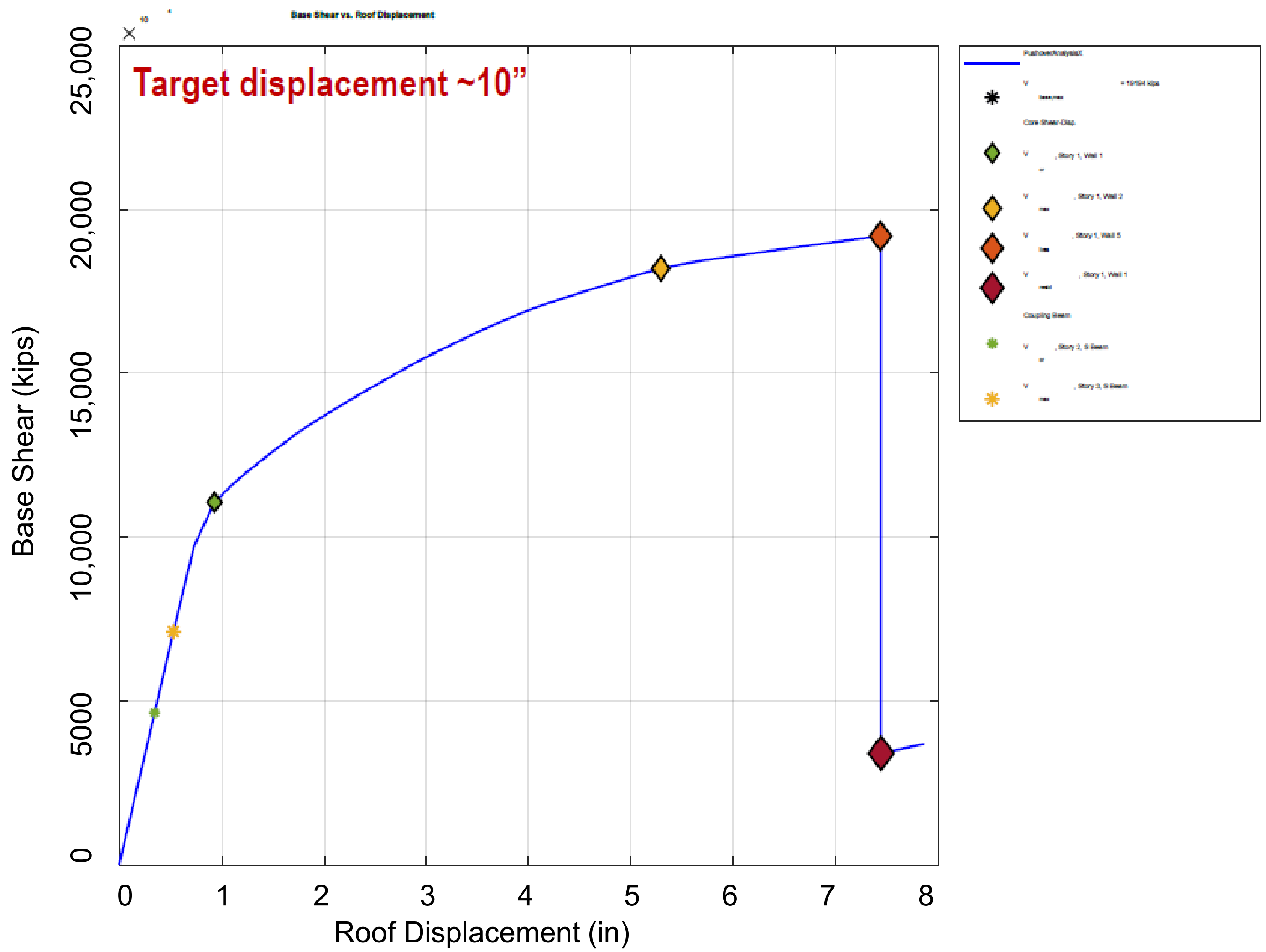
Nonlinear Response History Analysis

ASCE 41-17 Wall Modeling

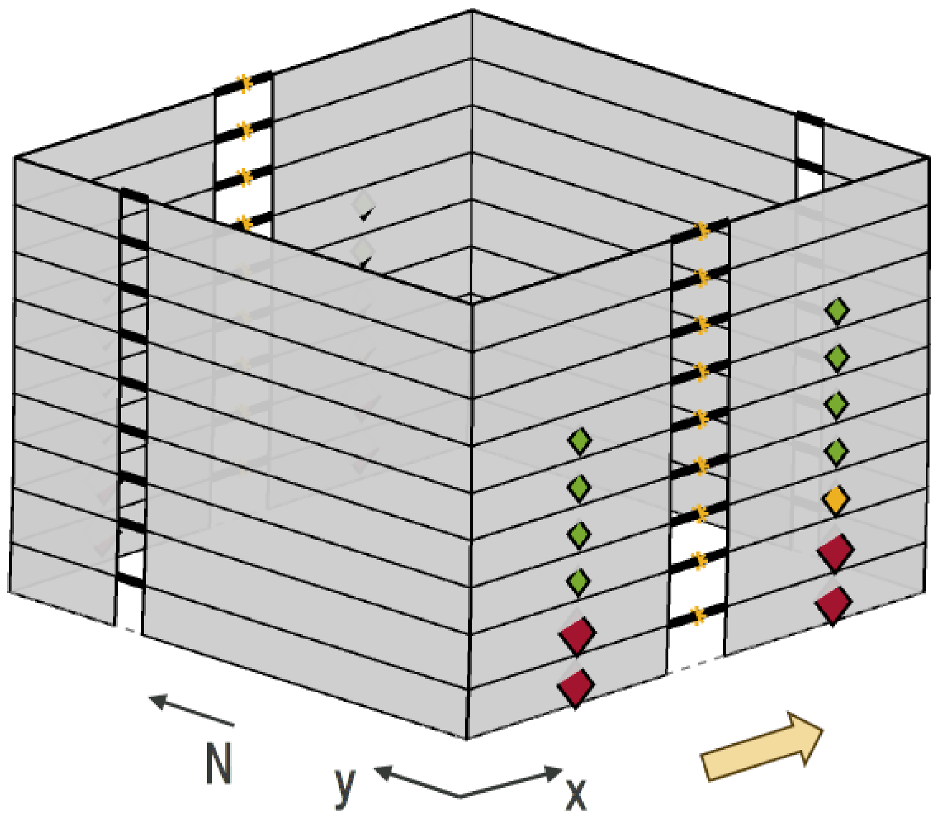


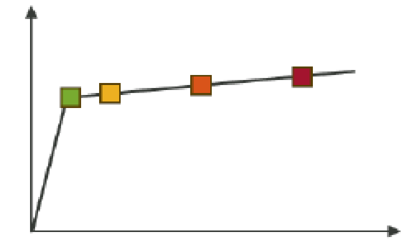


- Model shows "failure" when wall can no longer take shear force.
  - Limit specified by ASCE 41.
- This occurs at relatively low lateral deflection.
- Doesn't mean the wall can't carry vertical load.

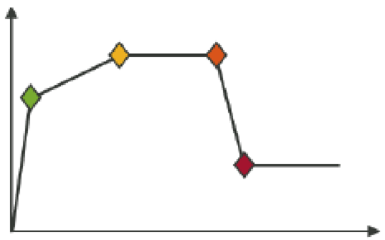


Nonlinear Demands at End of Pushover

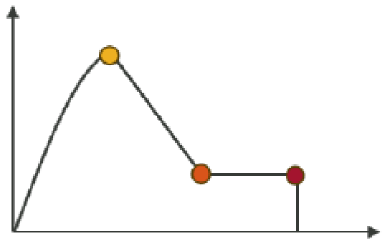




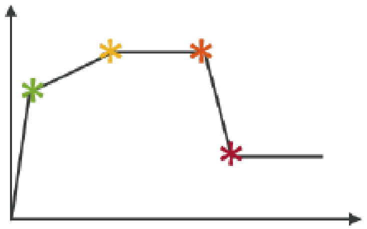
Reinforcement (tension)



Shear Behavior

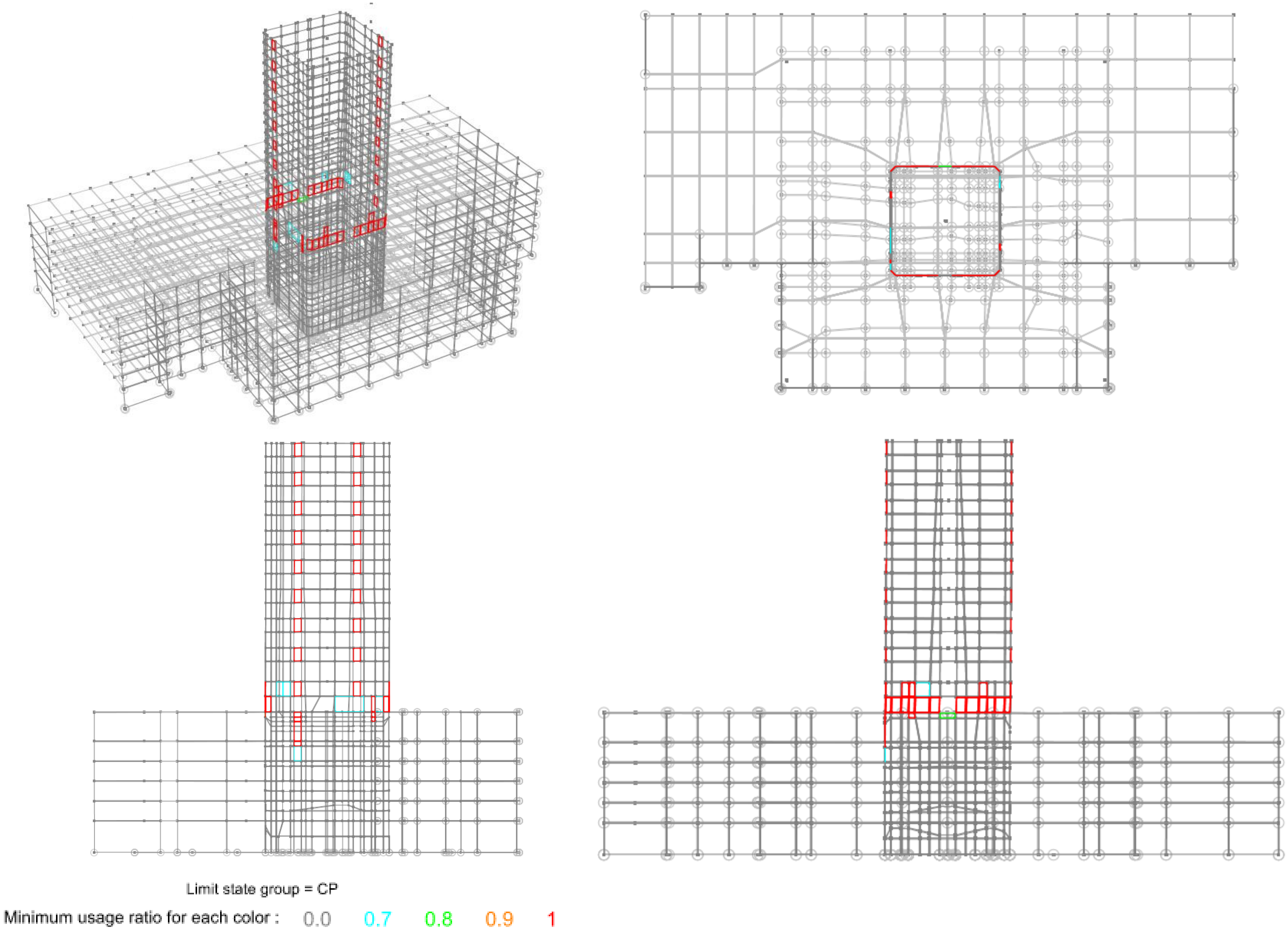


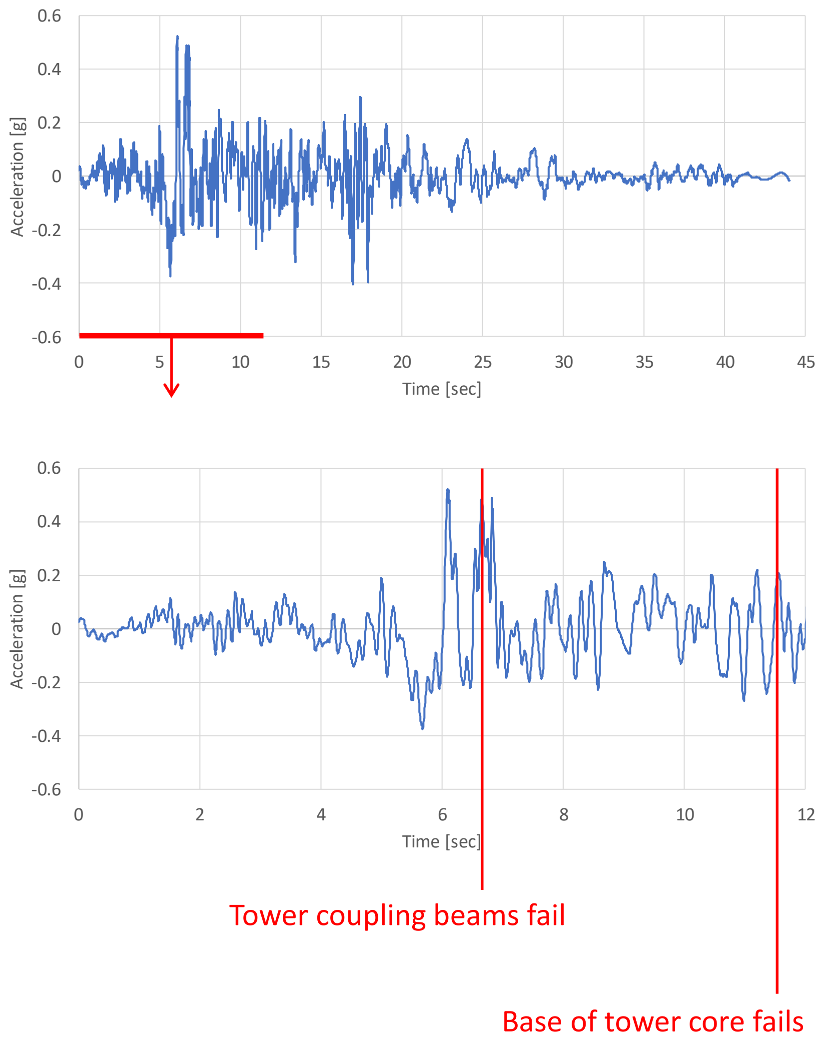
Concrete (compression)



Coupling Beam (shear)

Nonlinear Response History Analysis





Nonlinear Response History Analysis

ASCE 41-17 Partial NLRHA Results

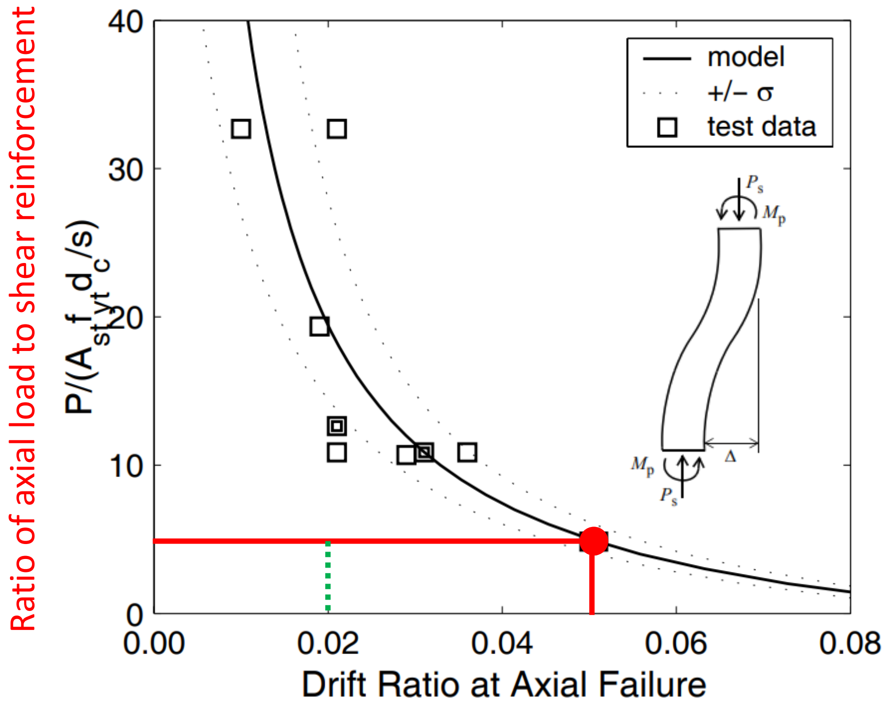
Component	Evaluation	
	Tier 1	**Tier 3**
Tower Core Walls	DCR = 2 near base	Fail in C (OK in R)*
Podium Core Walls	DCR = 0.7 - 1.3	OK in R and C
Coupling Beams	Potential issue	Fail in R and C*
Podium Perimeter Walls	DCR = 0.7 - 1.3	OK in R and C
Tower Frame	Expected to fail	Fail in R and C*
North Frame	Expected to fail	OK in R and C
Transfer Girder	Potential issue	OK for current tower, not for any retrofit
Diaphragms	May not transfer load	Damage doesn't significantly affect LFRS
Embedment Soil	Further evaluation required	Expected to fail, may cause ratcheting of podium*

Stability after Shear Failure

Shear failure in KOCIZN, KOCYPT

Typical shear failure of circular column

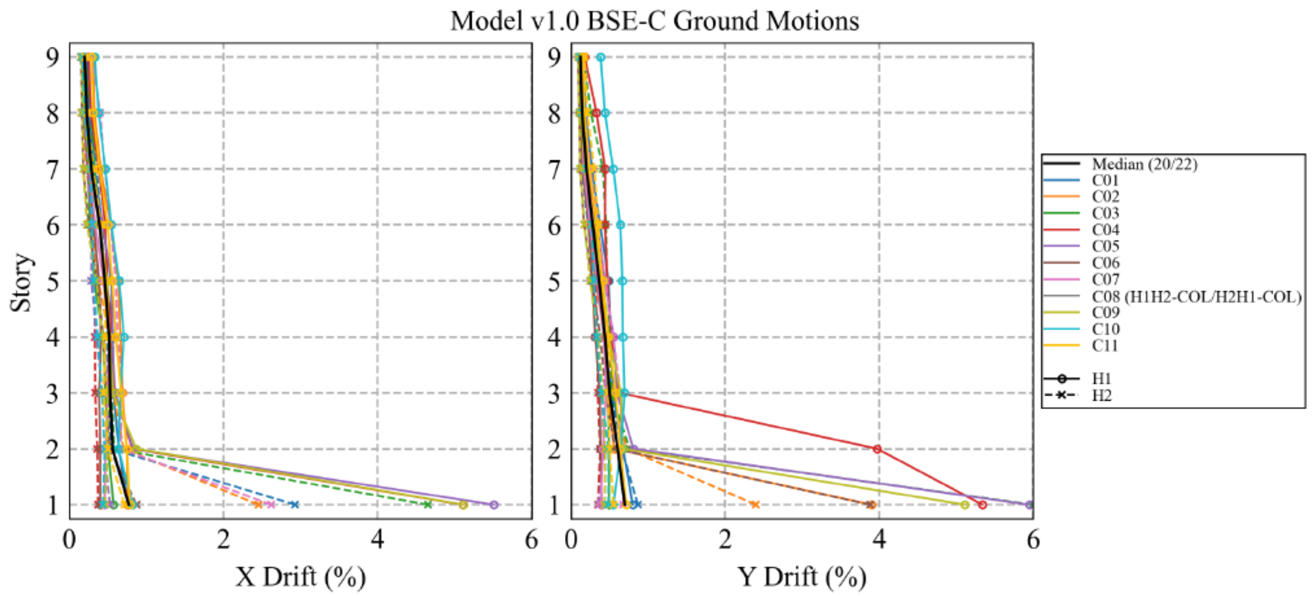
Lab testing to determine lateral deflection at collapse



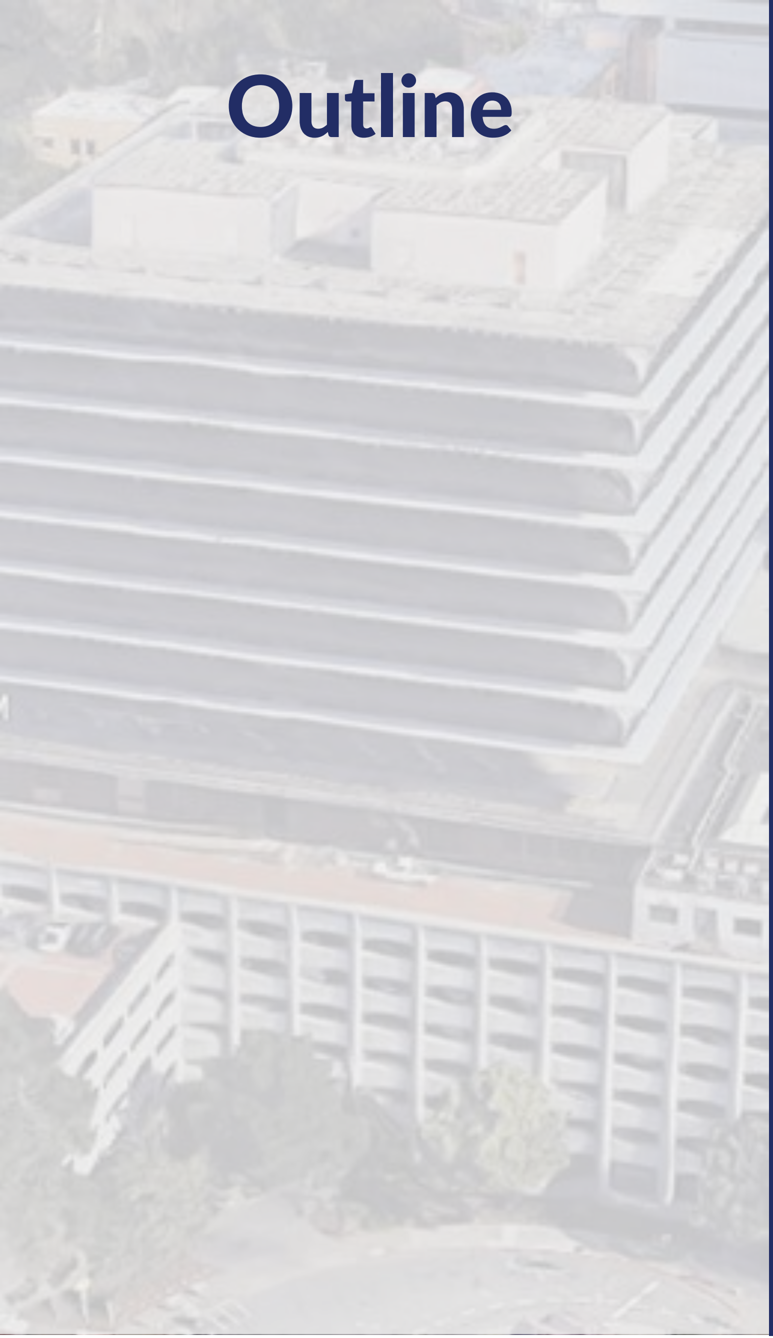
- Complete shear failure in model at 2% drift.
- Collapse at 5% drift.

ASCE 41-17 Partial NLRHA Conclusions

- Significant damage
- Complete collapse not likely
  - Doesn't meet ASCE 41 acceptance criteria
- UC SPR V still appropriate
  - Not satisfying IV
  - We/SRC believe could be better
- UCSF commissioned seismic retrofit schemes for pricing
  - Including architecture, MEP, and fire protection



Outline



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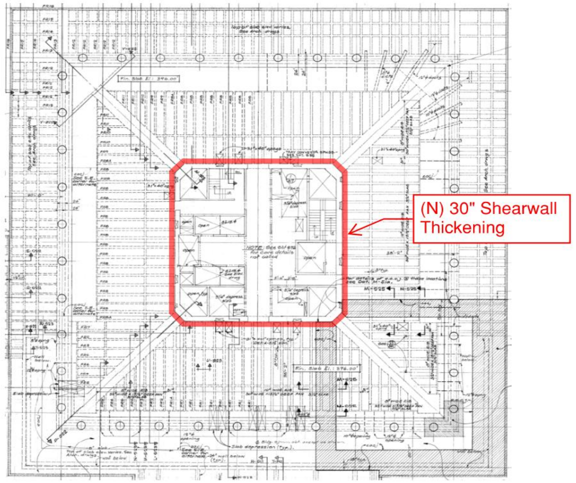
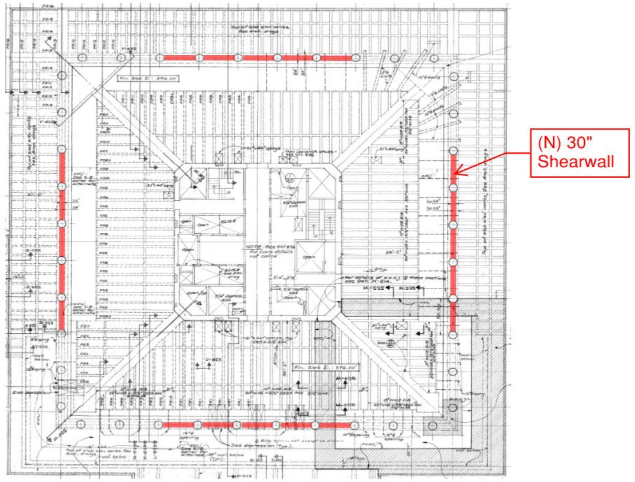
Seismic Retrofit Options

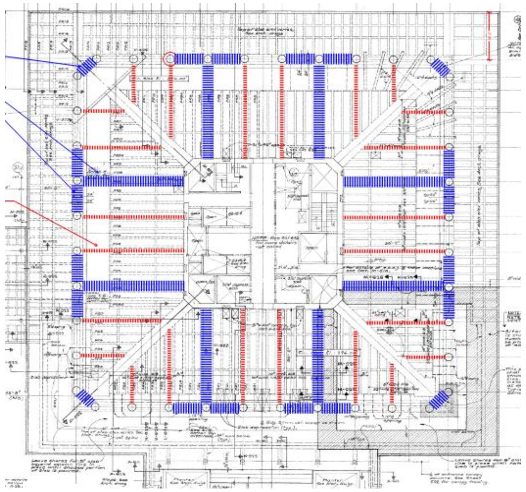
Option 1



Option 2



Option 3

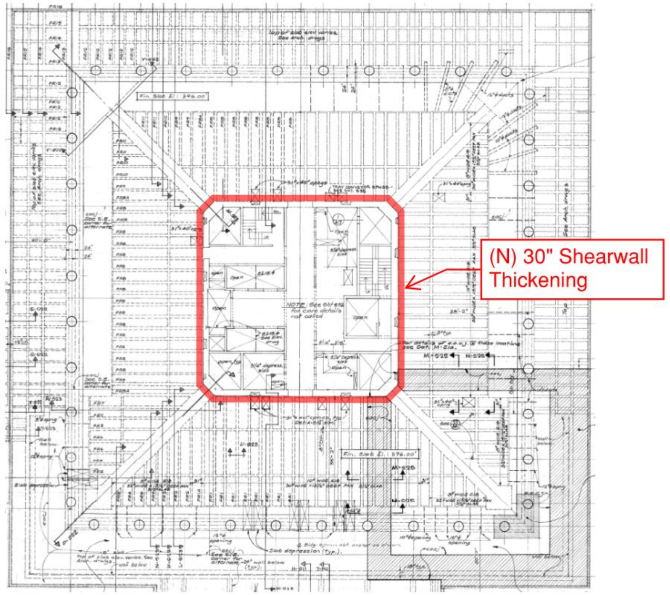


- Option 1
  - Increase core wall thickness
  - FRP perimeter tower columns
- Option 2
  - Add perimeter walls between columns
  - FRP perimeter tower columns not bound by new walls
- Option 3
  - Create isolation plane above Plaza level
  - Story-height outriggers below isolation plane
  - Isolators under core wall and perimeter columns

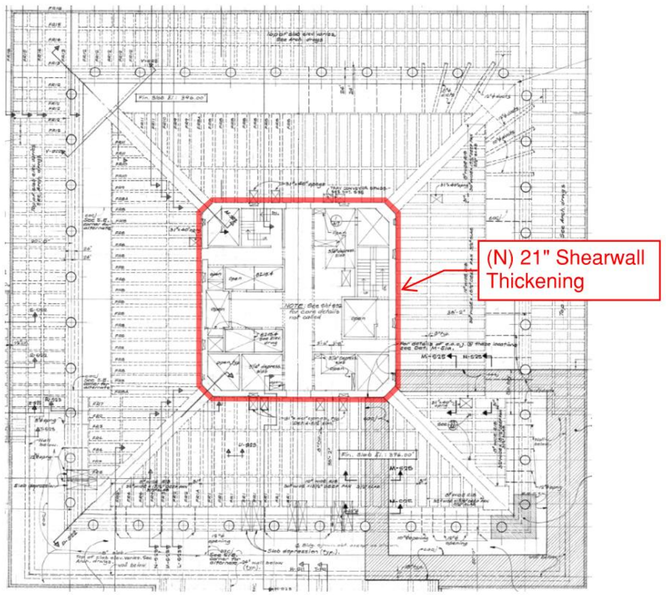
Option 1

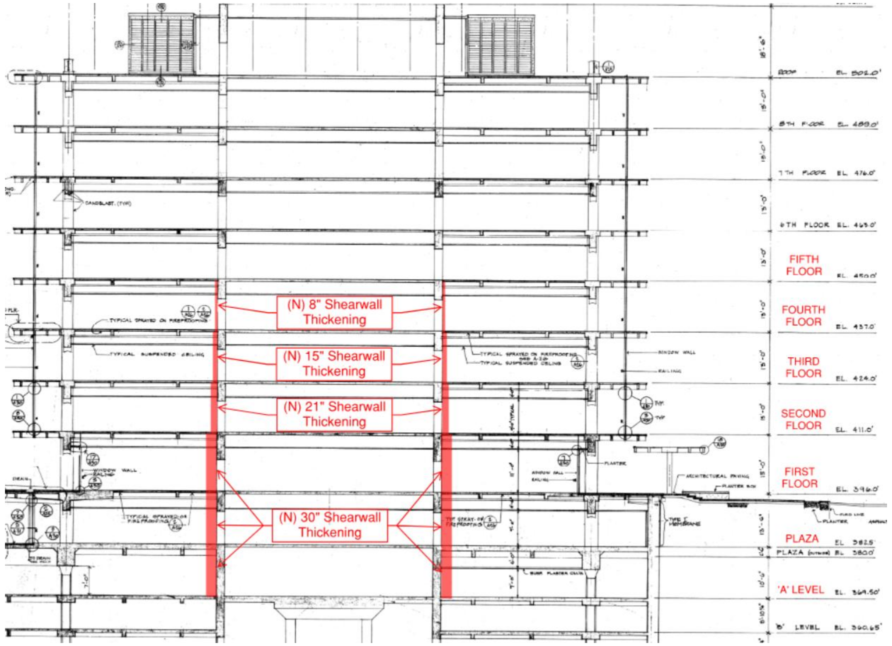
Increase core wall thickness at Plaza and Levels 1-5

Plaza, First, and Second



Third

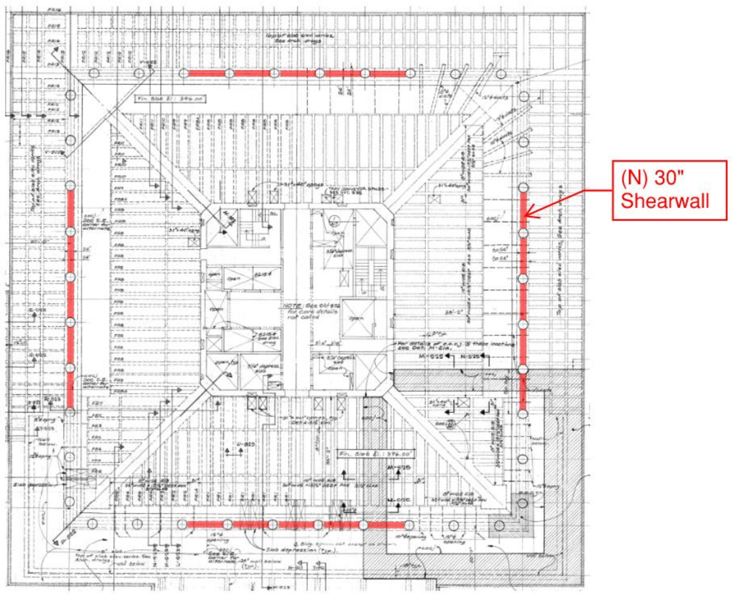




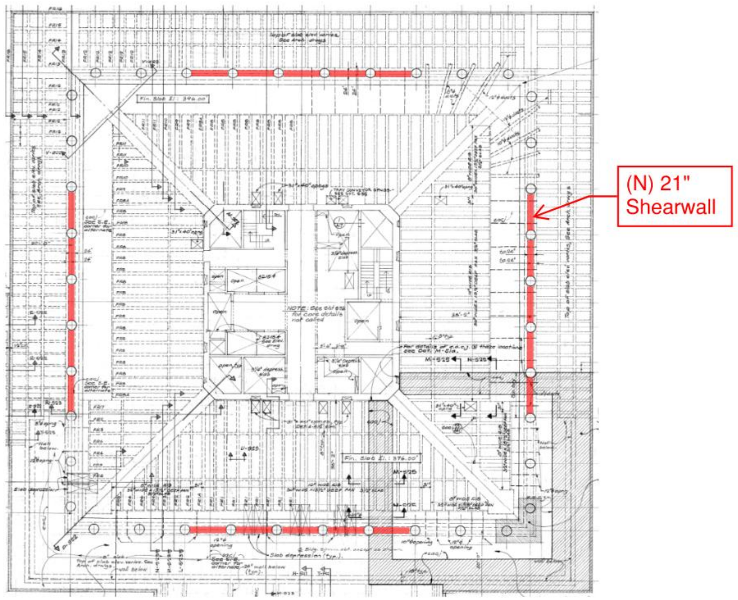
Option 2

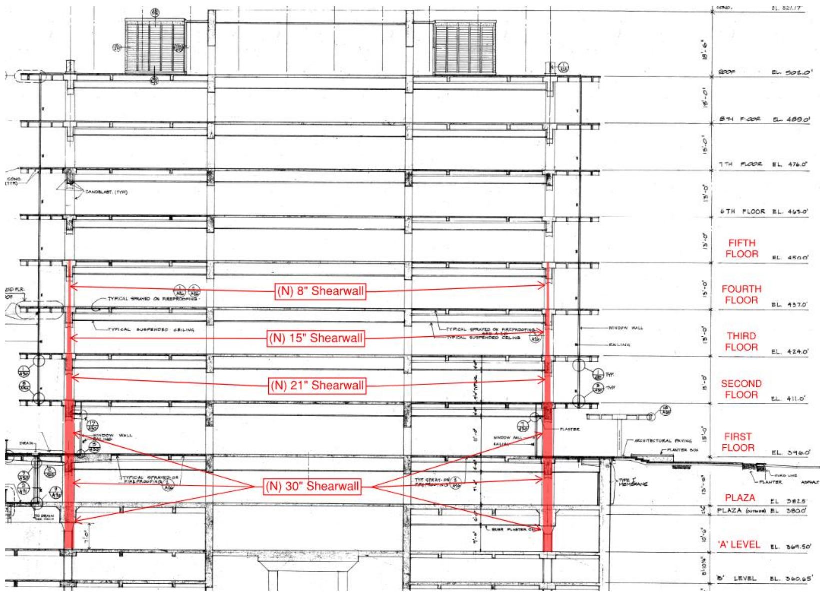
Add walls between perimeter columns at Plaza and Levels 1-5

Plaza, First, and Second

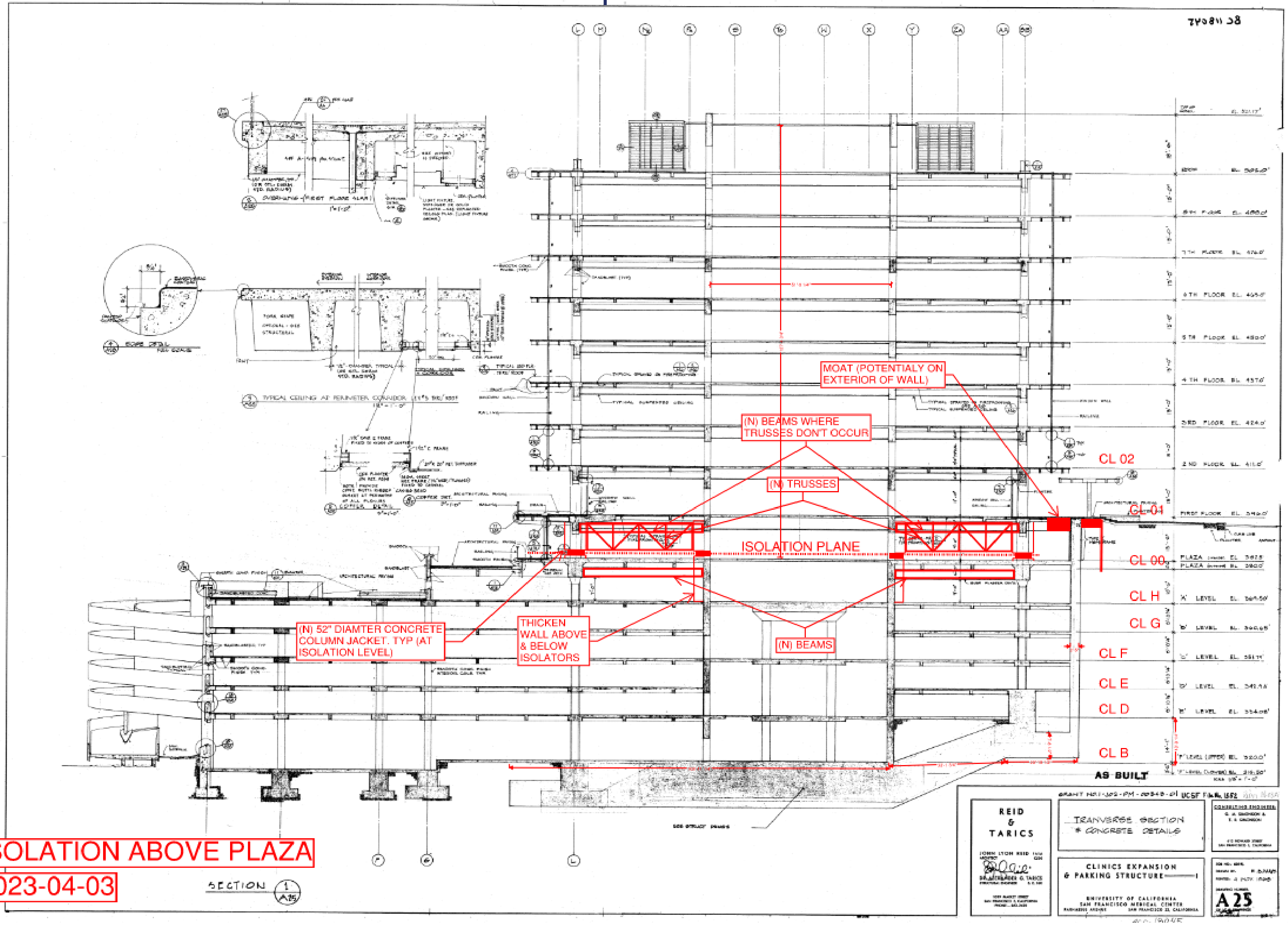


Third



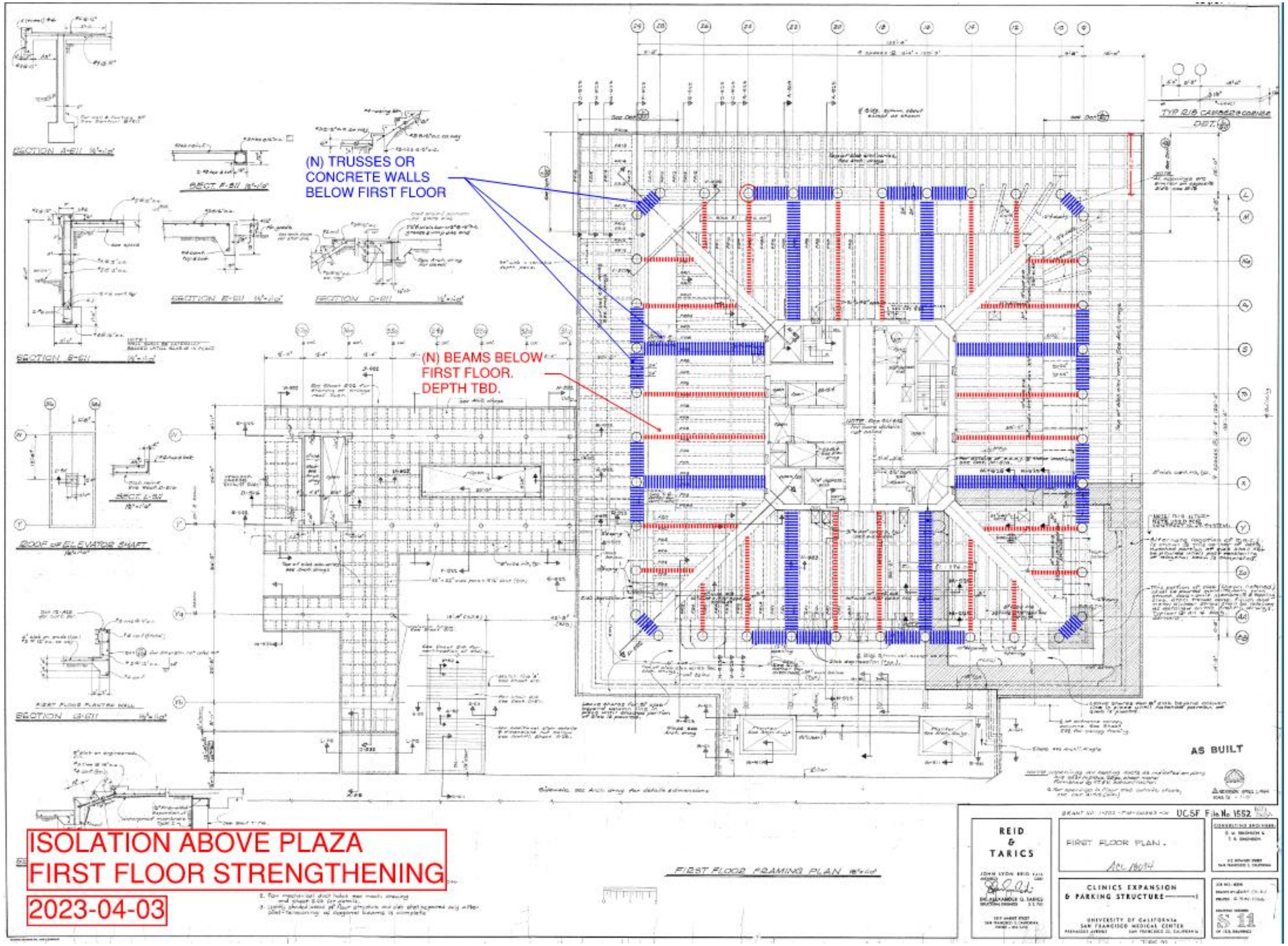


Option 3



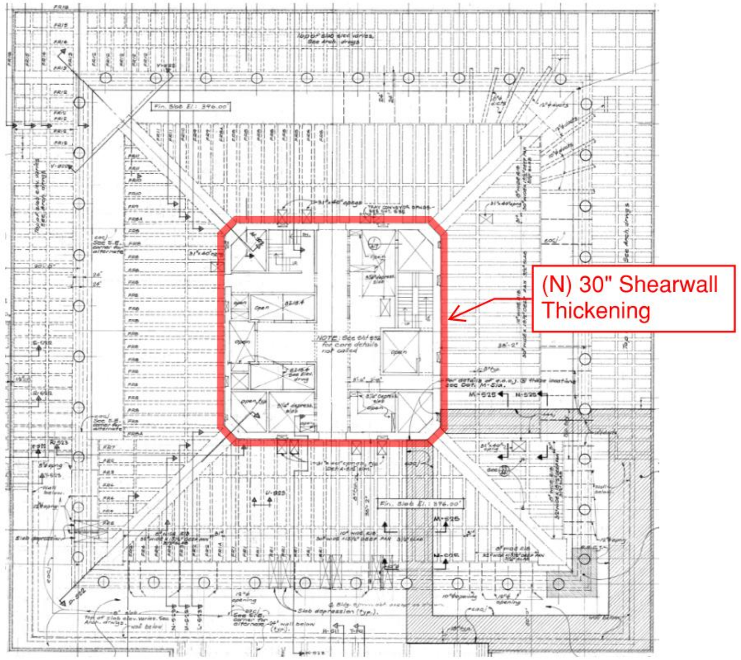
ISOLATION ABOVE PLAZA
2023-04-03

Option 3


(N) TRUSSES OR CONCRETE WALLS BELOW FIRST FLOOR
(N) BEAMS BELOW FIRST FLOOR. DEPTH TBD.
ISOLATION ABOVE PLAZA
FIRST FLOOR STRENGTHENING
2023-04-03
FIRST FLOOR FRAMING PLAN
AS BUILT
REID & TARICS
FIRST FLOOR PLAN
CLINICS EXPANSION & PARKING STRUCTURE
UNIVERSITY OF CALIFORNIA SAN FRANCISCO MEDICAL CENTER
S 11

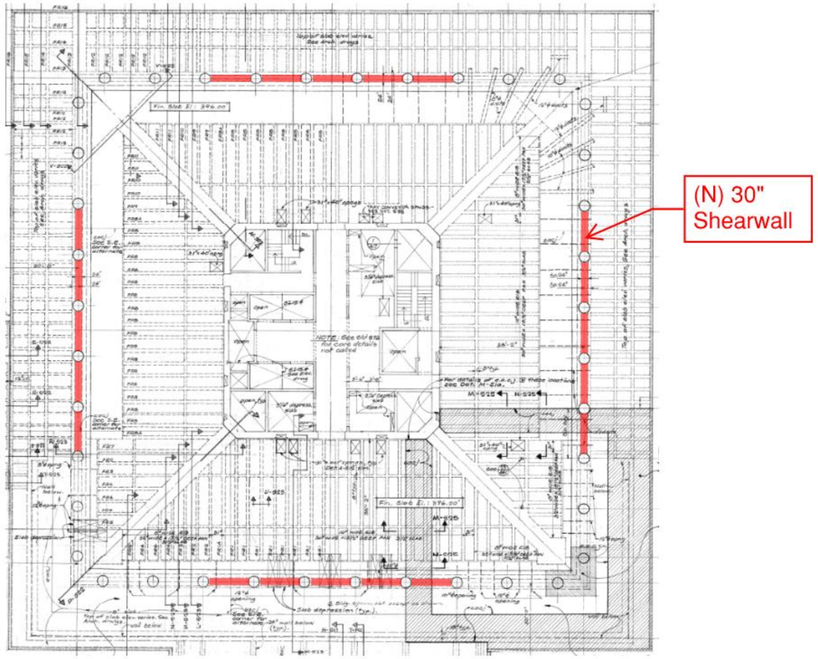
Seismic Retrofit Cost Estimates (Includes A,M,E,P,F/LS)

Option 1



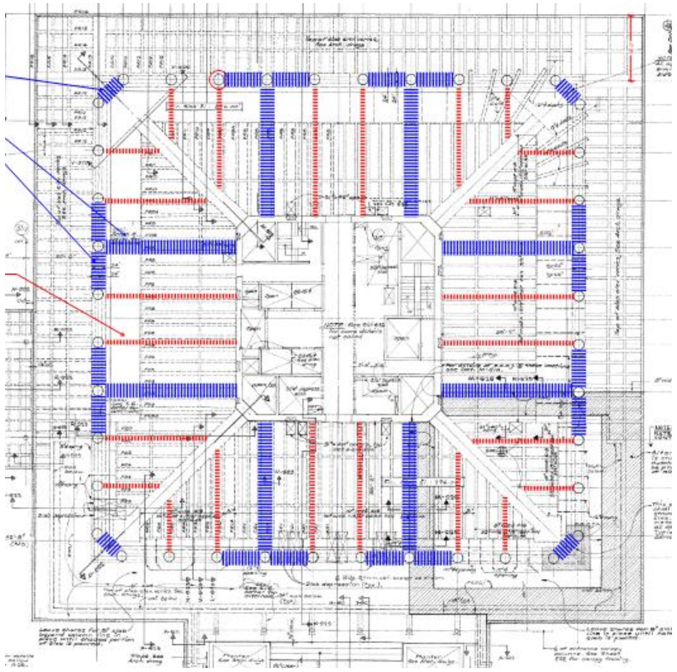
$$$$$

Option 2



$$$$$

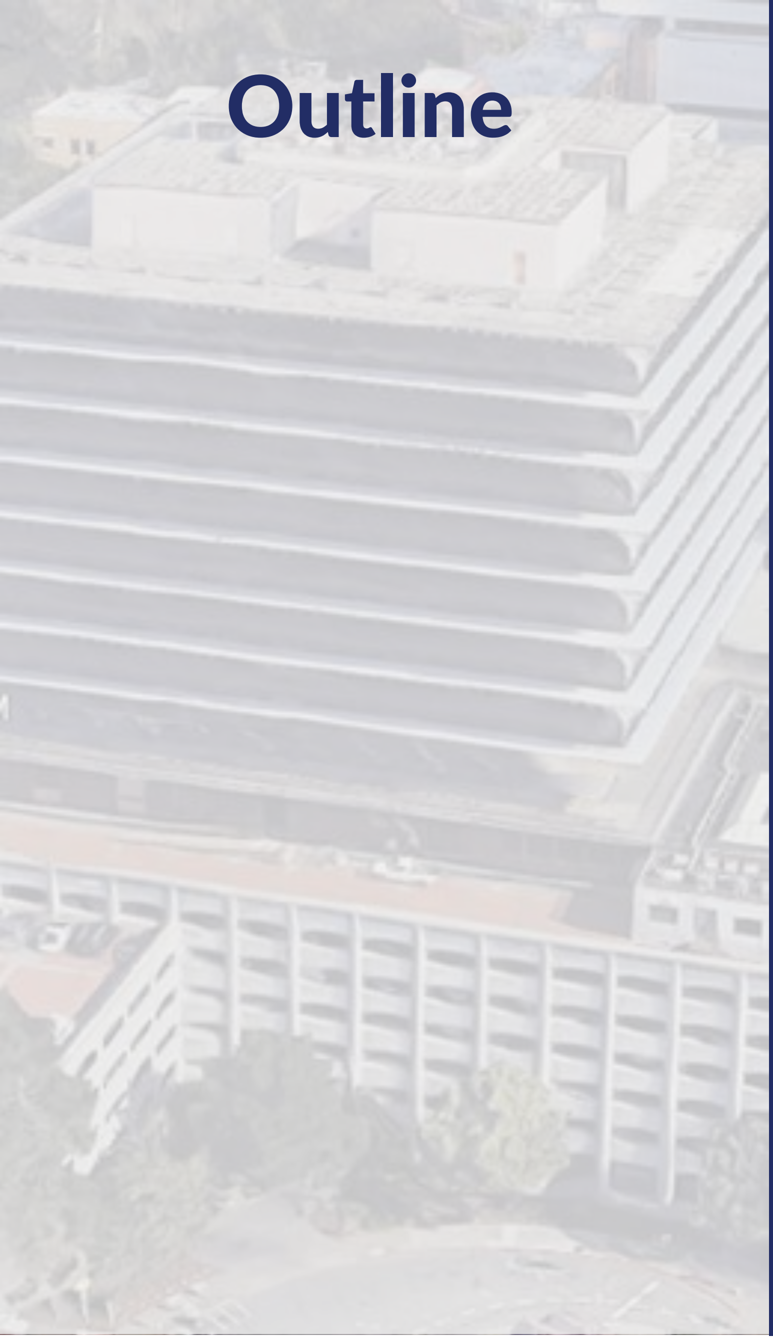
Option 3



$$$$

Big Picture Considerations

- Seismic retrofit requires significant upgrade to other building systems (A,M,E,P,F/LS)
- Total cost much more than replacement
- Replacement is too disruptive
- Isolation option is too disruptive to affected floors (mission critical facility)
- Potential for further engineering success is possible, but expensive (worth exploring)



Outline

- Building Overview
- Project Description
- ASCE 41 Analyses
- Retrofit Schemes
- Conclusions

Conclusions

- SPR V is untenable (requires closure/evacuation in 2030)
- Seismic retrofit costs too much and is too disruptive
- Building is incredibly well designed (see next slide)
- Kevin bet his career that the team could show SPR IV
- UCSF commissioned most advanced NLRHA/ASCE 41-23 analysis
  - Perform 3D and OpenSees models (full and complete)
  - Consider overall building collapse probabilities
  - FEMA P695 statistical considerations
  - Element calibration uses applicable test data
- **Stay tuned for Part II**

Specific thoughts about ACC as a uniquely good structure

- Negative: High-seismic site (comparator: the 975-year shaking acceleration is nearly the same as MCE).
- Negative: Concrete and massing creates a very heavy building.
- Positive: Core walls are well reinforced (4 layers).
- Positive: Core walls are relatively thick (24”); good vertical stability post-failure.
- Positive: Core walls have well confined boundary elements where PT beams enter into wall thickness.
- Positive: Circular columns have #4 spirals @ 3” pitch, interconnected with large well reinforced beams.
- Positive: Beams and columns provide a strong back-up frame (contributes much to collapse prevention).
- Positive: Pan joist floor slabs are less sensitive to punching and local collapses.
- Positive: Large outrigger PT beams couple walls to gravity framing (shown in analysis).
- Positive: Very low drift; great for post yield stability

SEOR: Alexander Tarics, S.E. #760 (SEAONC Lifetime Achievement)
(PhD in Hungary, Harvard fellowship, water polo gold medal).

Photo: SEAONC Legacy