

Long-Term Slab Deflection:
Practical Insights for Design Engineers

Analysis, Design and Construction of Los Angeles County Museum of Art

Jacqueline Li, PE
Associate - Structural Engineering
Skidmore, Owings & Merrill

THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

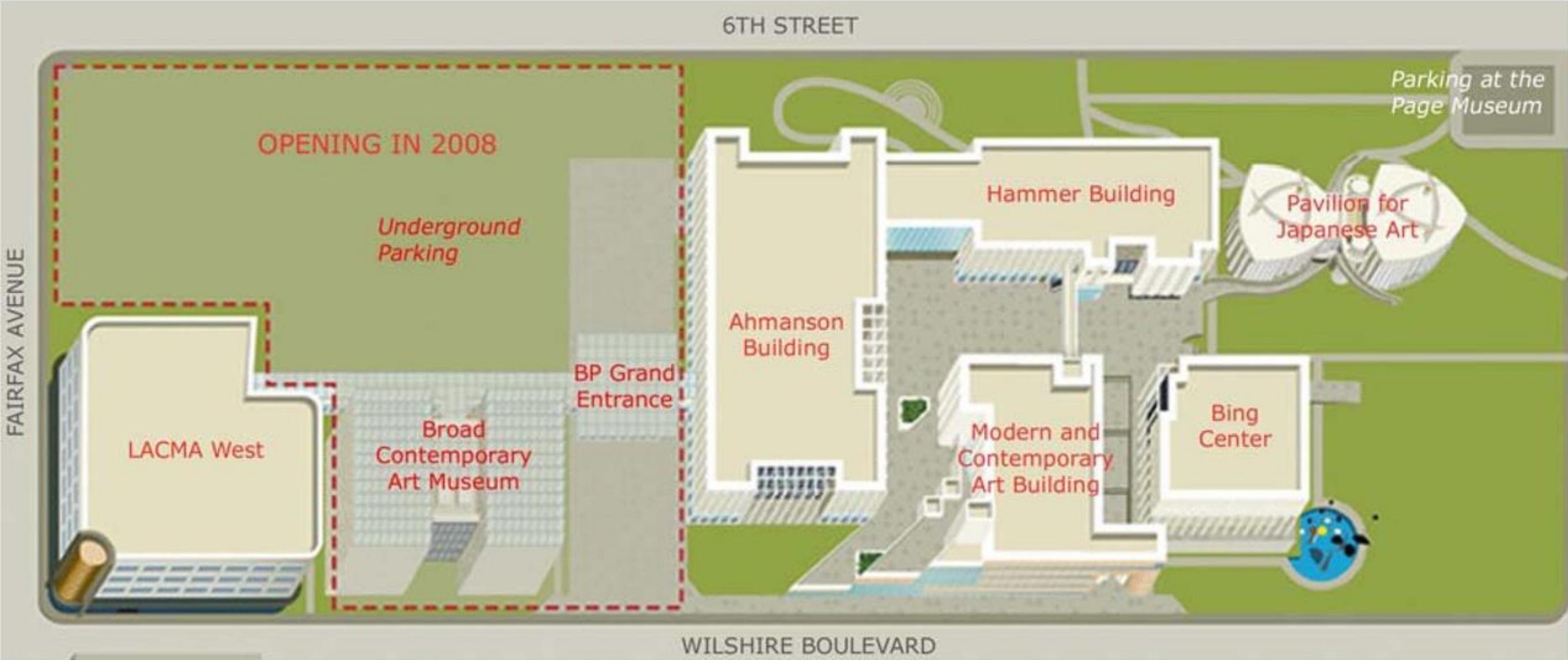


Background



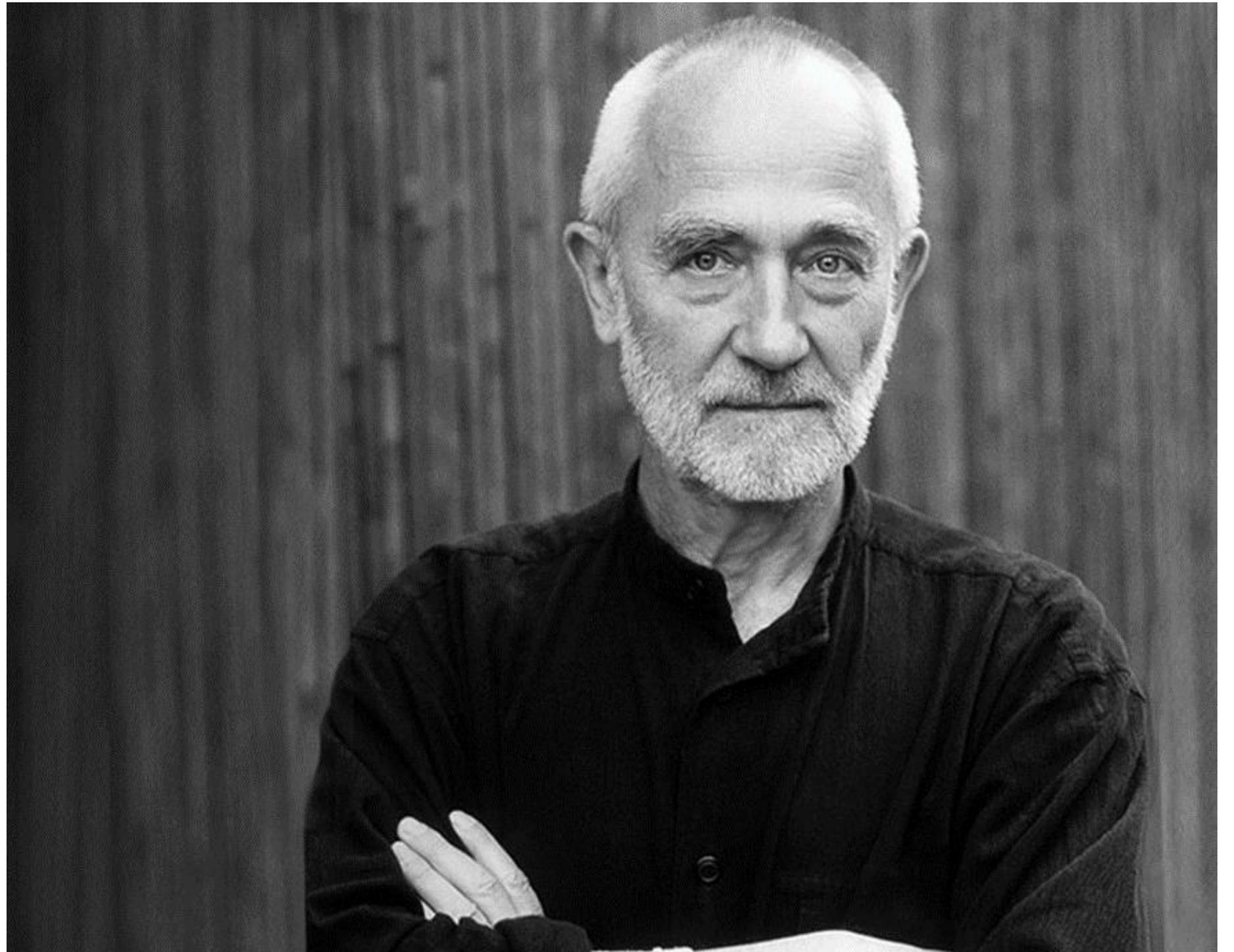
LACMA

Campus Plan, 2006



LACMA

Search for an Architect



Peter Zumthor
Pritzker Prize Laureate, 2009

Select Peter Zumthor Projects



Shelter for the Roman Ruins
Chur, 1986



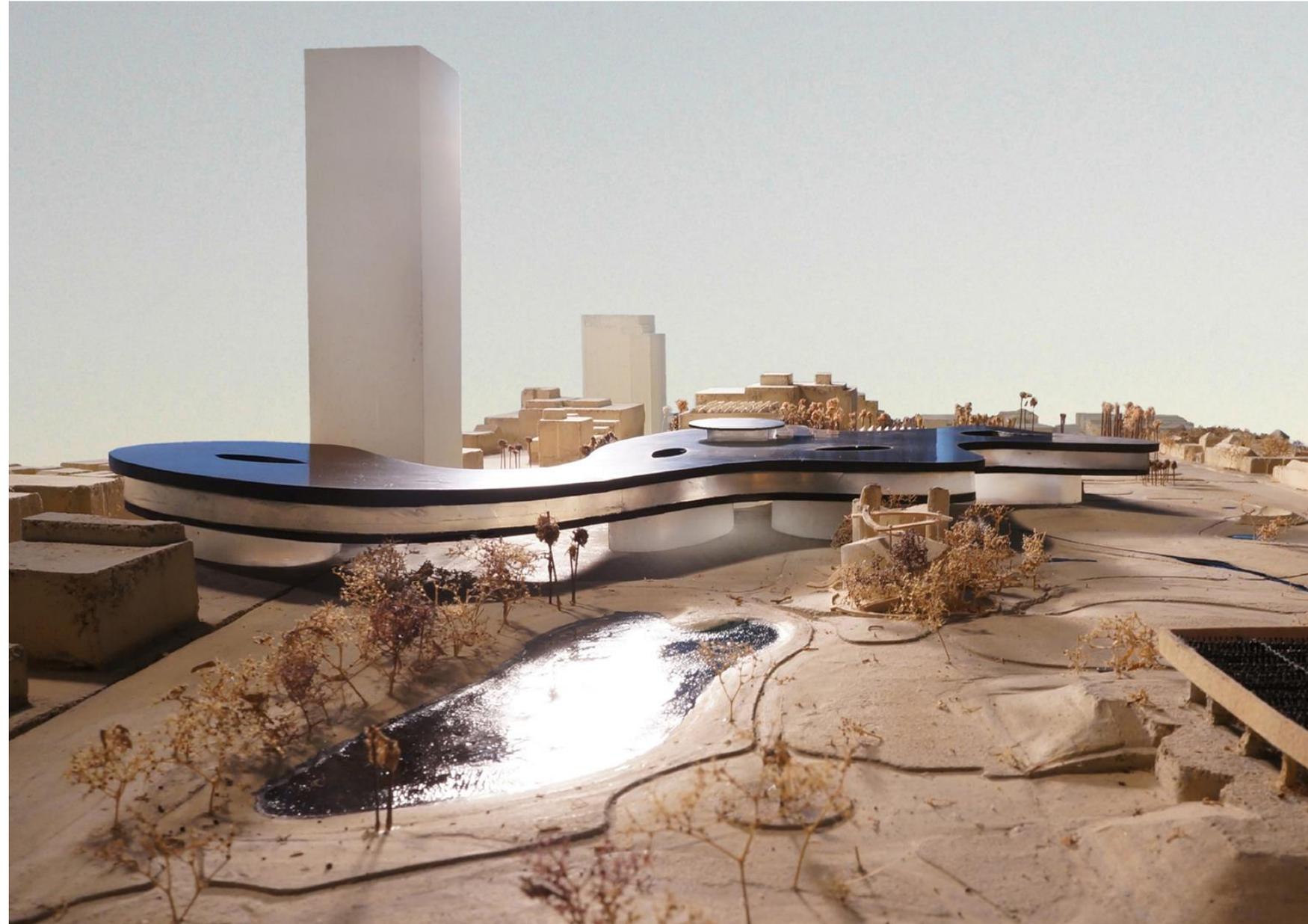
Therme Vals
Vals, 1996



Bruder Klaus Field Chapel, 2007
Mechernich, Germany

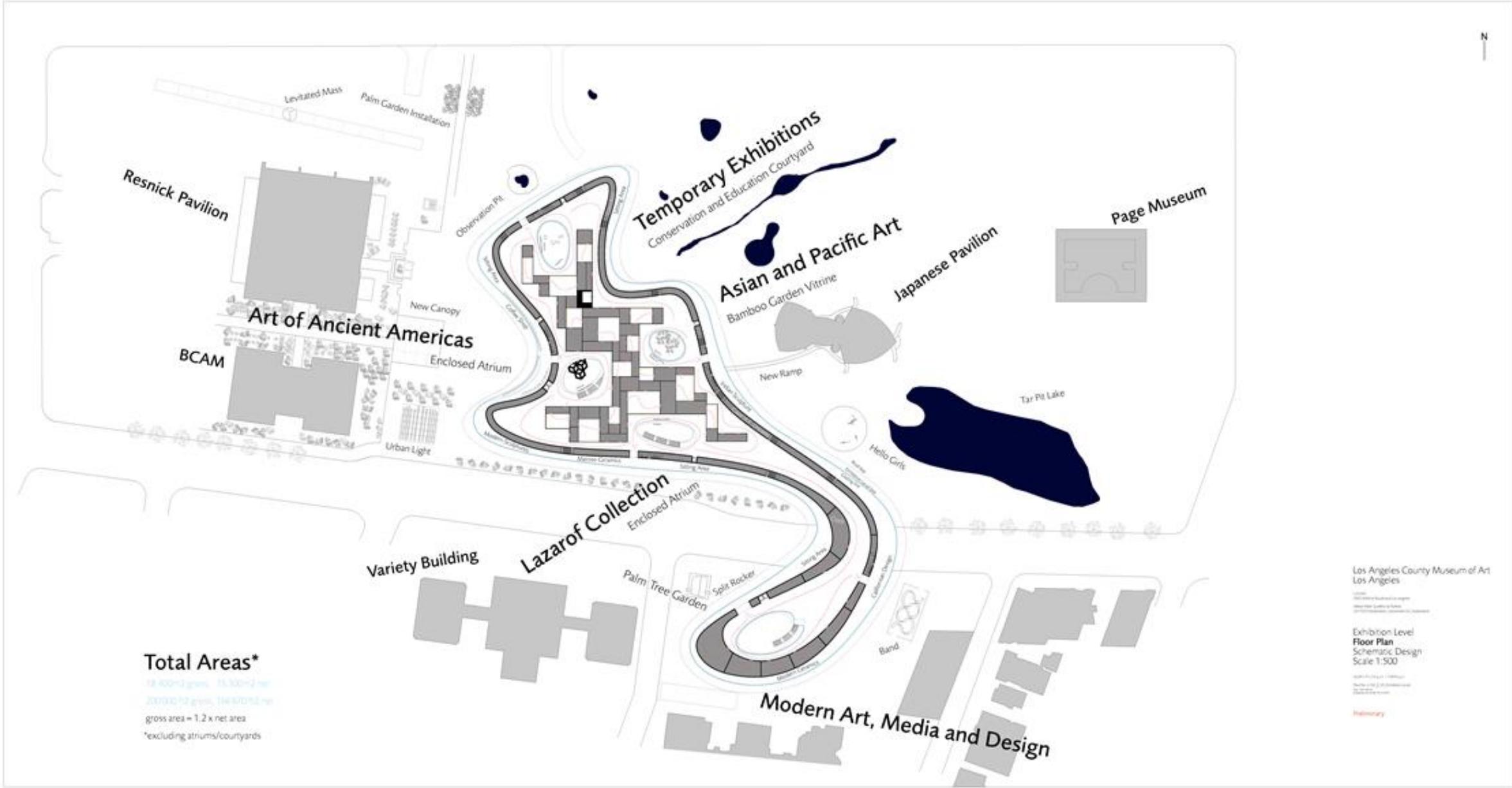
LACMA

January 2015



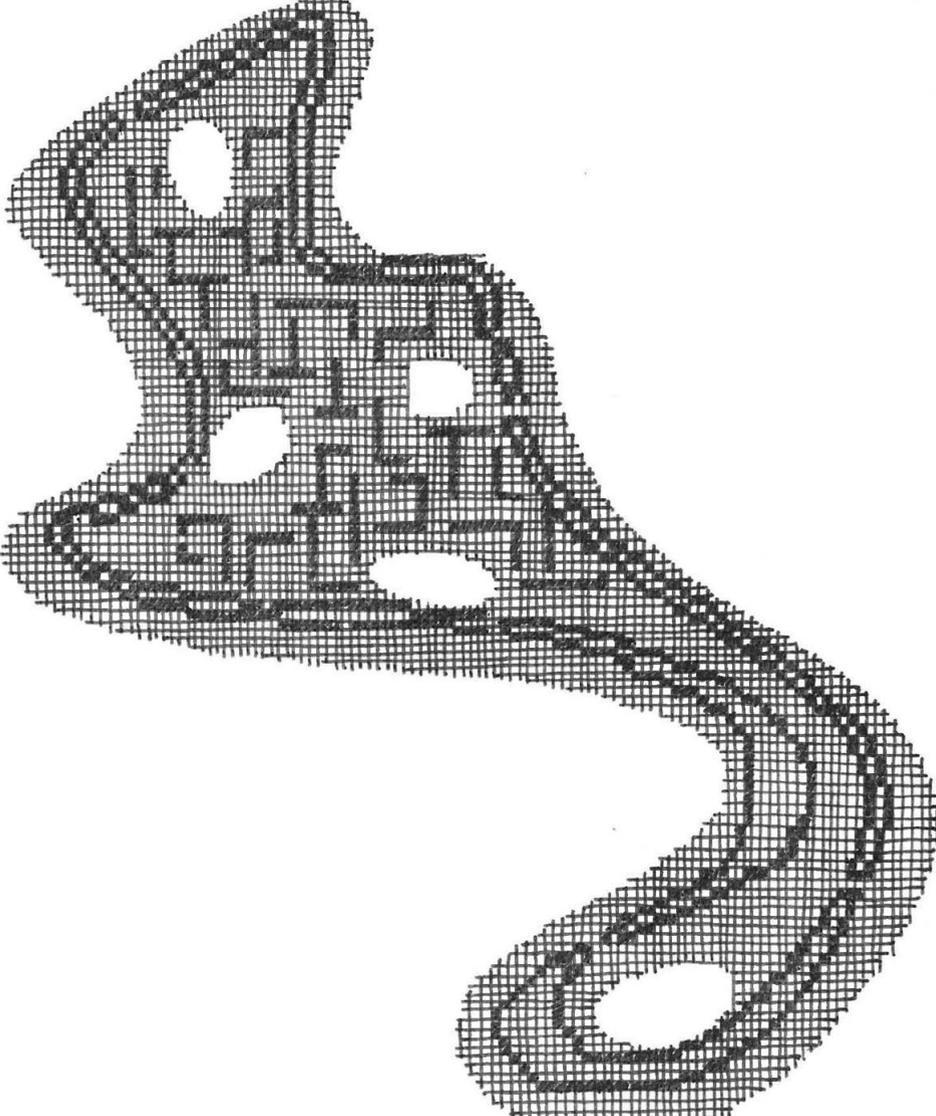
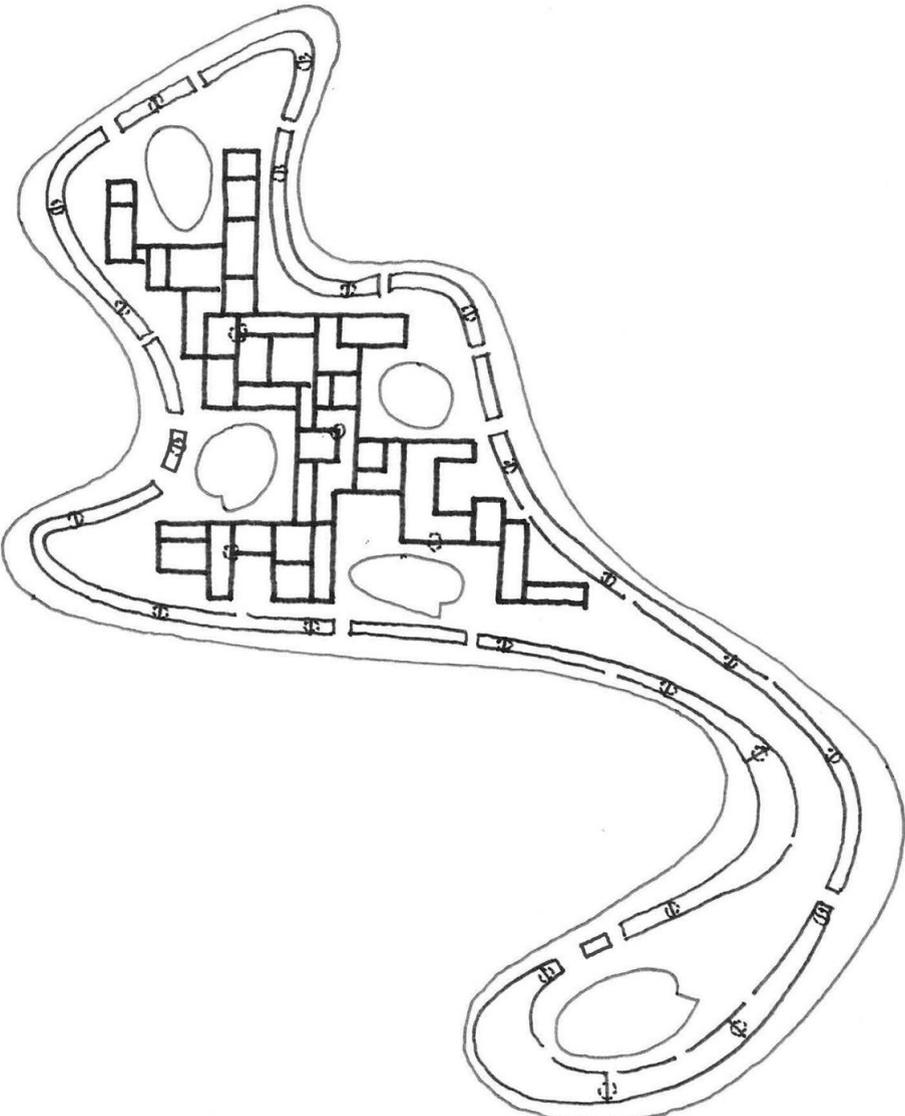
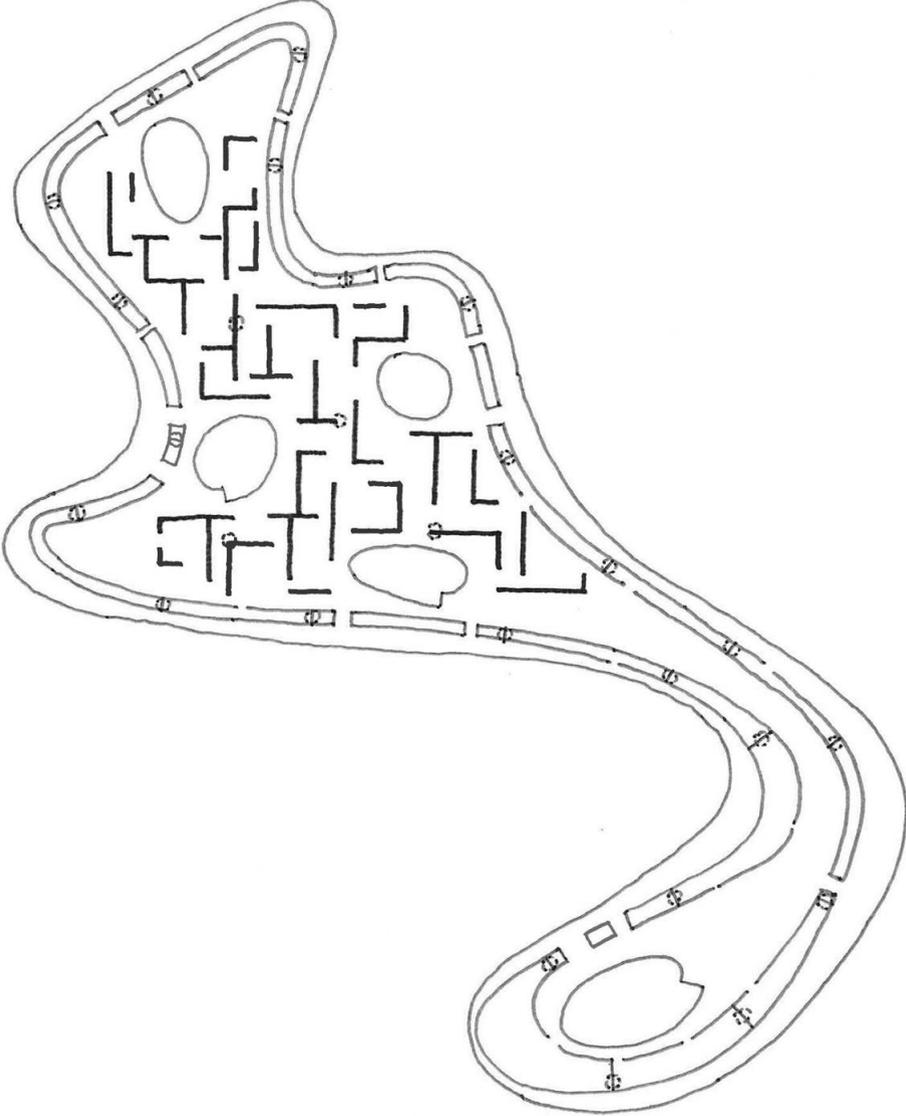
LACMA

January 2015



LACMA

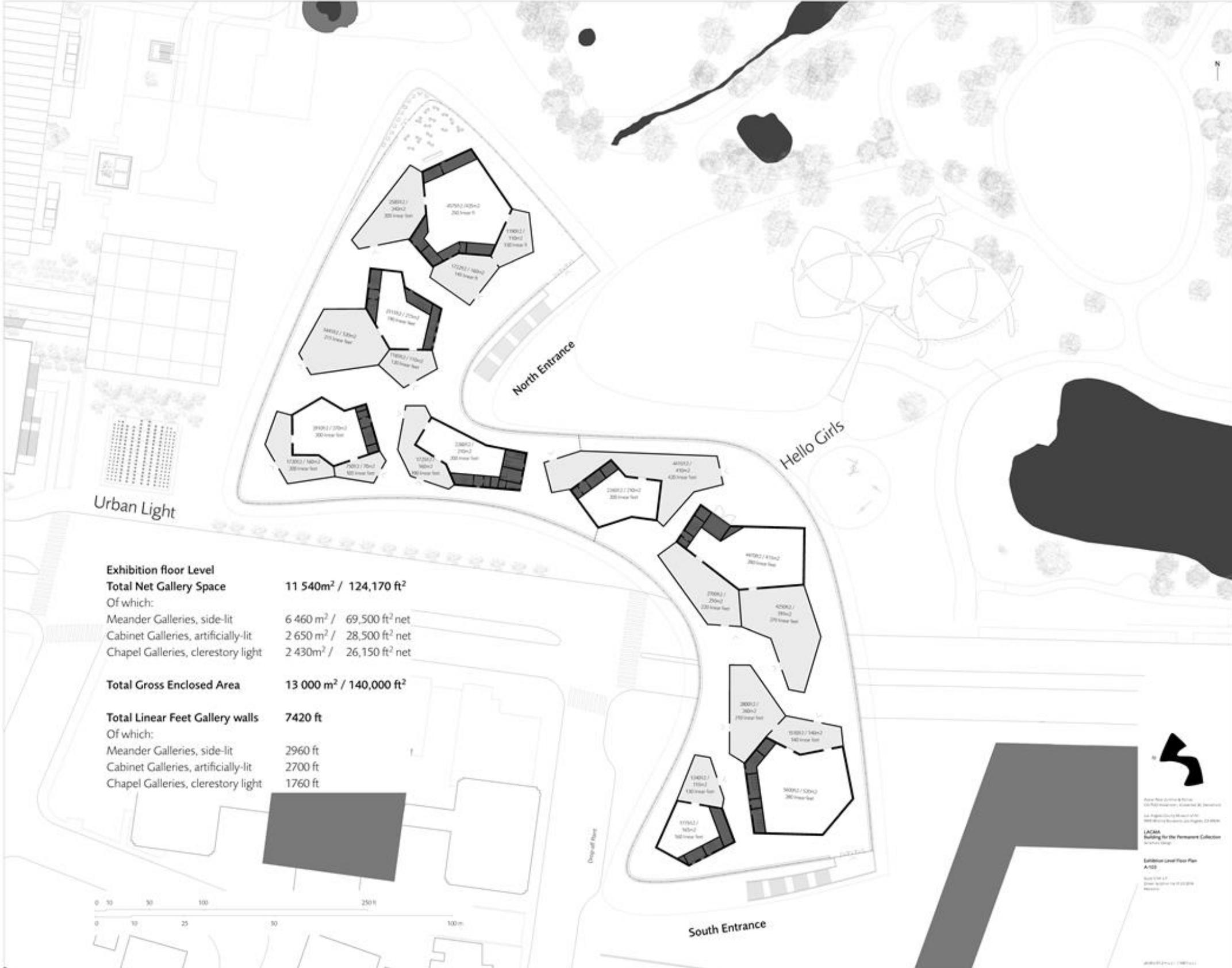
January 2015





Exhibition Floor Plan

April 2016



0 50 100 250 ft
 0 10 25 50 100 m
 LACMA
 Building for the Permanent Collection
 Exhibition Level Floor Plan
 A-102
 Scale: 1/8" = 1'-0"
 Date: 04/16/16
 Author: [unreadable]

Art House Tower Section

April 2016



Urban Light

Art House 3

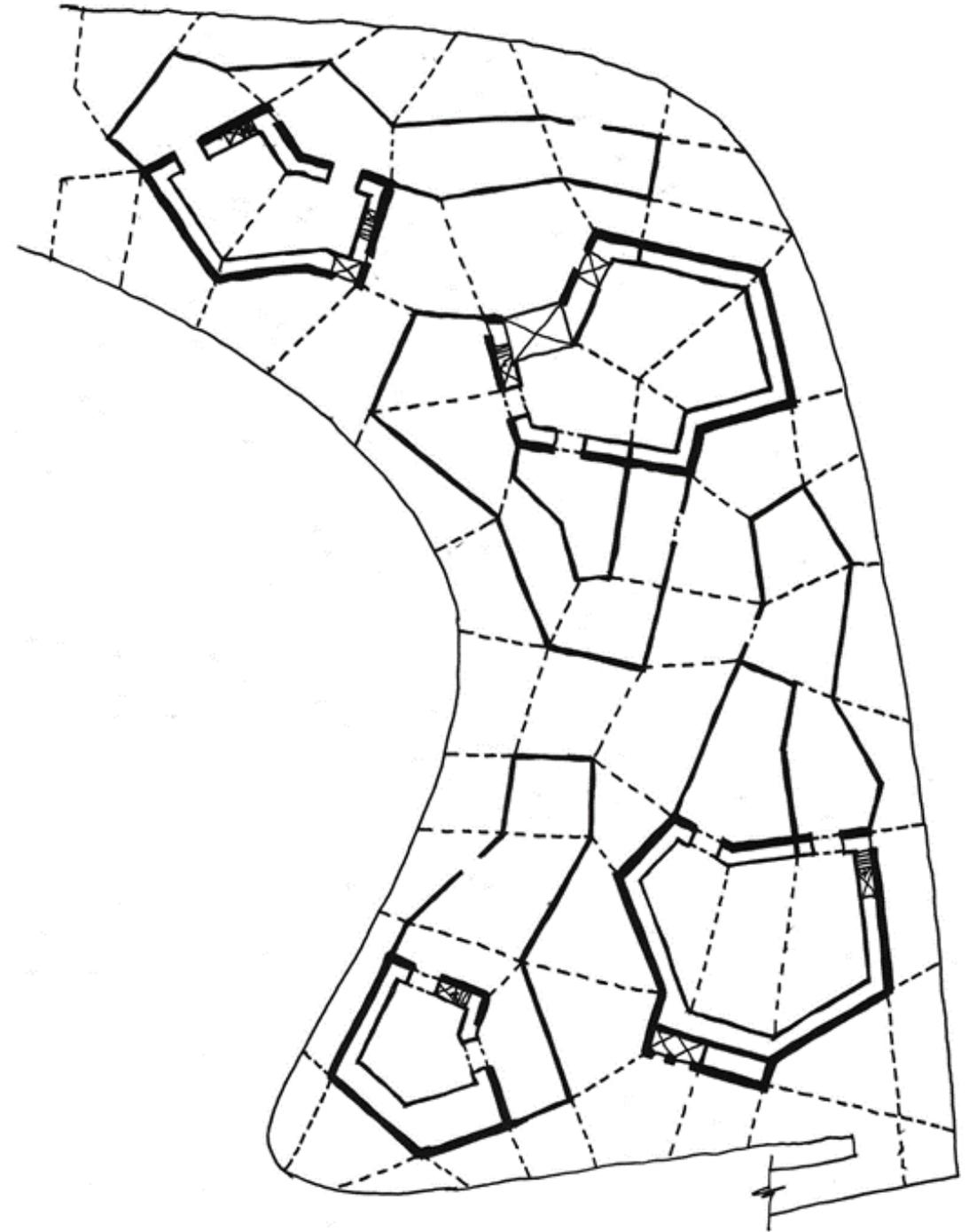
Art House 4

Art House 5

Art House 6
Loading Dock

Structural Concept Sketch

April 2016



A EXHIBITION FRAMING PLAN
SCALE: 1/32" = 1'-0"



New Gallery Shapes

Summer 2018



Exhibition Level

Enclosed Galleries (18 Chapel Galleries and 3 Transitional Galleries) are numbered from 1 to 23.
Open Galleries are numbered from 24 to 50.

Open Galleries*	7,803 m ² / 84,463 ft ²
March 26, 2018 open gallery	7,327 m ² / 78,546 ft ²
*Including Non-A1 museum area	1,142 m ² / 12,359 ft ²
Enclosed Galleries	2,052 m ² / 21,876 ft ²
March 26, 2018 enclosed gallery	1,822 m ² / 19,572 ft ²
Total Galleries	9,855 m² / 106,339 ft²
March 26, 2018 Total Galleries	10,149 m ² / 108,118 ft ²
Total Exhibition Level net area	9,916 m² / 106,730 ft²
March 26, 2018 Exhibition Level net area	10,199 m ² / 108,880 ft ²
Total Linear meters	2,056 m / 6,745 ft
March 26, 2018 Total Linear meters	2,094 m / 6,870 ft
Total enclosed gross area	11,672 m² / 125,634 ft²
March 26, 2018 Total enclosed gross area	11,886 m ² / 127,853 ft ²
Total slab gross area	12,233 m² / 131,894 ft²
March 26, 2018 Total slab gross area	12,289 m ² / 132,140 ft ²
Total roof gross area	16,110 m² / 173,405 ft²
March 26, 2018 Total roof gross area	16,136 m ² / 173,480 ft ²

Louvers are oriented for summer



Archi Real - Zurich
100-1000 Museum, Vancouver, BC, Switzerland

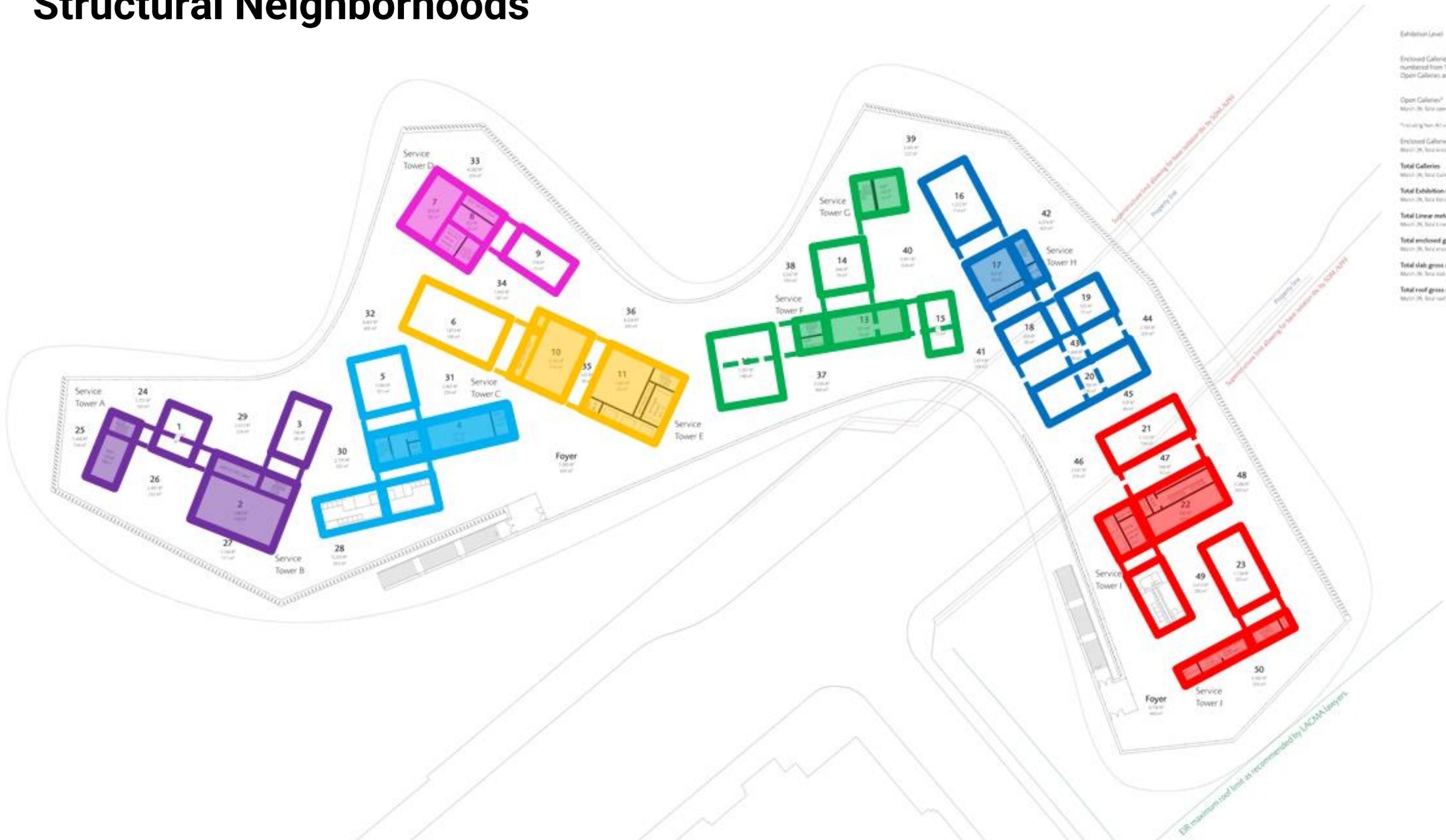
LACMA
3900 Wilshire Boulevard Los Angeles
Los Angeles County Museum of Art
Building for the Permanent Collection

Post Design Development
Reduced Version 4/18
Coordinated with Structure
Exhibition Level Plan

Preliminary
Scale 1:500
4/26/18 10:30 a.m. / J. Archi Real
Plan No. 1306_PSD_024
PDD Phase
Scale: 1/8" = 1'-0"
Drawn: 18 March 2018 11:00 AM
Revised:

Fair maximum road limit as recommended by LACMA lawyers

Structural Neighborhoods



Exhibition Level

Enclosed Galleries (18 Chapel Galleries and 3 Transitional Galleries) are numbered from 1 to 23.
Open Galleries are numbered from 24 to 50.

Open Galleries*	7,803 m ² / 84,463 ft ²
March 26, 2014 open galleries	7,327 m ² / 78,546 ft ²
*Including Non-AI museum area	1,142 m ² / 12,333 ft ²
Enclosed Galleries	2,052 m ² / 21,876 ft ²
March 26, 2014 enclosed galleries	1,822 m ² / 19,572 ft ²
Total Galleries	9,855 m² / 106,339 ft²
March 26, 2014 Total Galleries	9,149 m ² / 98,118 ft ²
Total Exhibition Level net area	9,916 m² / 106,730 ft²
March 26, 2014 Total Exhibition Level net area	9,199 m ² / 98,880 ft ²
Total Linear meters	2,056 m / 6,745 ft
March 26, 2014 Total Linear meters	2,054 m / 6,743 ft
Total enclosed gross area	11,672 m² / 125,634 ft²
March 26, 2014 Total enclosed gross area	11,486 m ² / 123,953 ft ²
Total slab gross area	12,233 m² / 131,894 ft²
March 26, 2014 Total slab gross area	11,289 m ² / 121,140 ft ²
Total roof gross area	16,110 m² / 173,405 ft²
March 26, 2014 Total roof gross area	16,118 m ² / 173,440 ft ²

Louvers are oriented for summer



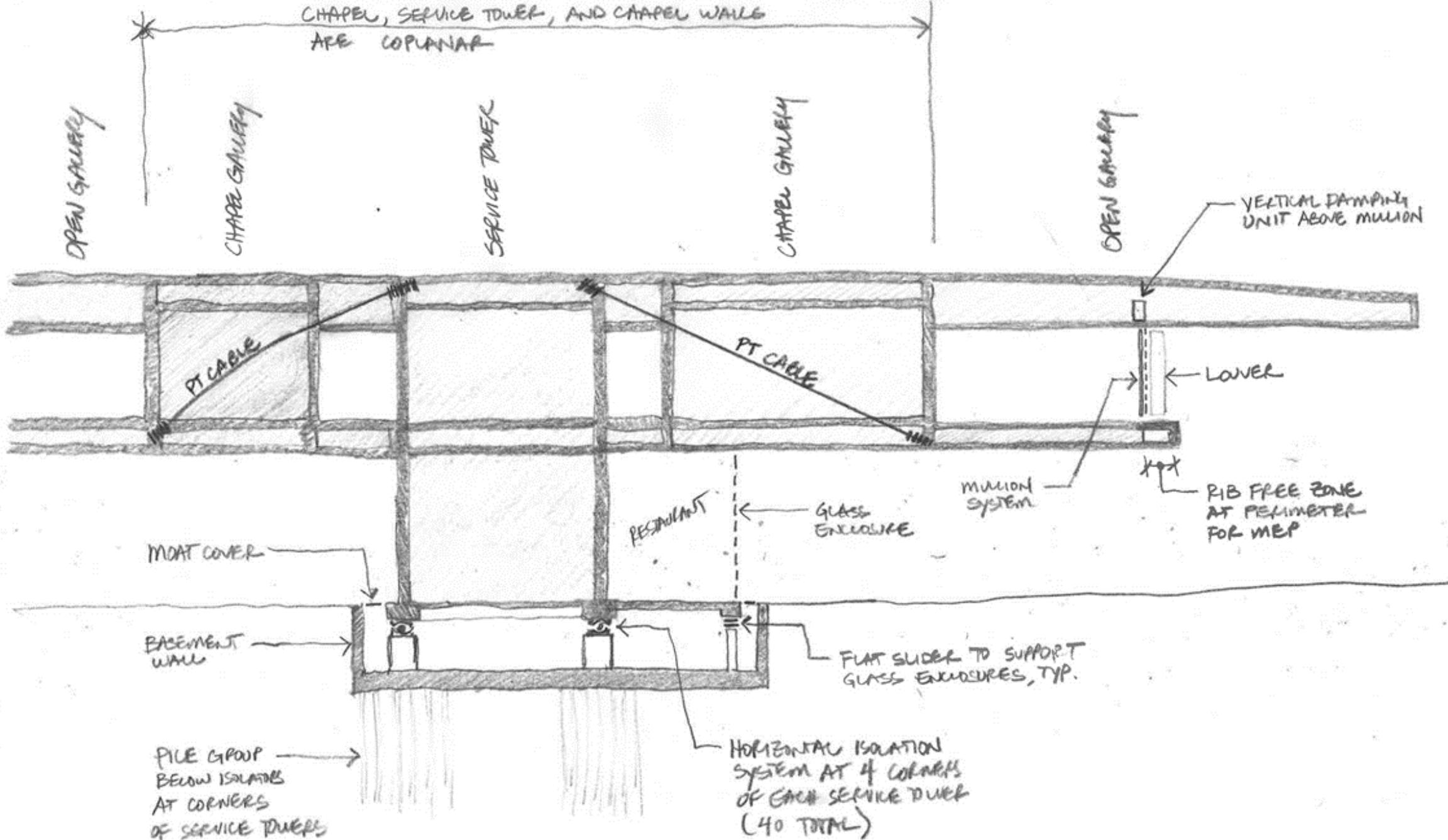
Archi-Plan Systems
100 West Main Street, Suite 200, Berkeley, CA

LACMA
6060 Wilshire Boulevard, Los Angeles
Los Angeles County Museum of Art
Building for the Permanent Collection

Post Design Development
Reduced Version 4/18
Coordinated with Structure
Exhibition Level Plan
Preliminary
Scale 1:500
4/18/18 - 4/18/18 m.e.a. / J.M.H. & A.L.
Plan No. E106_PSD_018
PDD Phase
Scale: 8 1/4" = 1'-0"
Drawn: 10/18/18 by E.L. & J.M.H.
Revised:

1/8" maximum road limit as recommended by LACMA lawyers

Concept Section

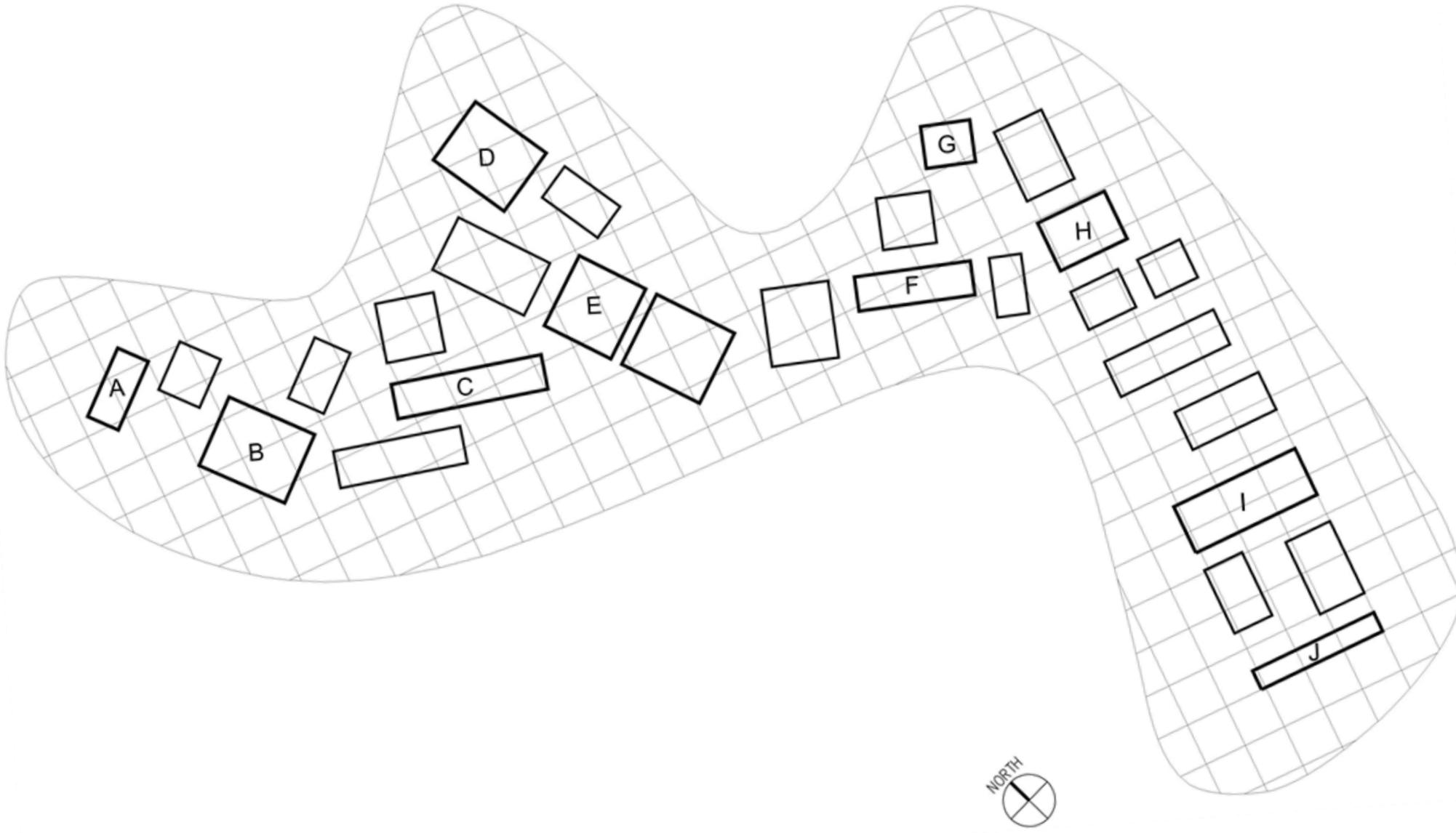


Exhibition Level Framing Plan



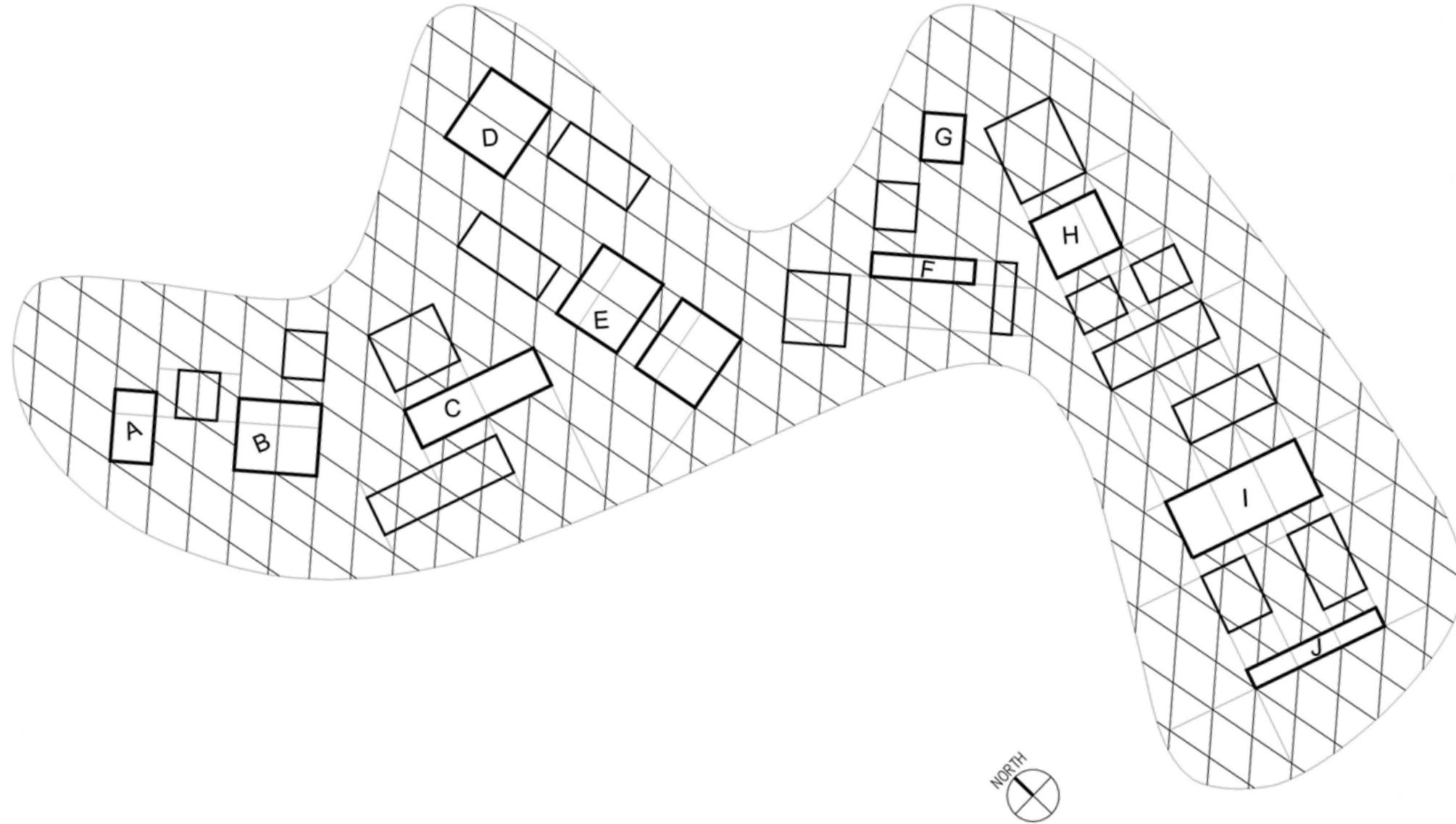
Grid Studies

25ft. Rectilinear



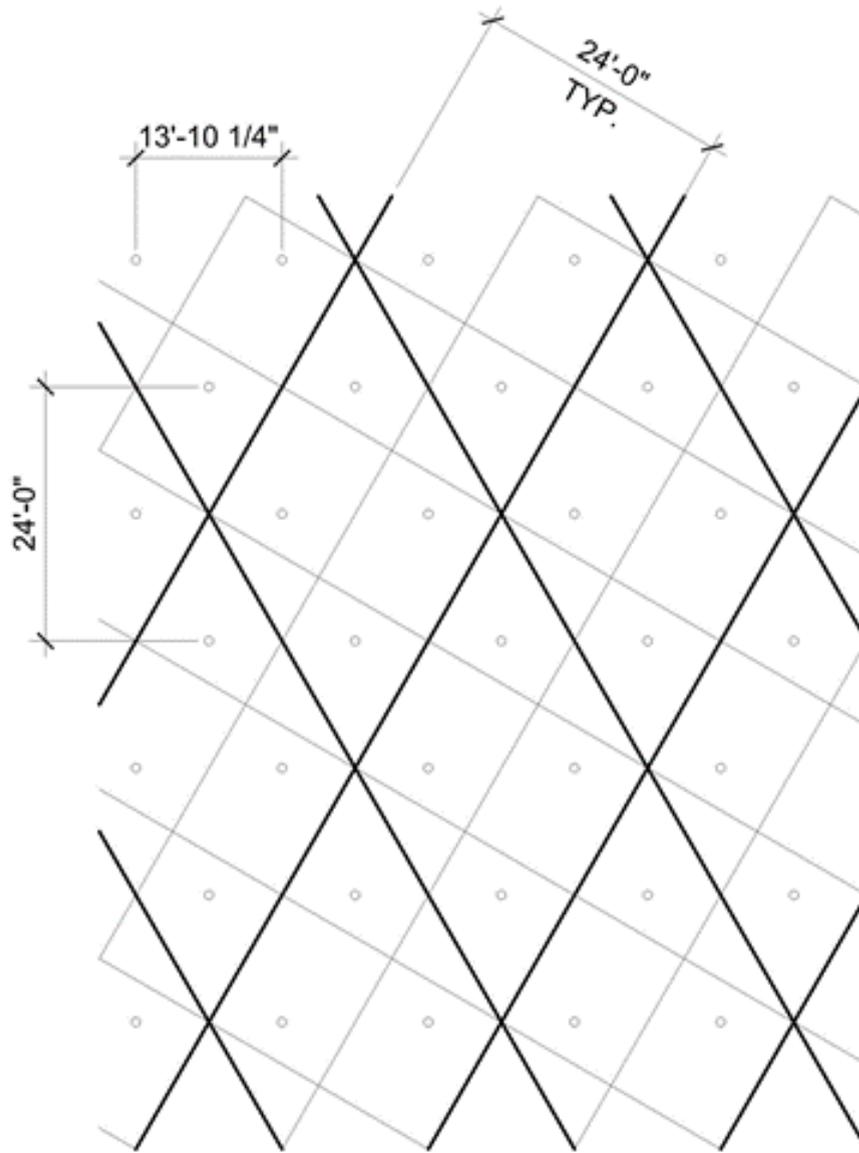
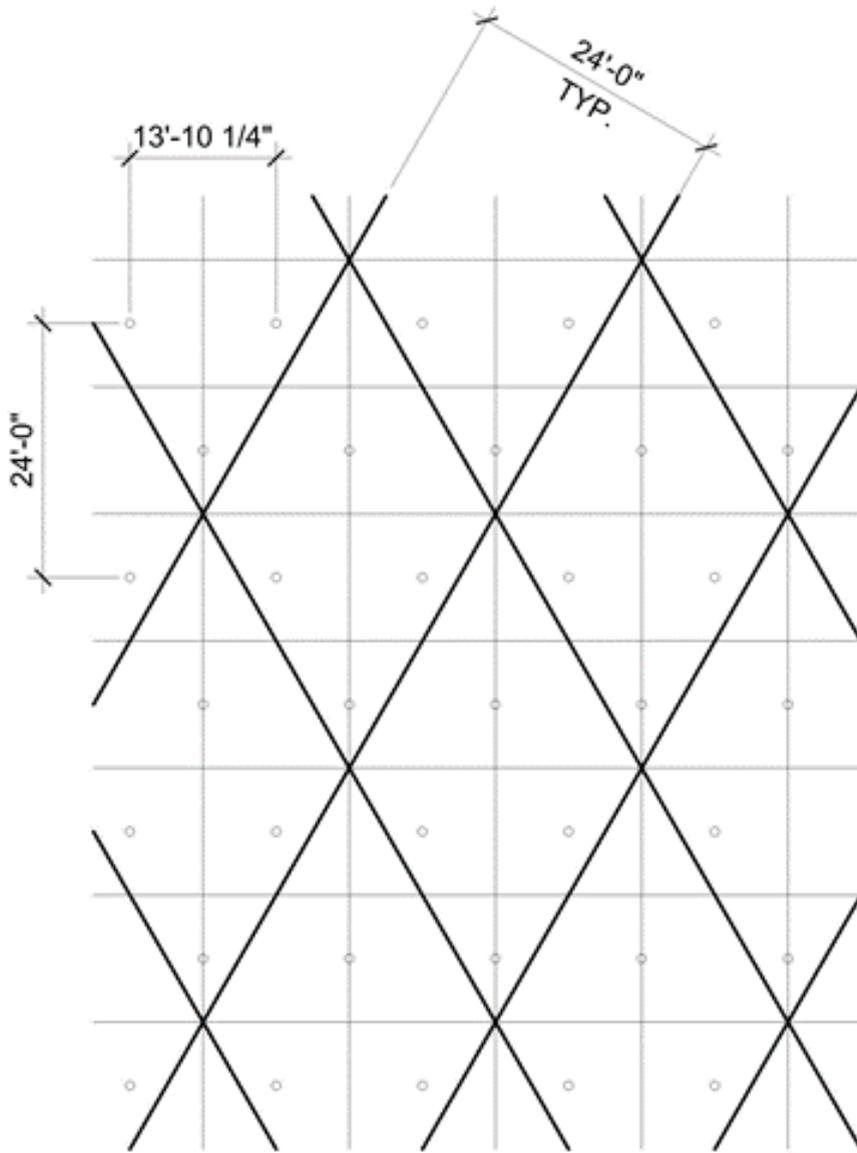
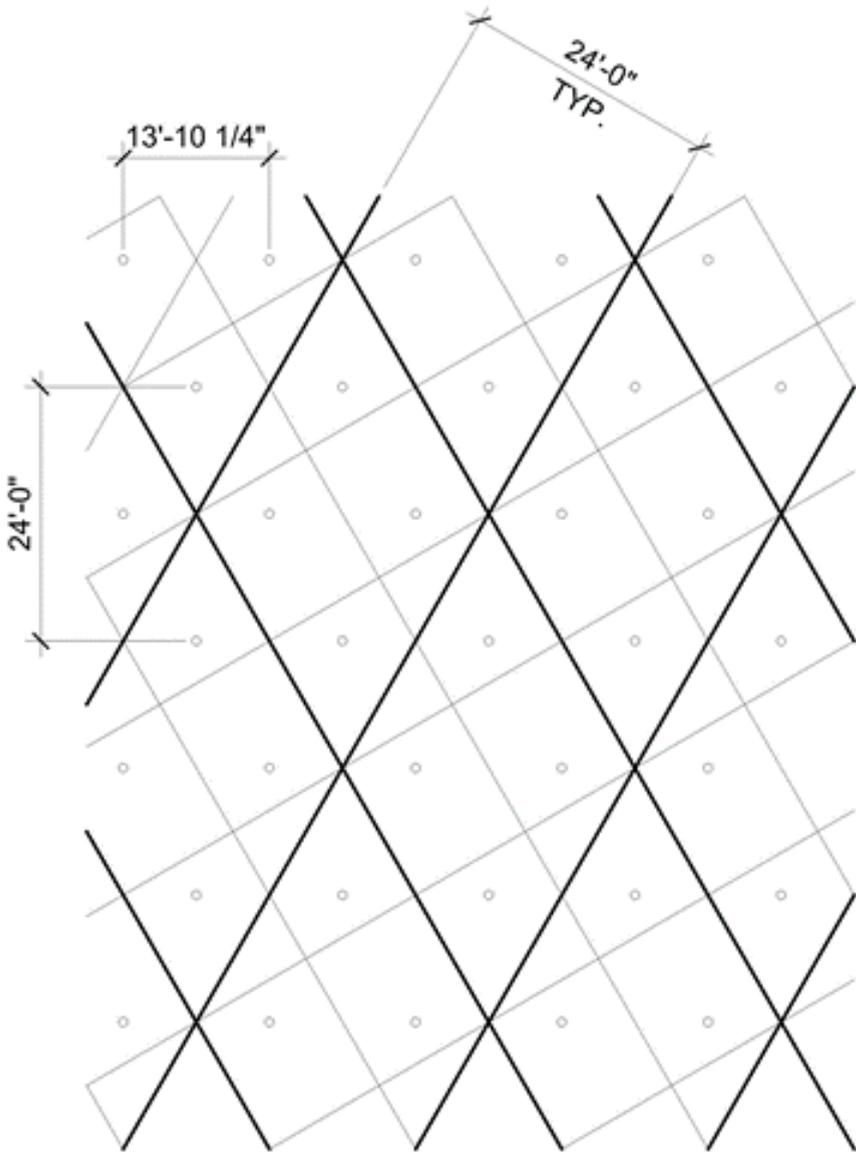
Exhibition Level Framing Study

Proposed Gallery Layout with Ribs



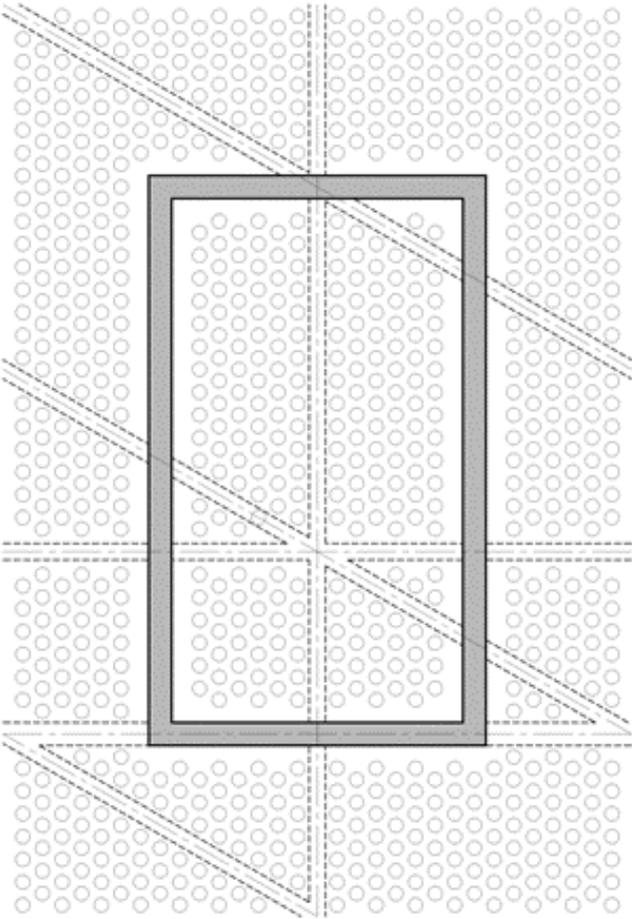
Organizing Principle

Three Directions

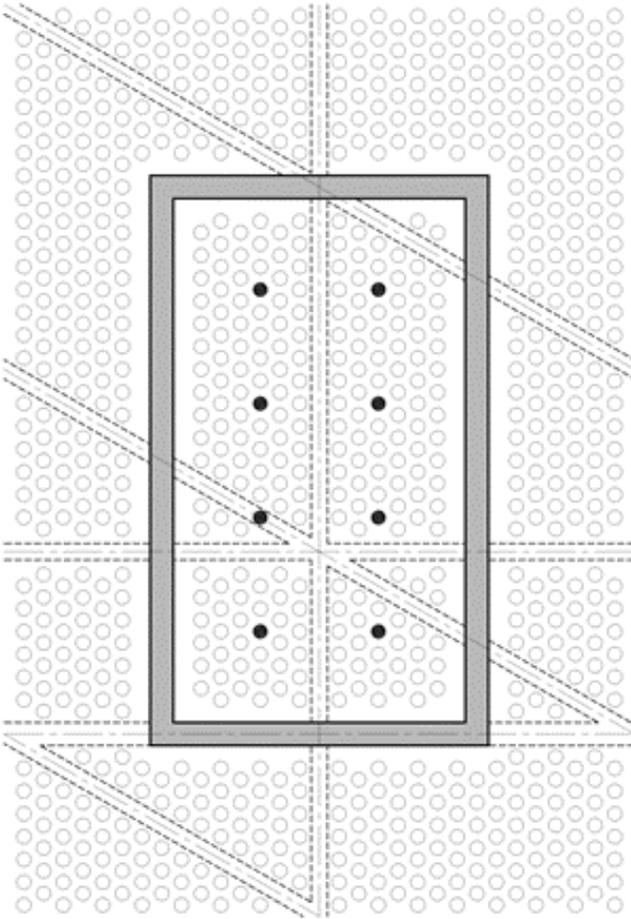


Integrating Systems

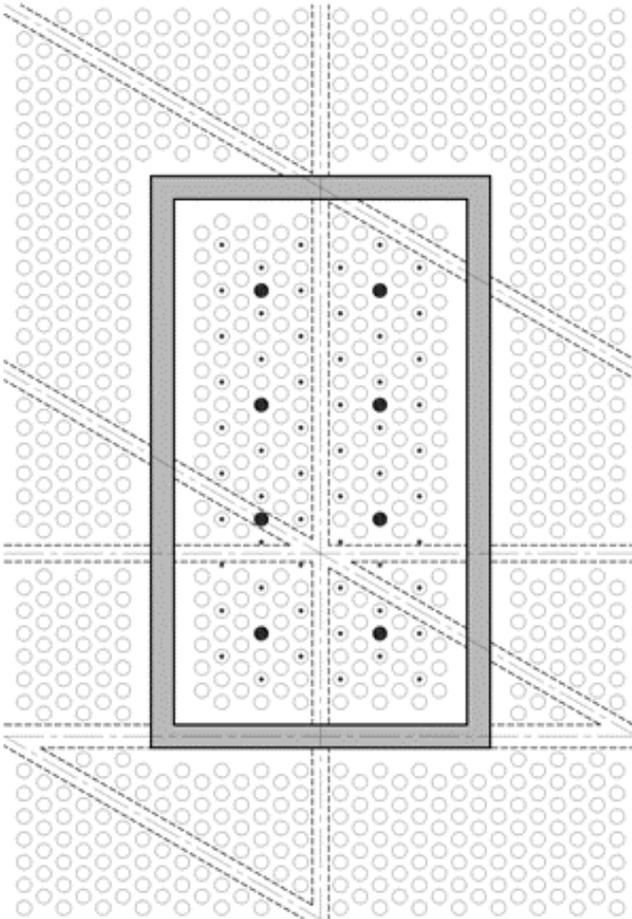
Lighting and Mechanical Design



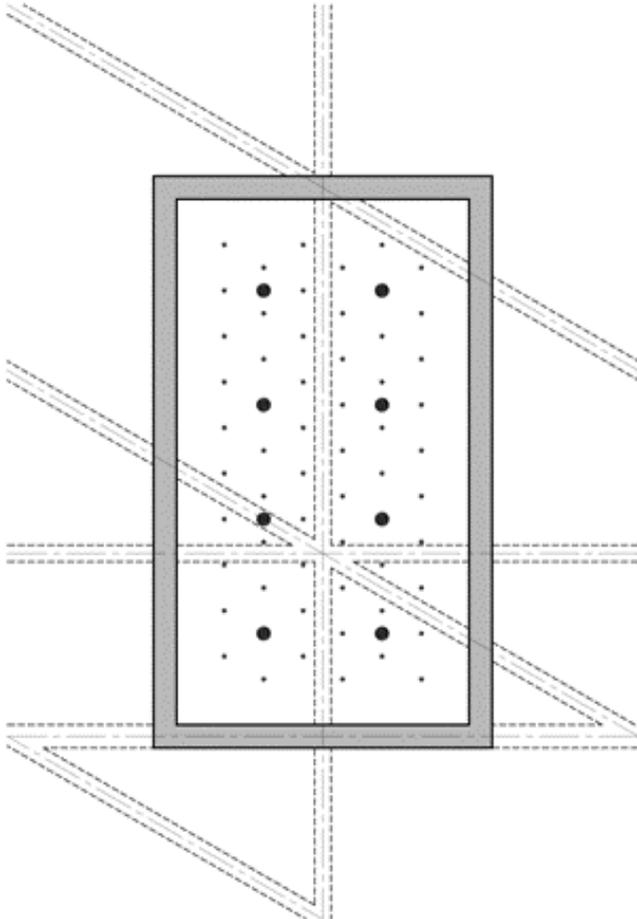
Potential Openings
between rebar



Lighting Locations
Rectilinear Pattern



Mechanical Openings
Triangular Pattern



Proposed RCP







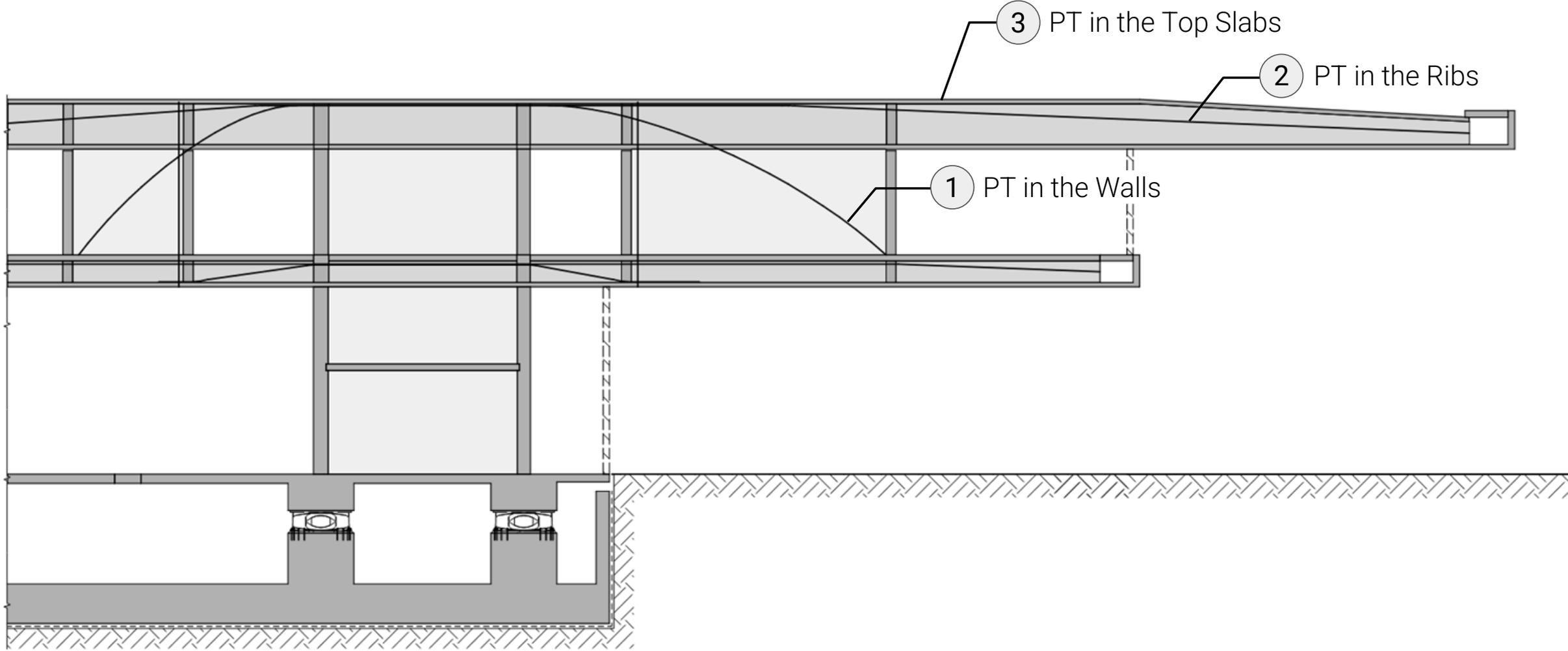




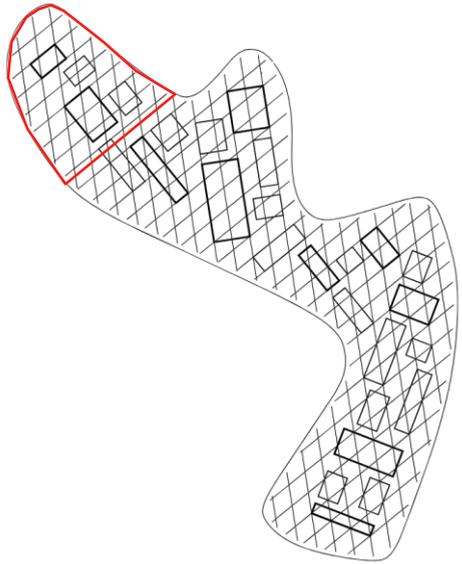


Post-tensioning System Analysis and Detailing

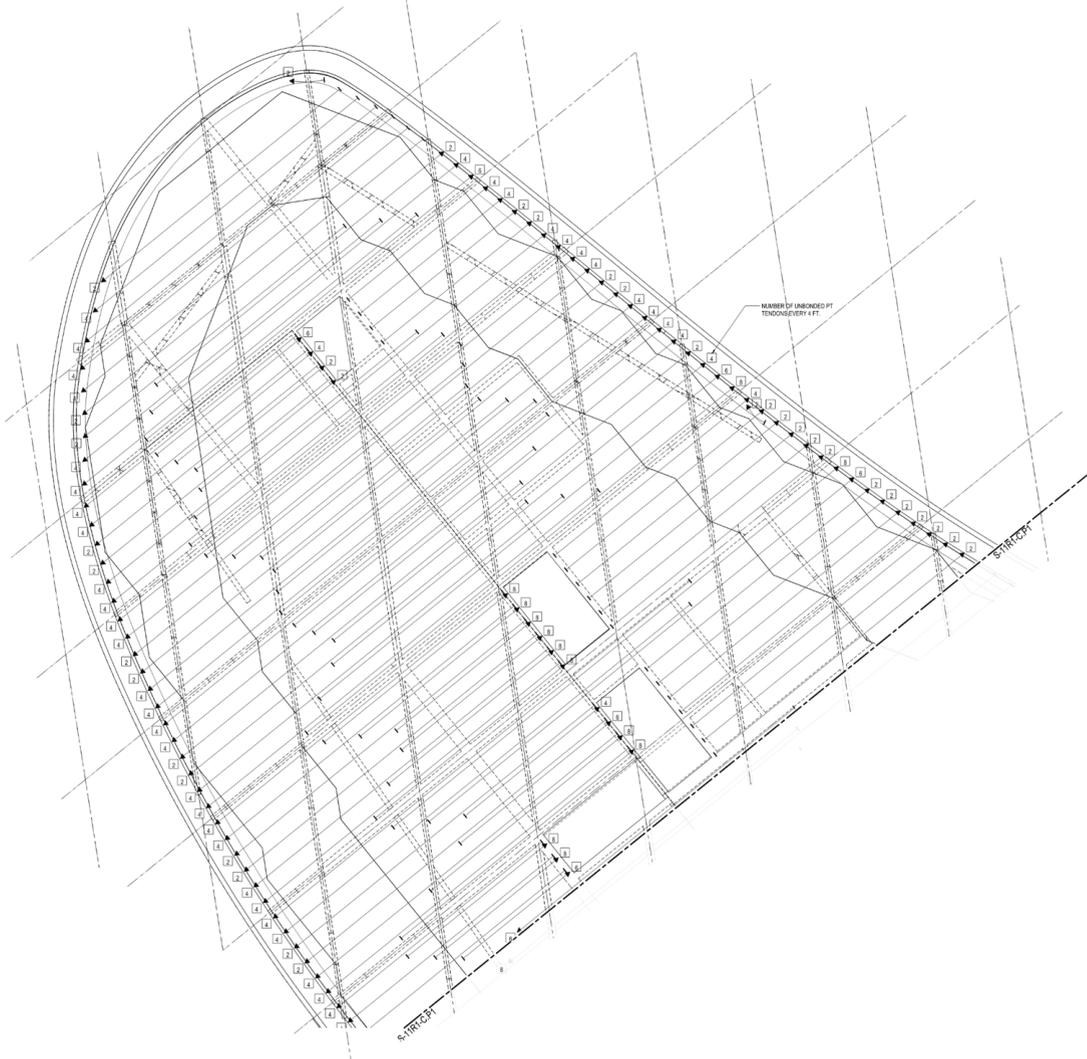
PT System Hierarchy



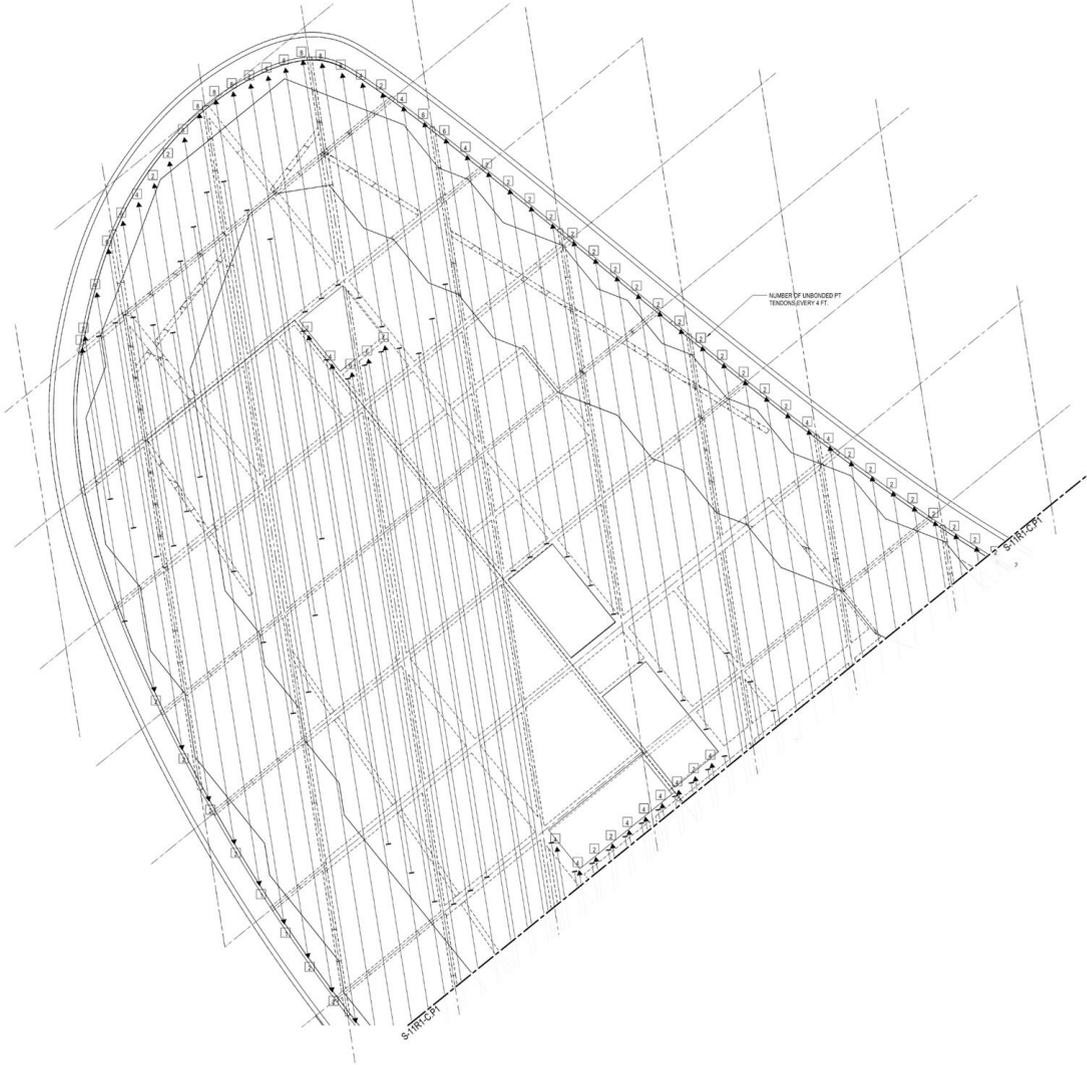
Slab PT



Key Plan

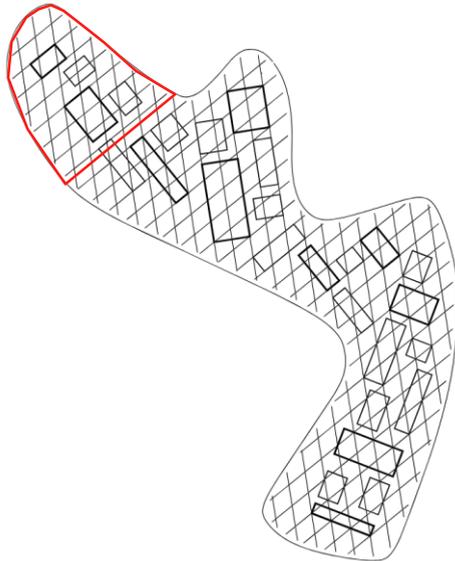


Slab PT in Direction A

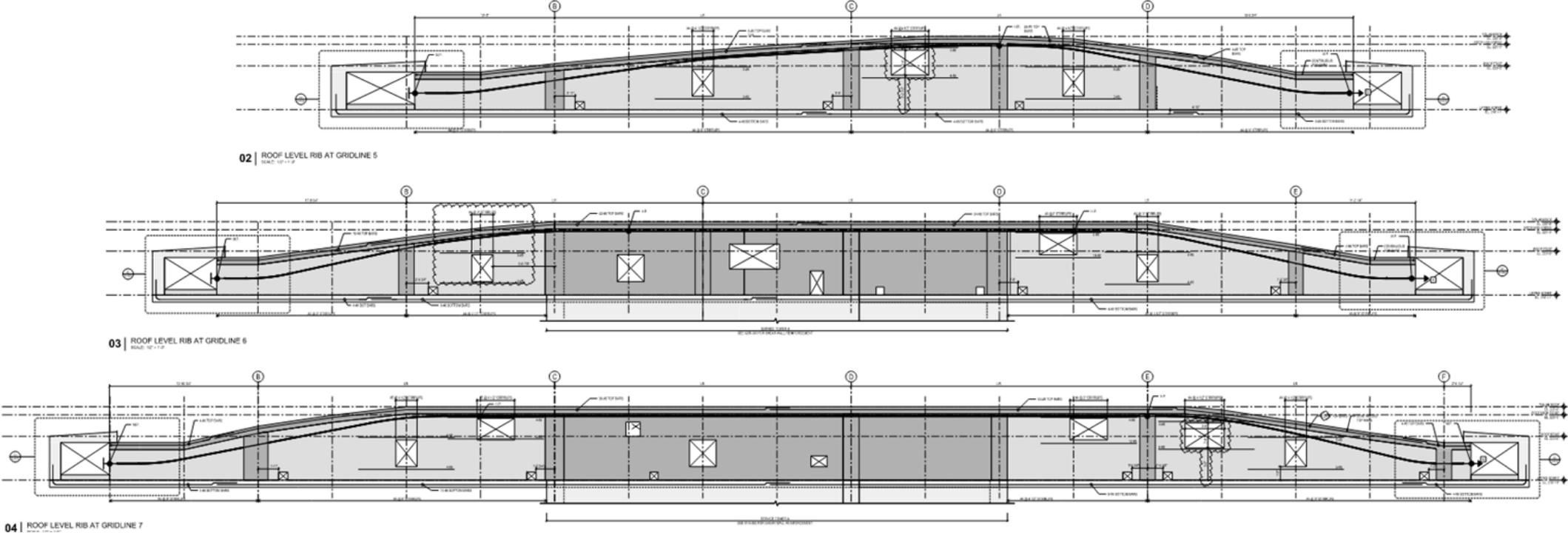


Slab PT in Direction B

Rib PT

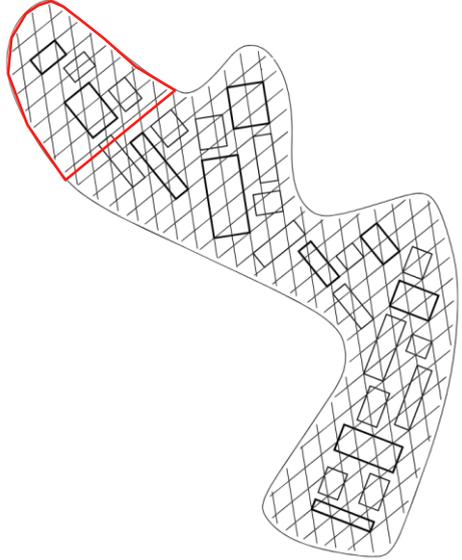


Key Plan

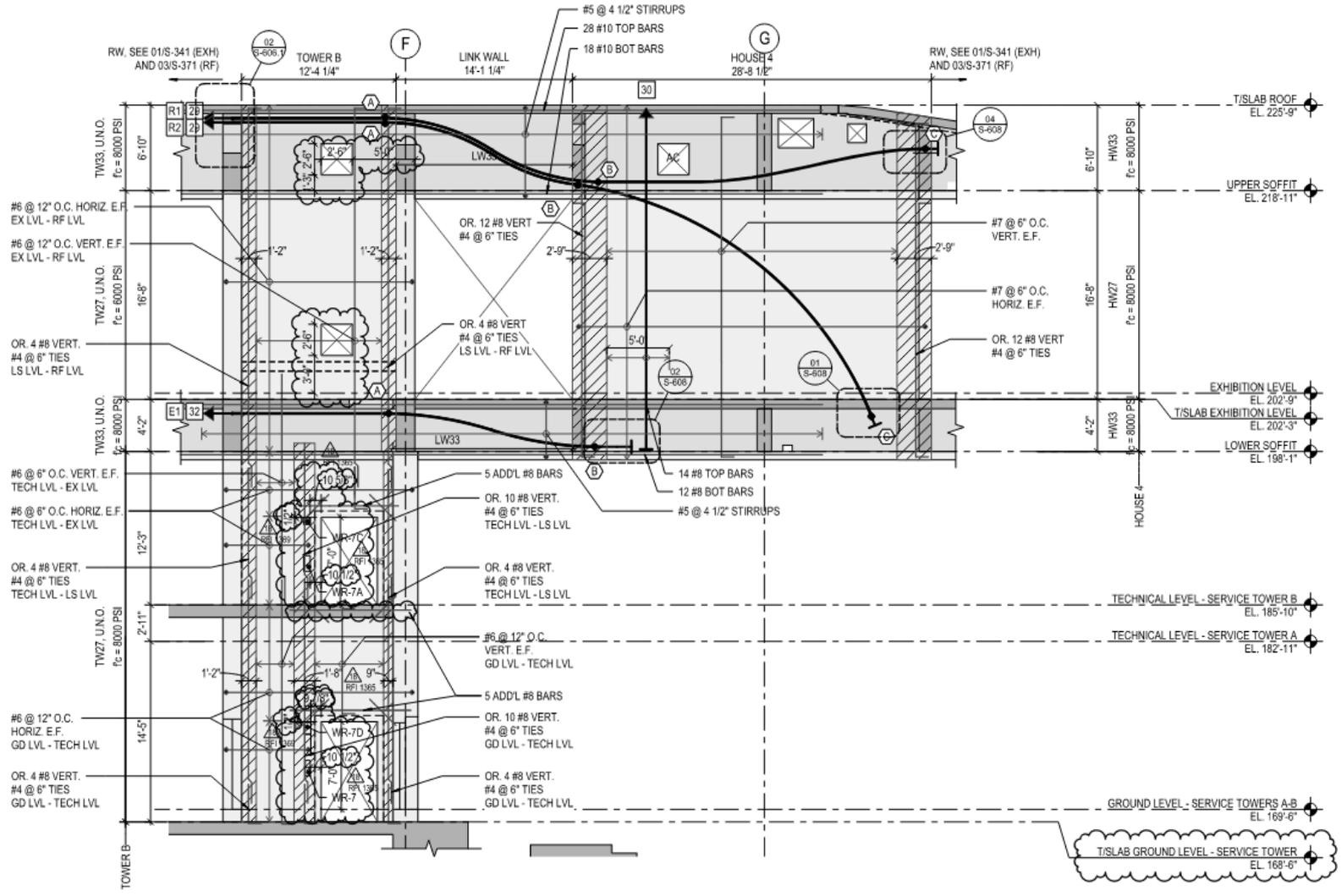


Rib PT in Direction A

Wall PT



Key Plan

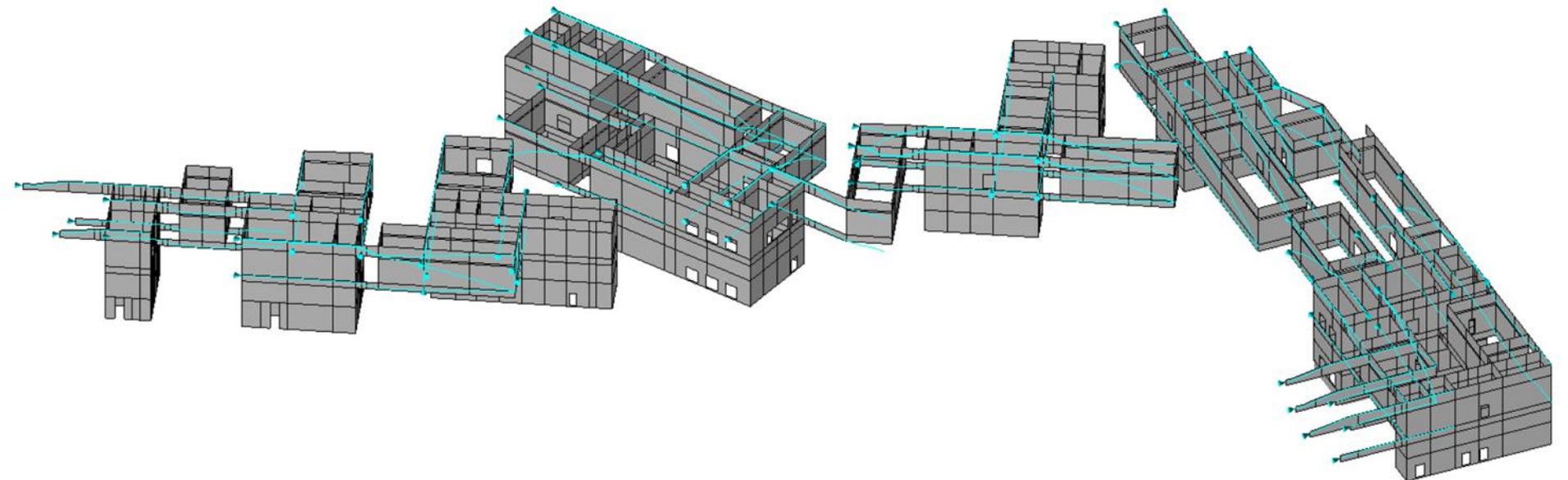
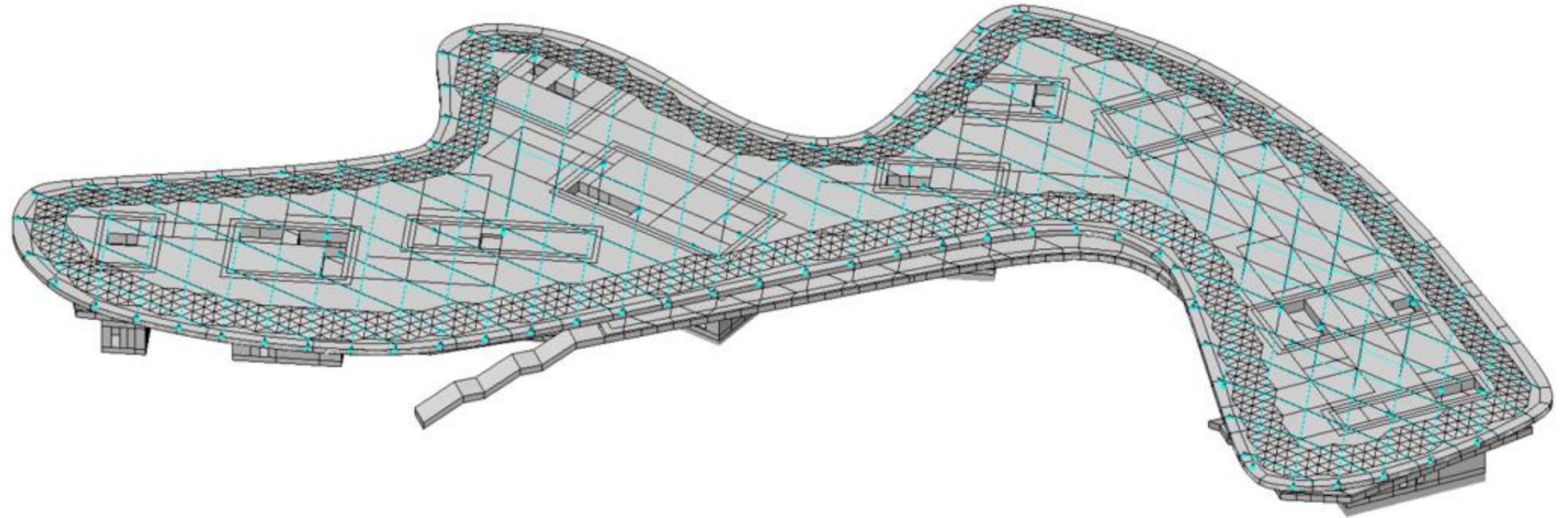


Wall PT in Direction A

Modeling Post-Tensioning

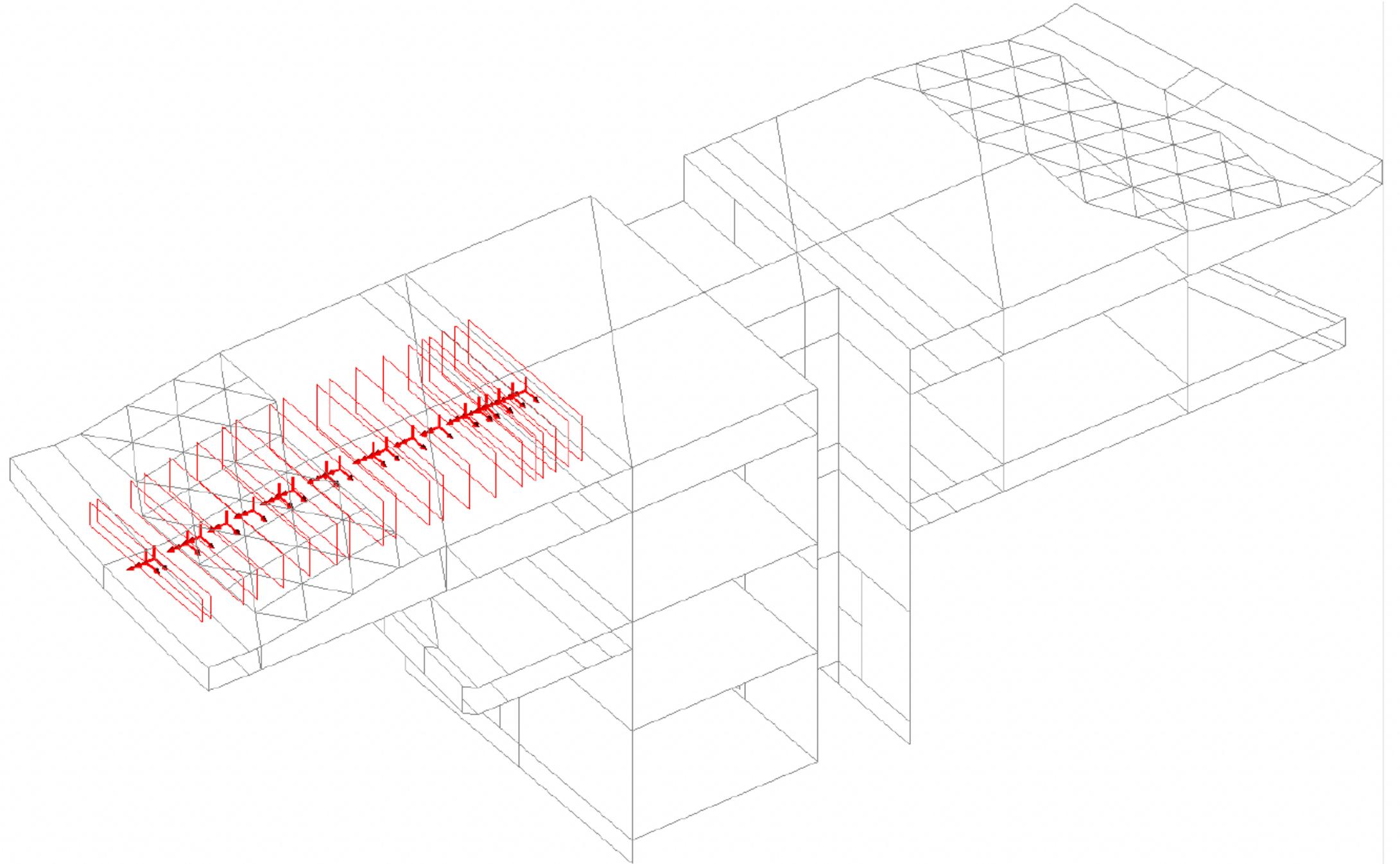
LUSAS Model

- Model used for gravity system design
- Accounts for creep, shrinkage, cracking and prestress losses
- Both serviceability and strength cases are considered

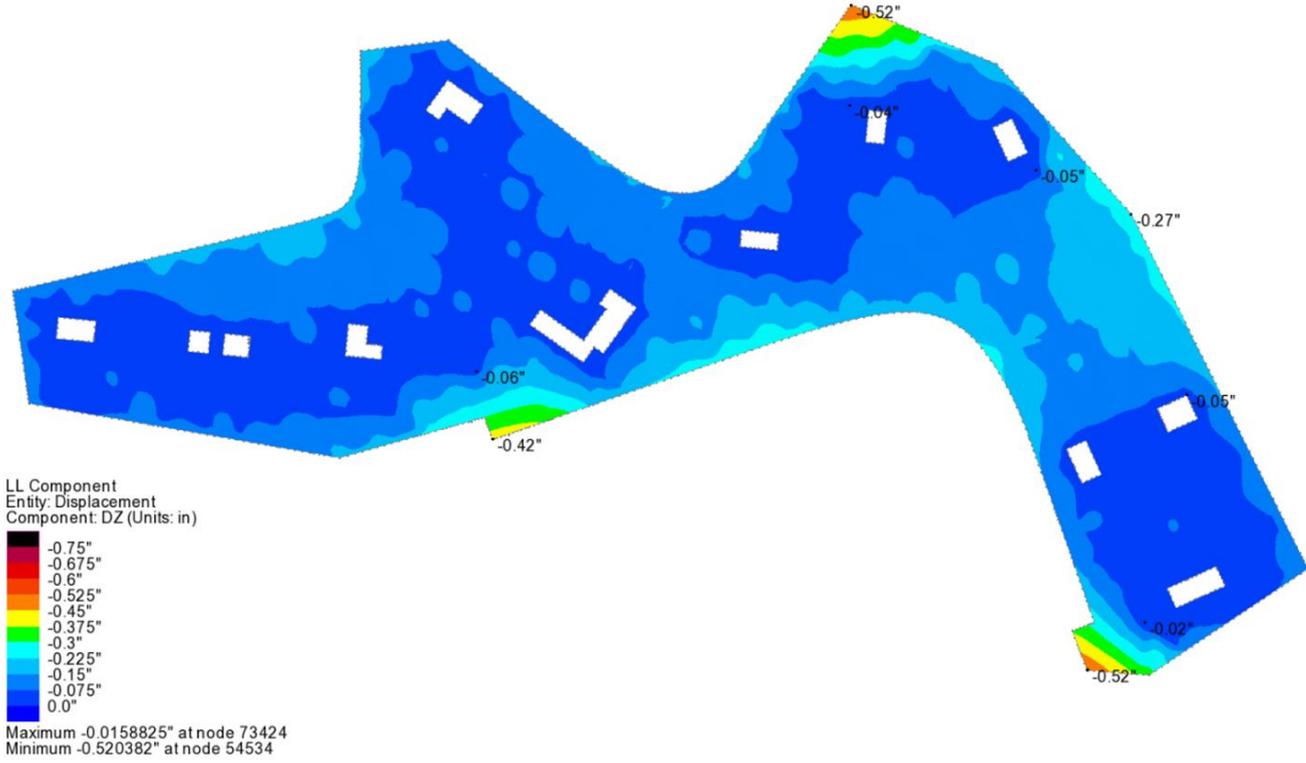


Tracking the Forces

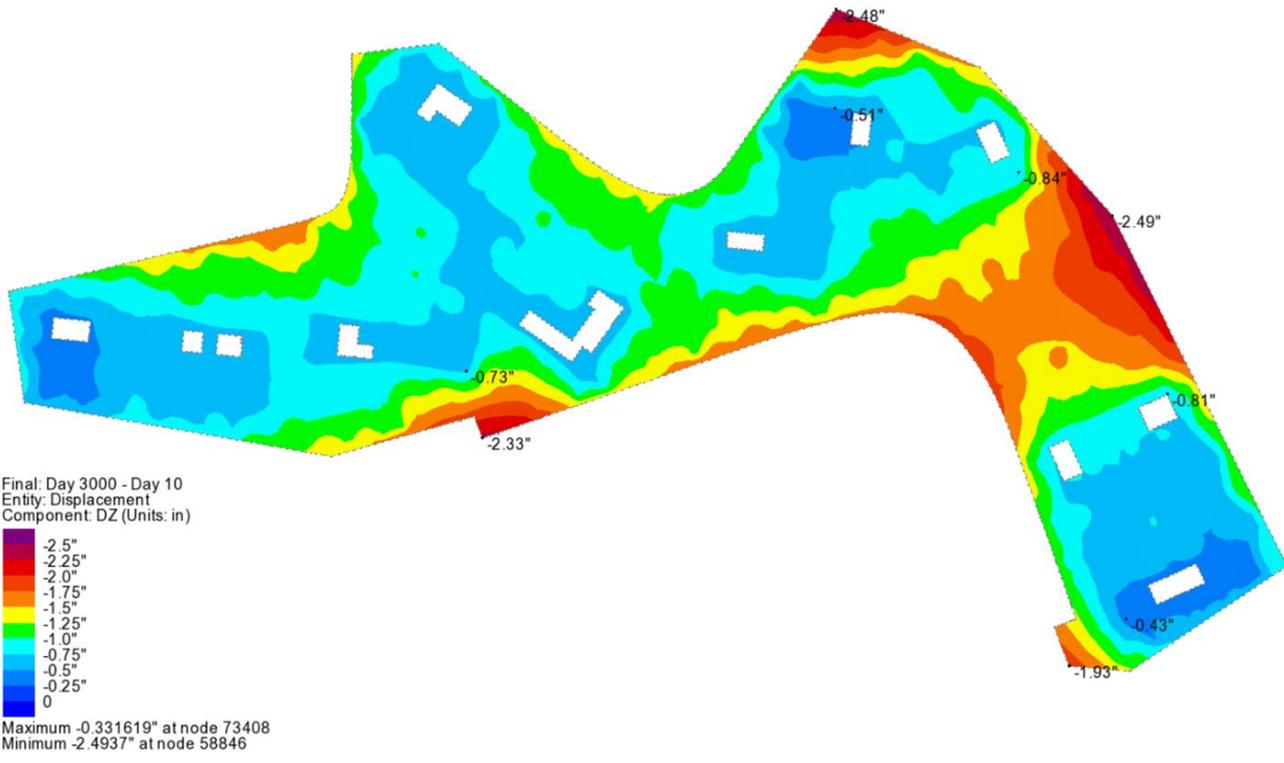
- Forces tracked by integrating over slices
- Multiple slices considered over the rib length



Deflection Analysis



Live Load Deflection

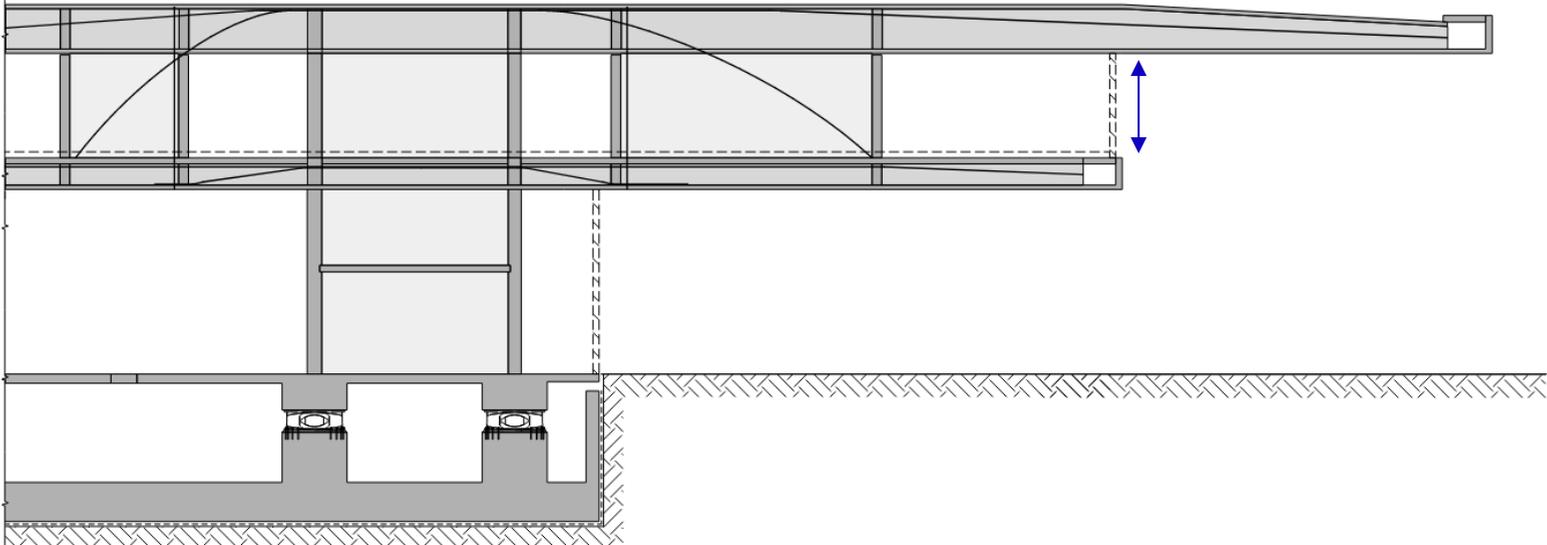


Long Term Deflection



Differential Deflection at Facade

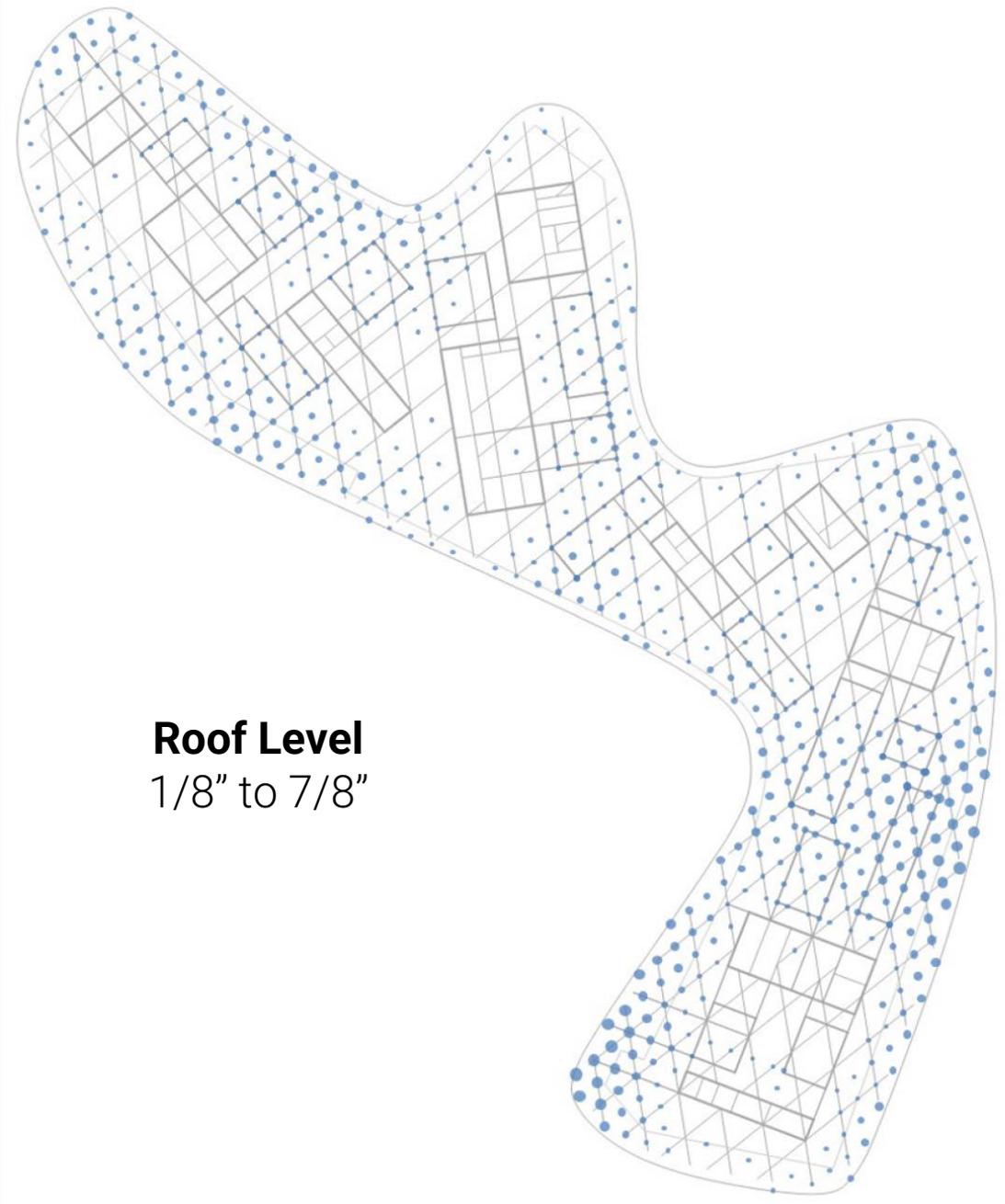
- Differential deflection between roof and exhibition levels needs to be within exterior wall tolerance



Camber

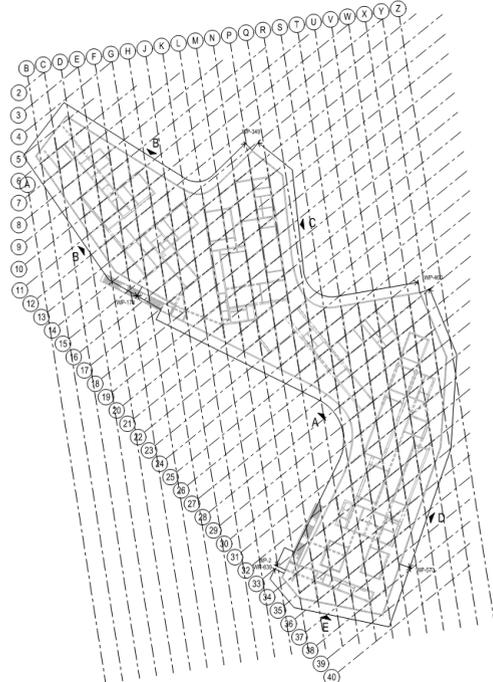


Exhibition Level
1/8" to 3/4"



Roof Level
1/8" to 7/8"

Expected Deflections



02 | KEY PLAN

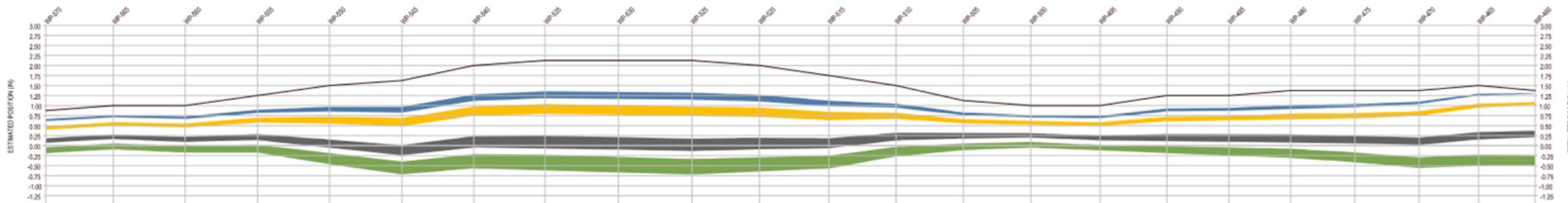
LEGEND:

- DESIGNED CONCRETE POSITION WHEN SHORED
- ESTIMATED CONCRETE POSITION AT EXTERIOR WALL INSTALLATION
- ESTIMATED CONCRETE POSITION AT FINISH FLOOR INSTALLATION
- ESTIMATED CONCRETE POSITION AT MUSEUM OPENING
- FINAL ESTIMATED CONCRETE POSITION

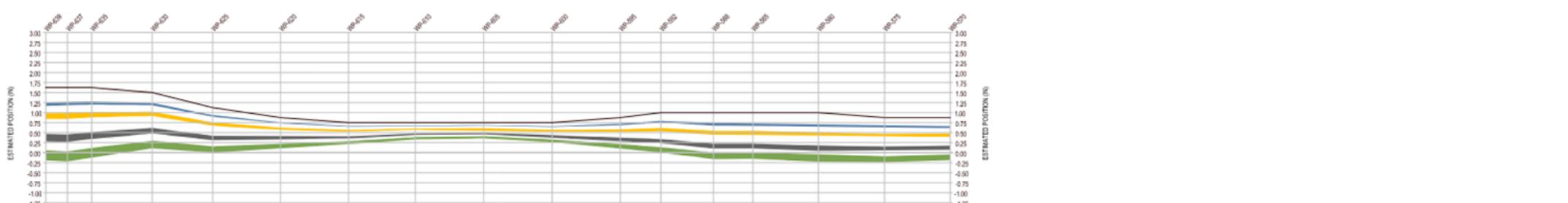
WP WORKPOINT, SEE S-102-S AND S-10R1-S FOR WP LOCATION



C ESTIMATED POSITION FROM WP-349 TO WP-460



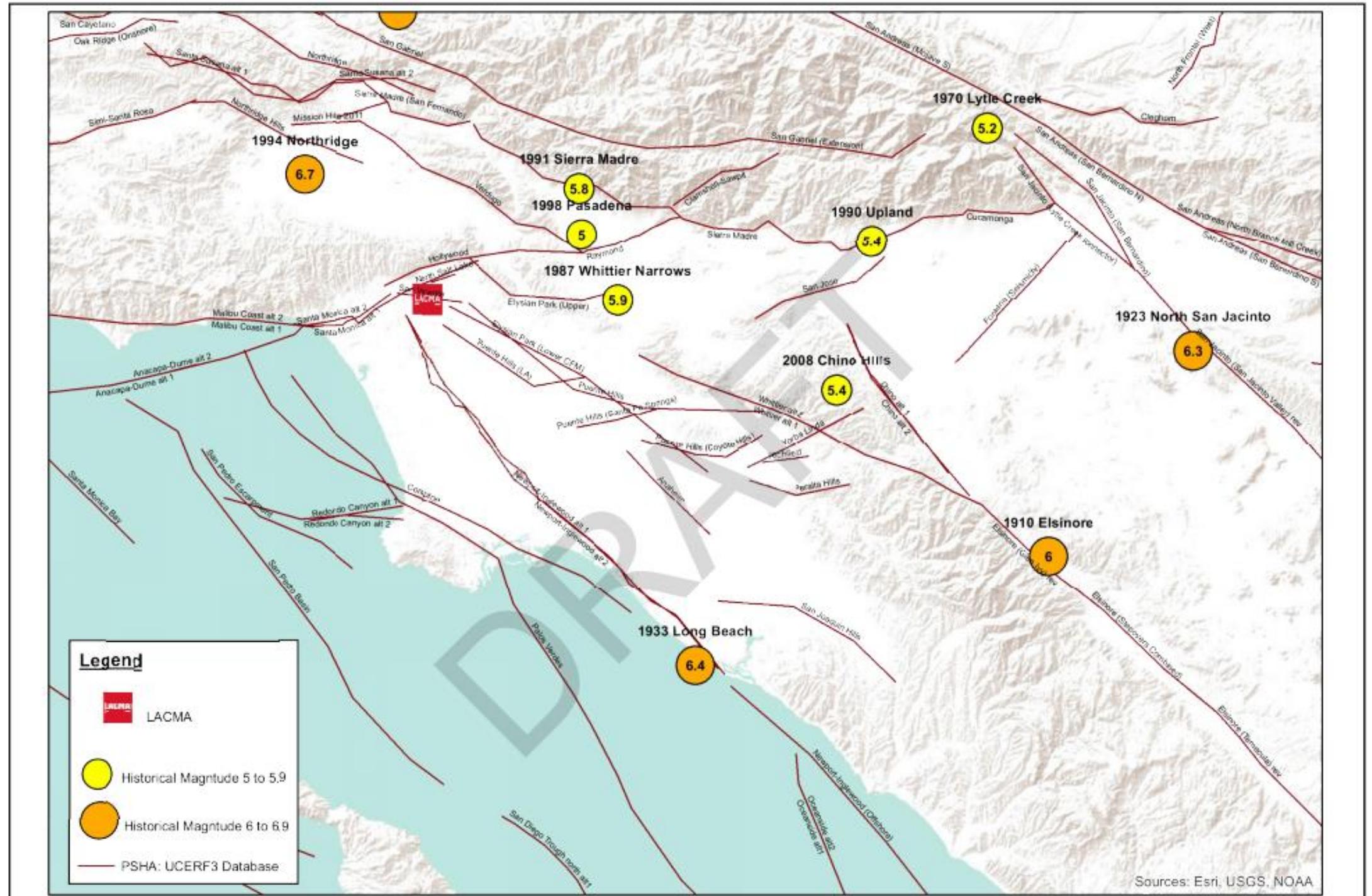
D ESTIMATED POSITION FROM WP-460 TO WP-570



E ESTIMATED POSITION FROM WP-570 TO WP-639



Seismicity

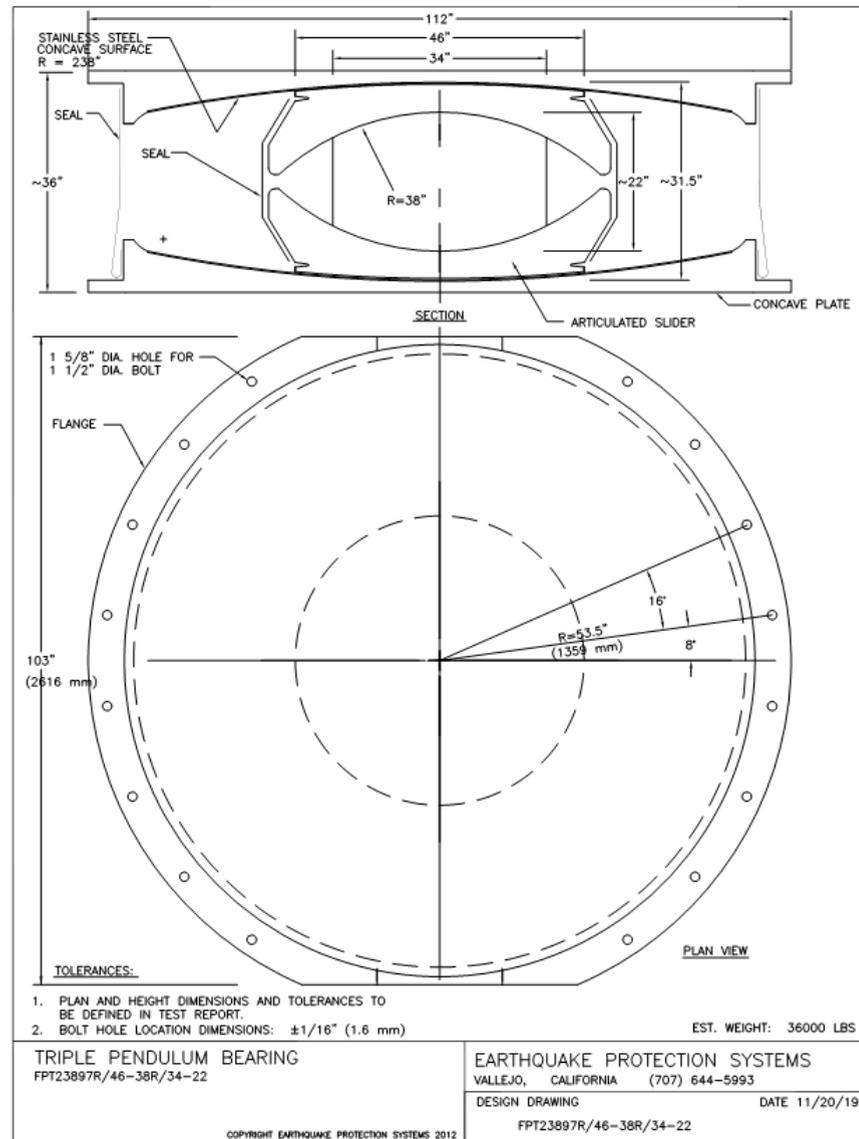


REGIONAL FAULT MAP

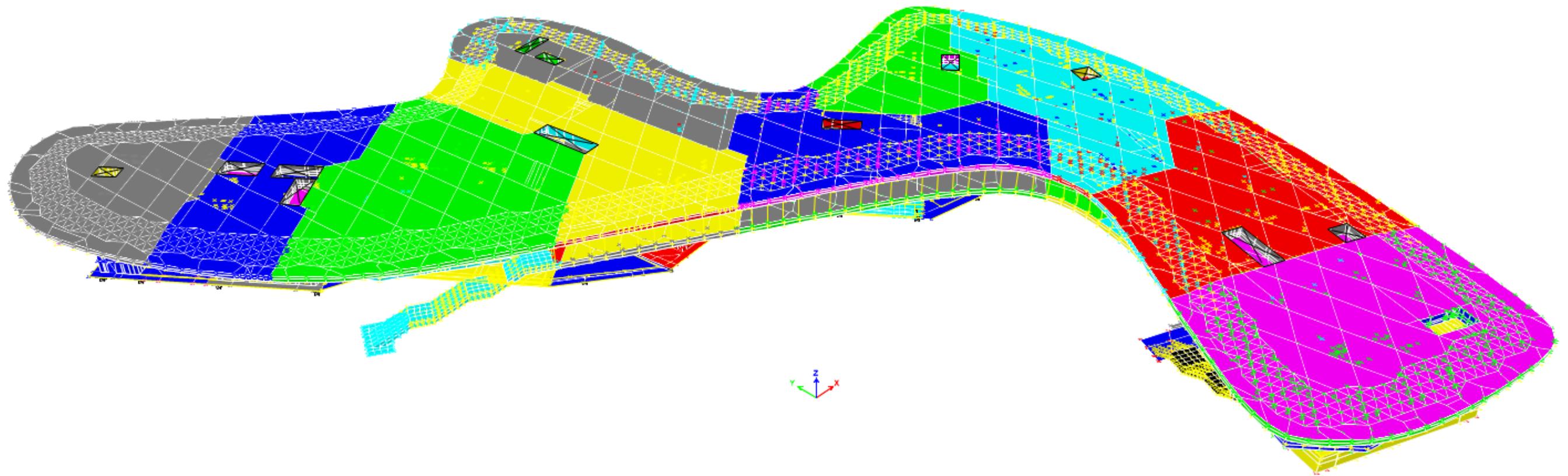
Phase III Transformation Project
 Los Angeles County Museum of Art
 5905 Wilshire Boulevard, Los Angeles, CA 90036



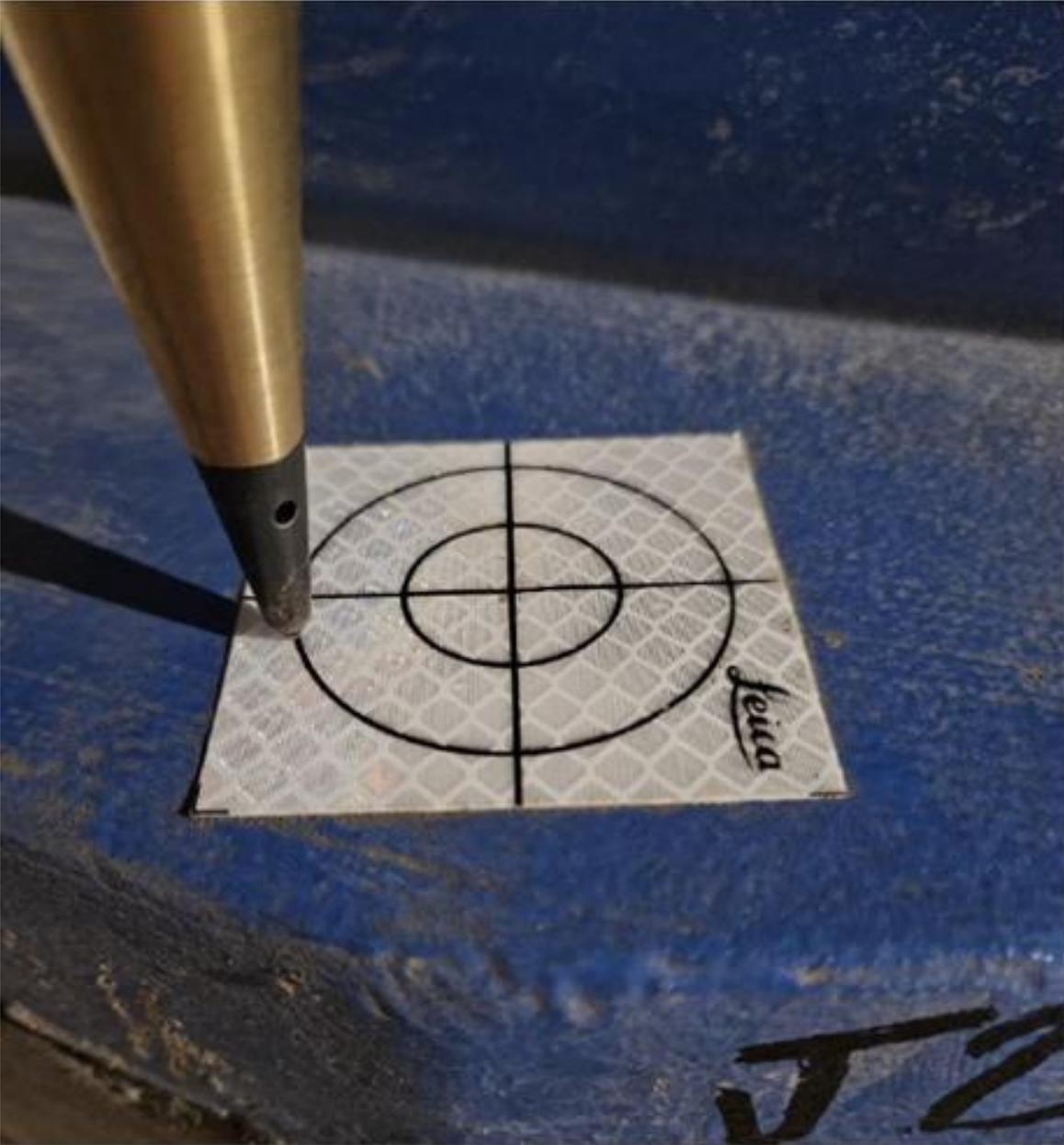
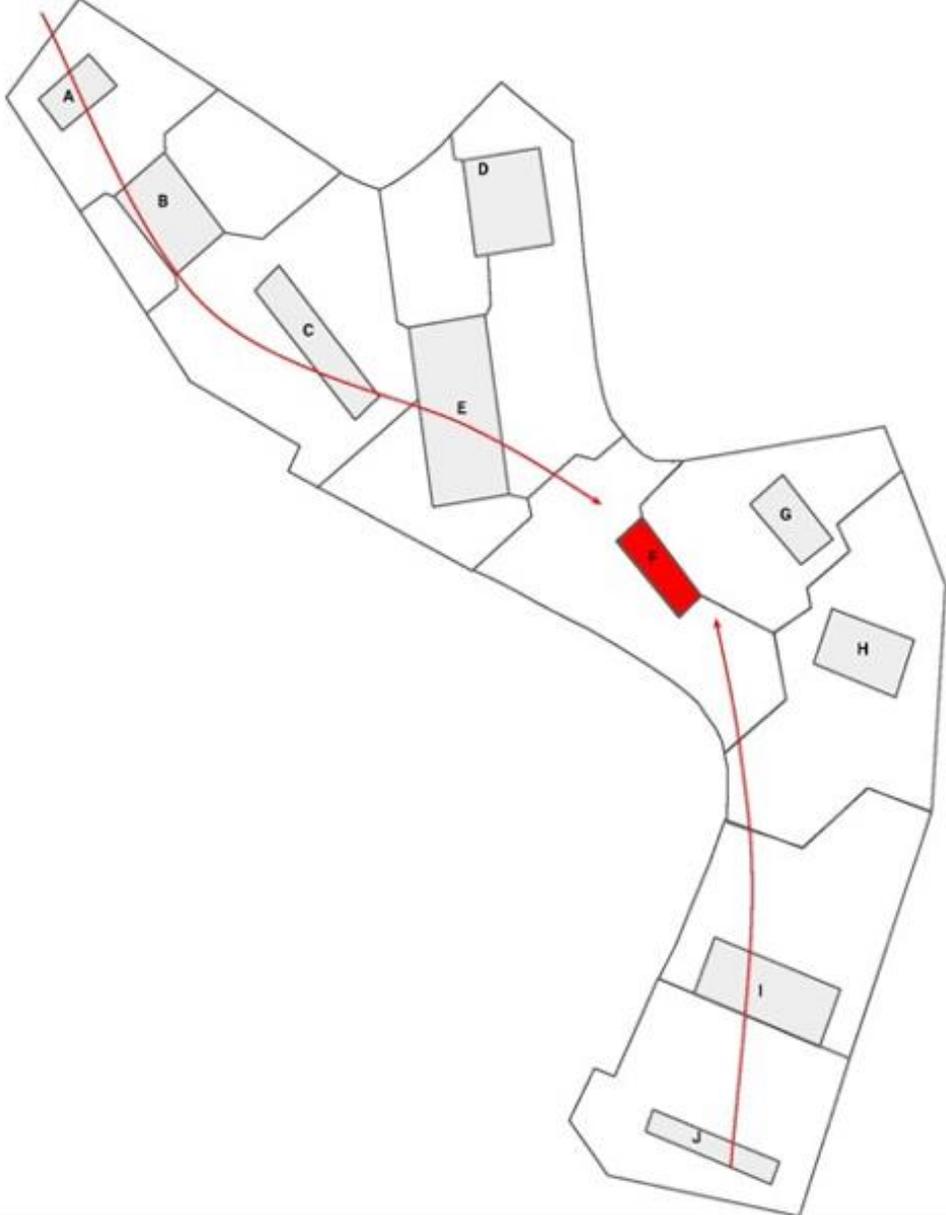
Horizontal Isolation Bearing



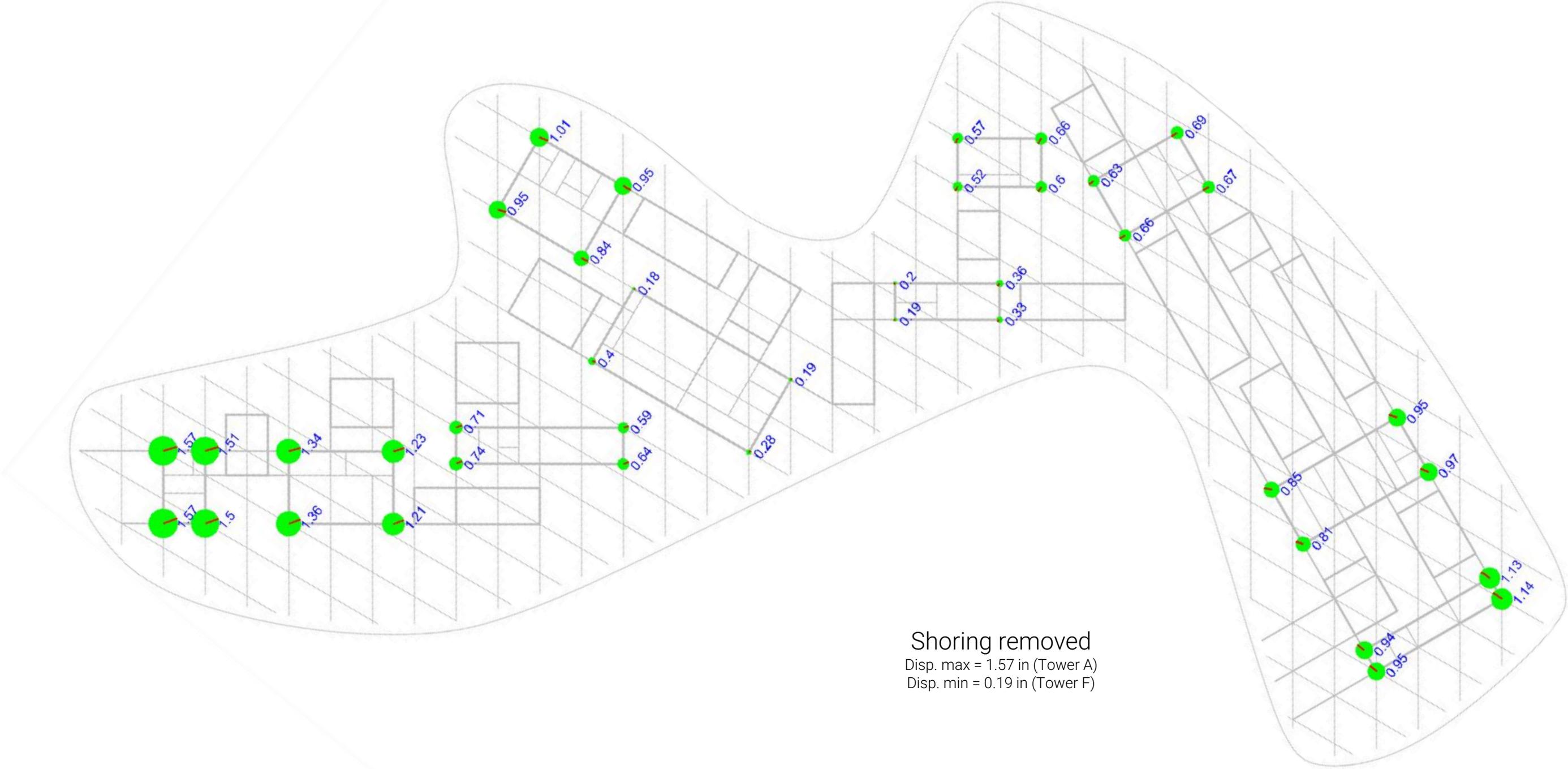
Shrinkage Analysis



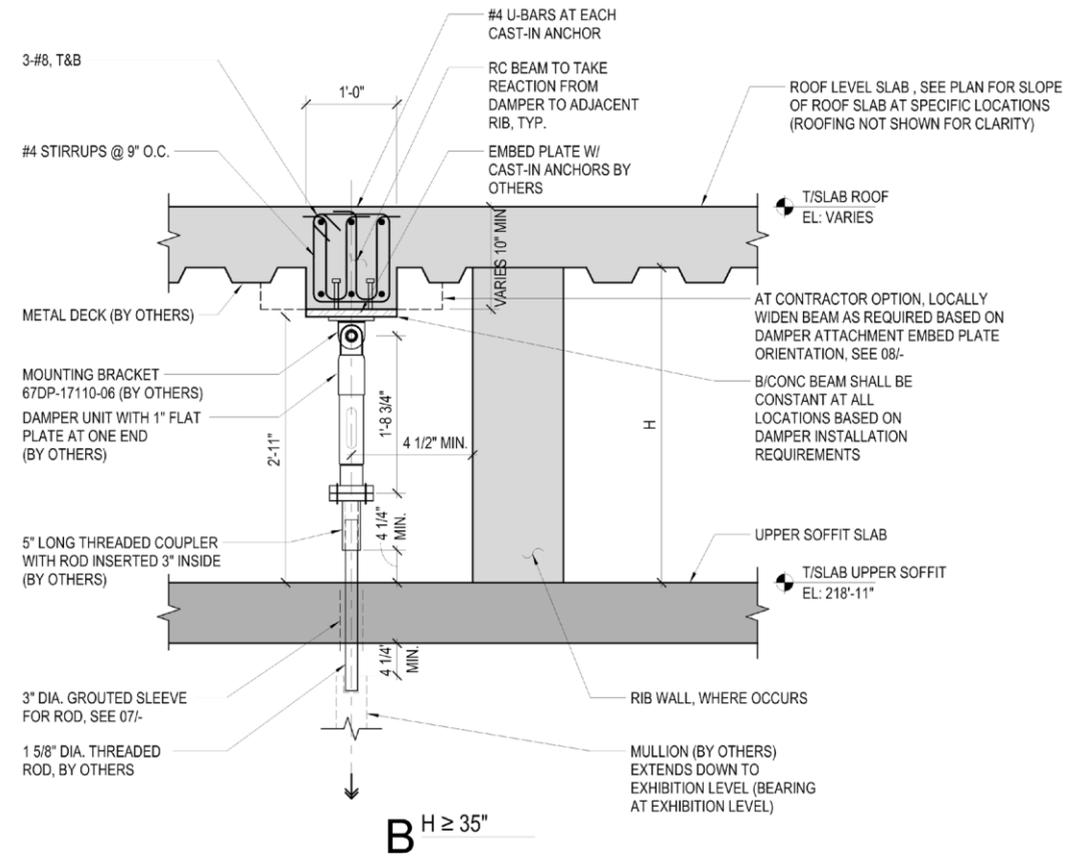
Isolator Locking Sequence



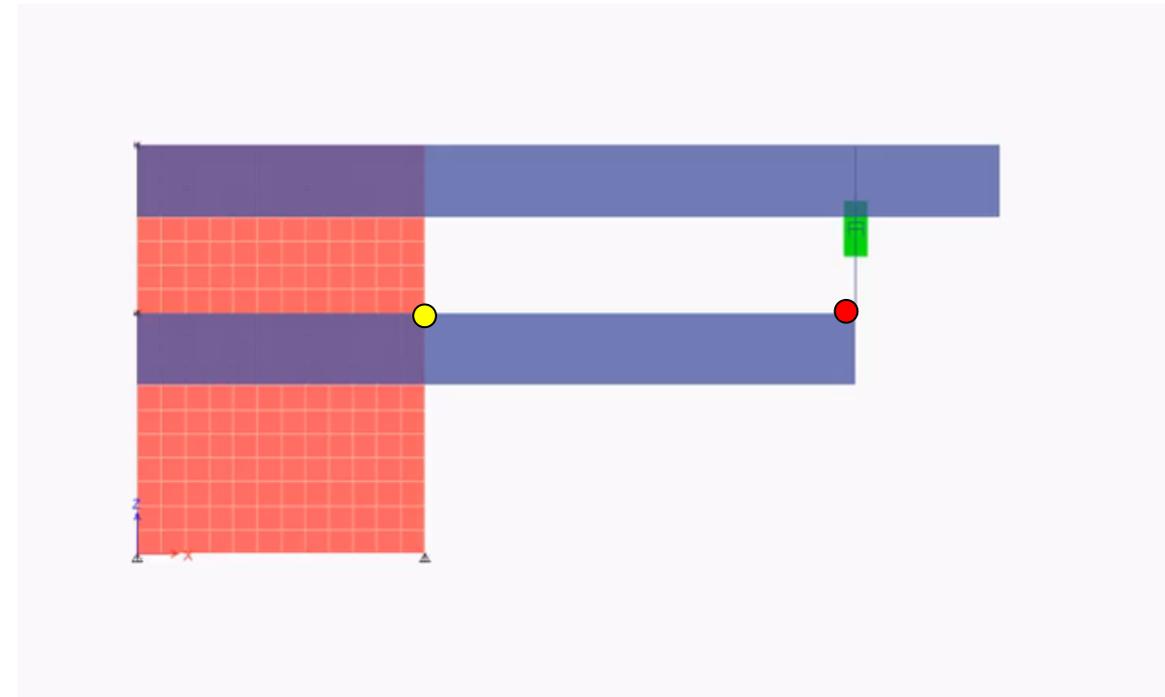
Isolator Displacements at Shoring Removal



Vertical Dampers

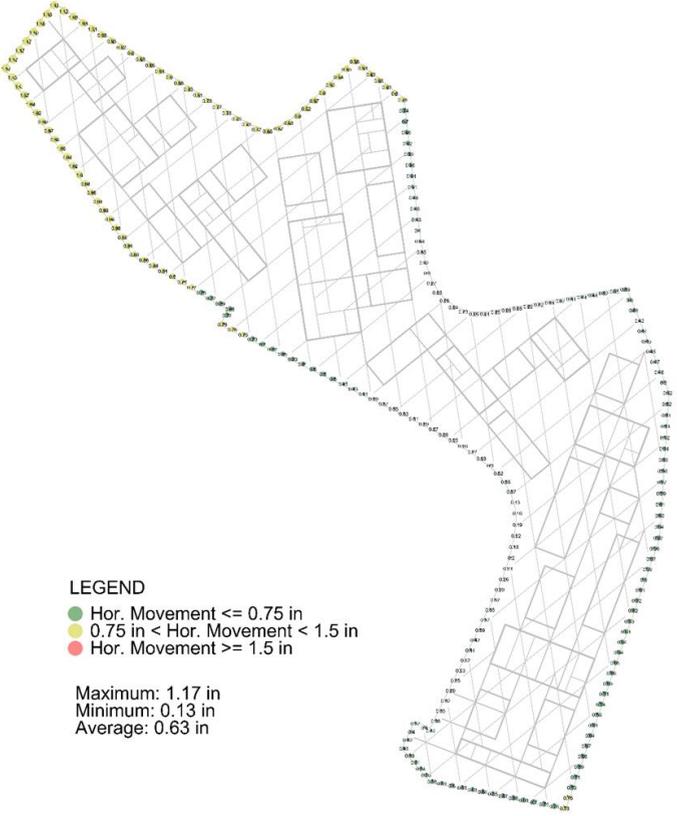


- NOTES:
1. SLAB REINFORCING NOT SHOWN FOR CLARITY. ROOF SLAB SLOPE VARIES, SEE PLAN.
 2. BOLTED CONNECTION AT BOTTOM OF DAMPER TO REMAIN LOOSE UNTIL GLASS AND ALL FINISHES ARE INSTALLED. FOR FINAL CONDITION, THREAD COUPLER PLATE UP TO CREATE FULL BEARING CONNECTION AND TIGHTEN BOLTS.
 3. DESIGN OF DAMPER ATTACHMENTS AND MULLIONS BY OTHERS.



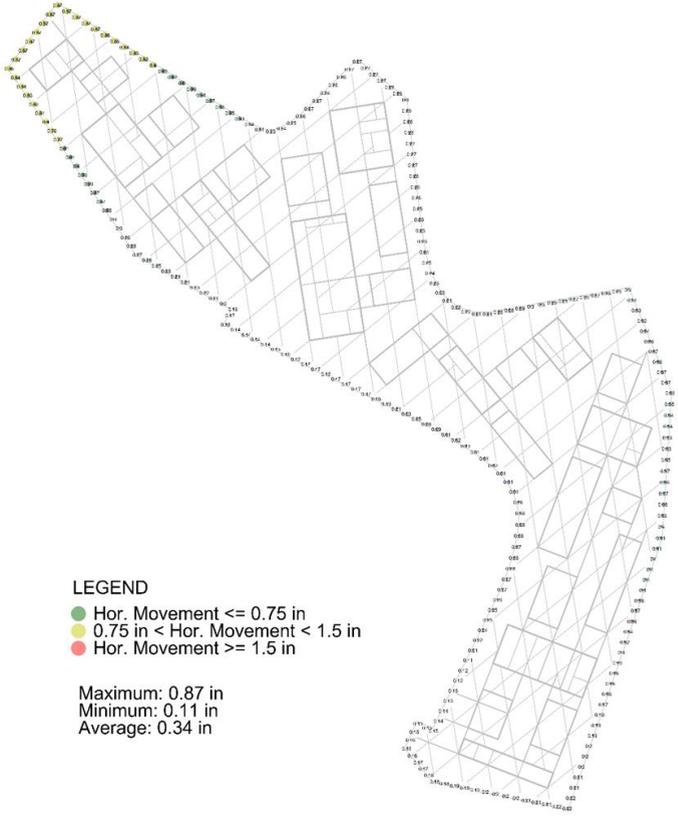
Exhibition Level Mullion Movements

Absolute Movement of mullion base between casting of concrete and setting of mullions [in]



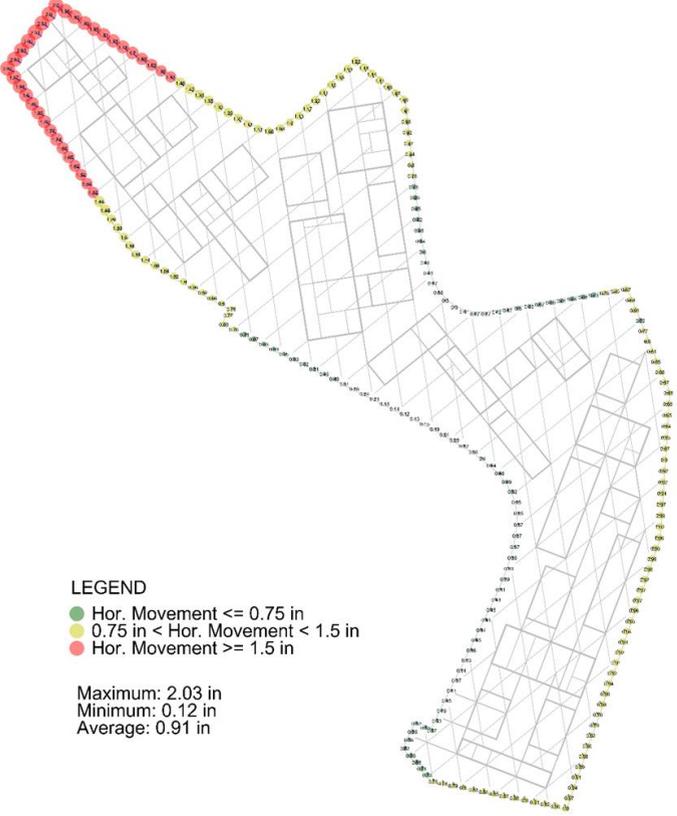
Start - Mid

Absolute Movement of mullion base between setting of mullions and 5 years after construction [in]



Mid - End

Absolute Movement of mullion base between casting of concrete and 5 years after construction [in]

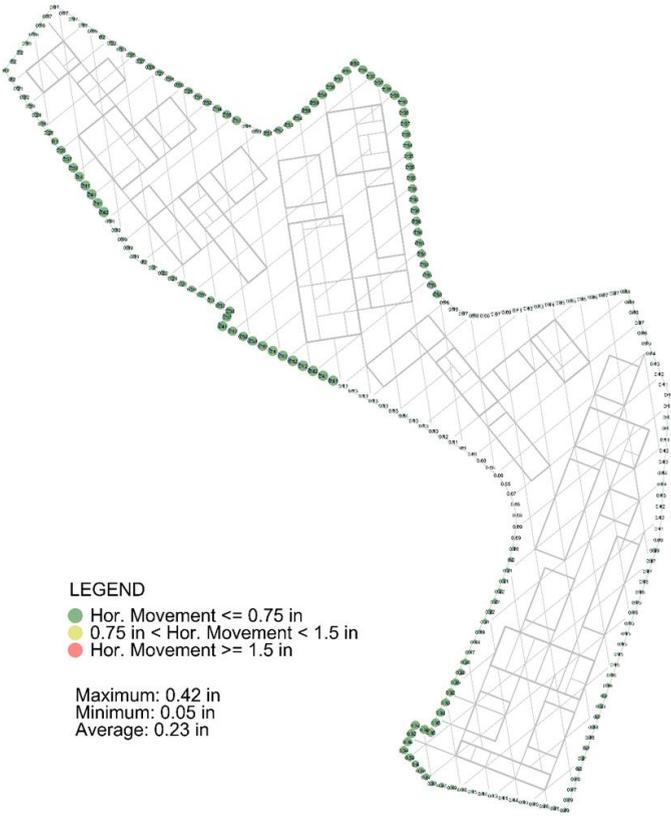


Start - End

- Legend**
- Start - casting of concrete
 - Mid - Setting of mullions
 - End - 5 years after construction

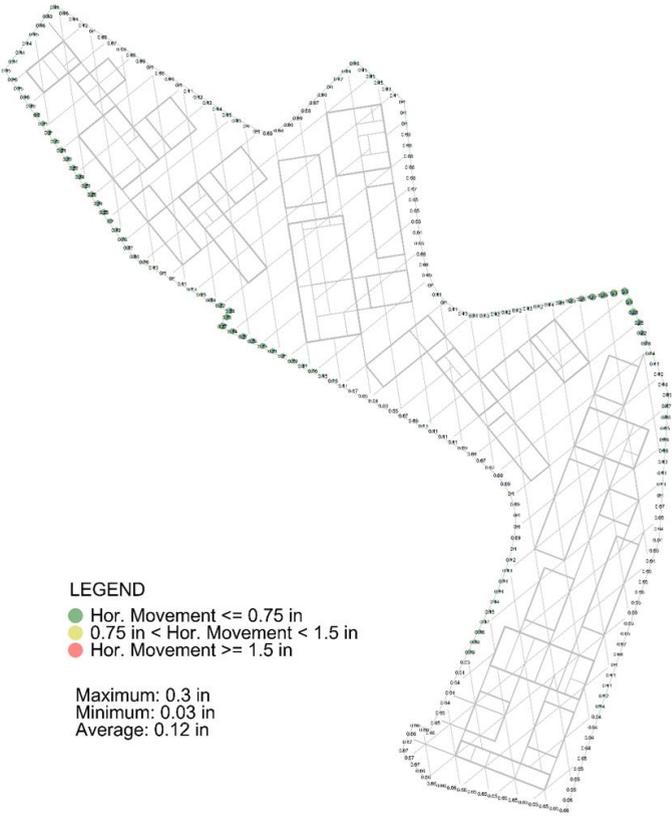
Relative Mullion Movements

Relative Movement of mullion ends between casting of concrete and setting of mullions [in]



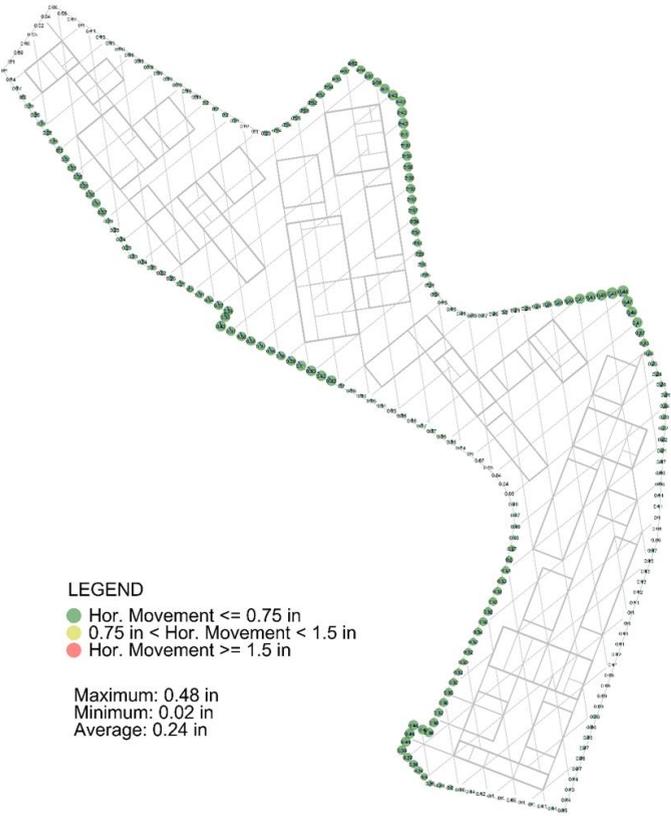
Start - Mid

Relative Movement of mullion ends between setting of mullions and 5 years after construction [in]



Mid - End

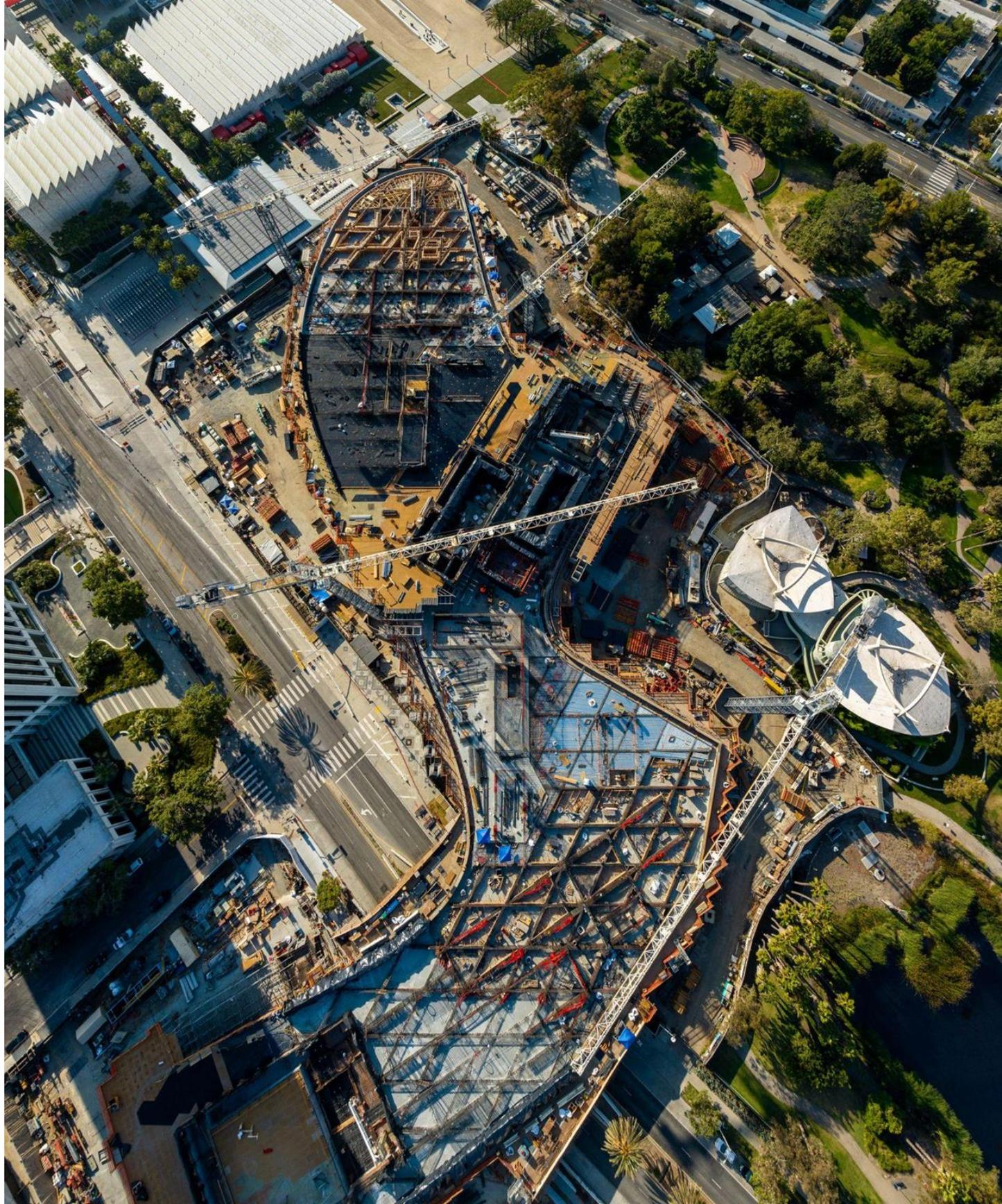
Relative Movement of mullion ends between casting of concrete and 5 years after construction [in]



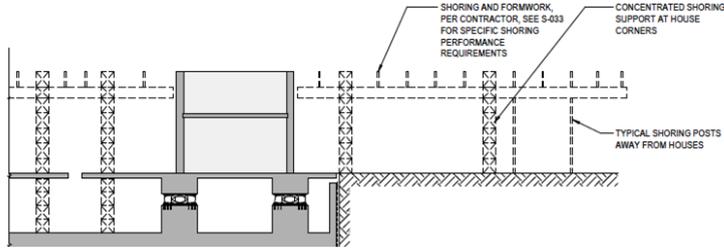
Start - End

- Legend**
- Start - casting of concrete
 - Mid - Setting of mullions
 - End - 5 years after construction

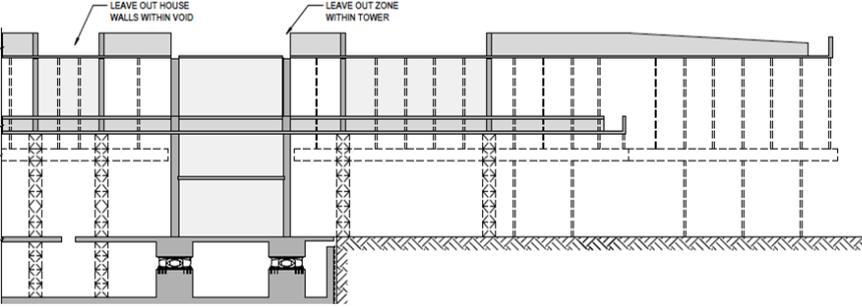
Construction Sequence



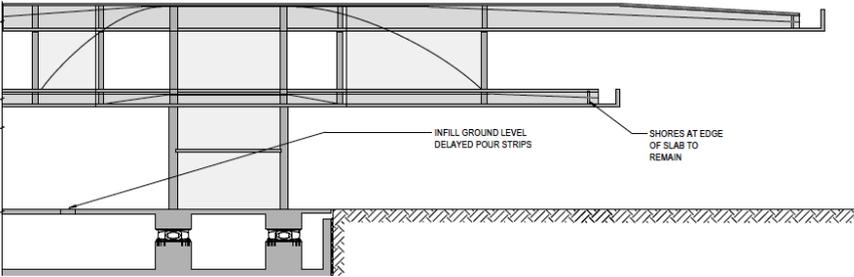
Vertical Construction Sequence



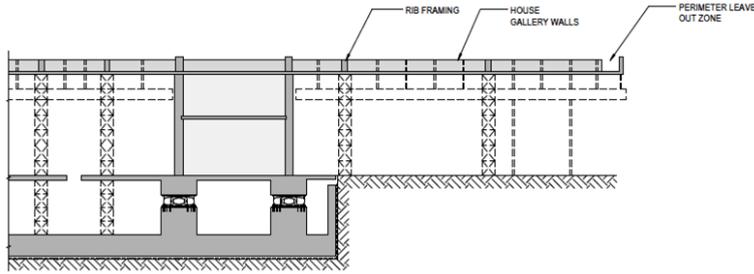
Install shoring system



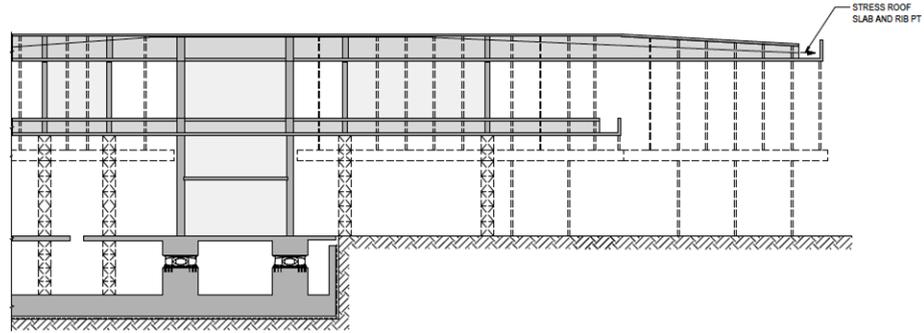
Pour roof ribs and leave out tower walls



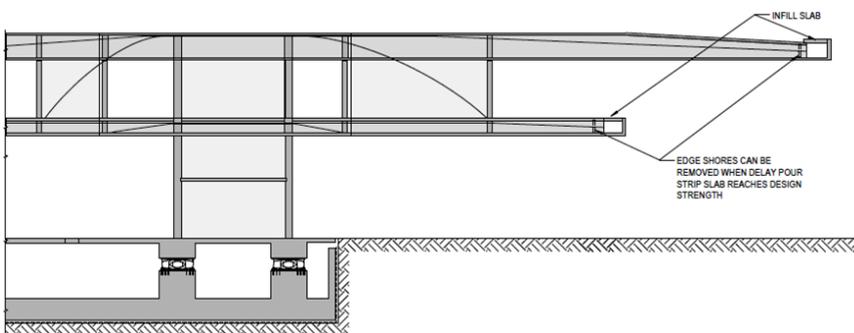
Break exhibition level shoring



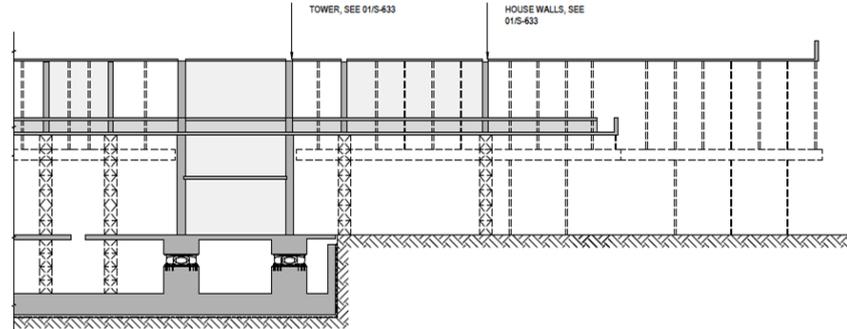
Pour exhibition level ribs



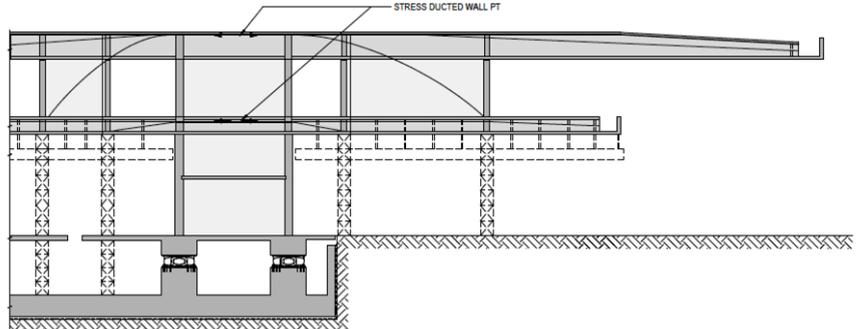
Stress roof rib and slab PT



Infill perimeter leave out strip

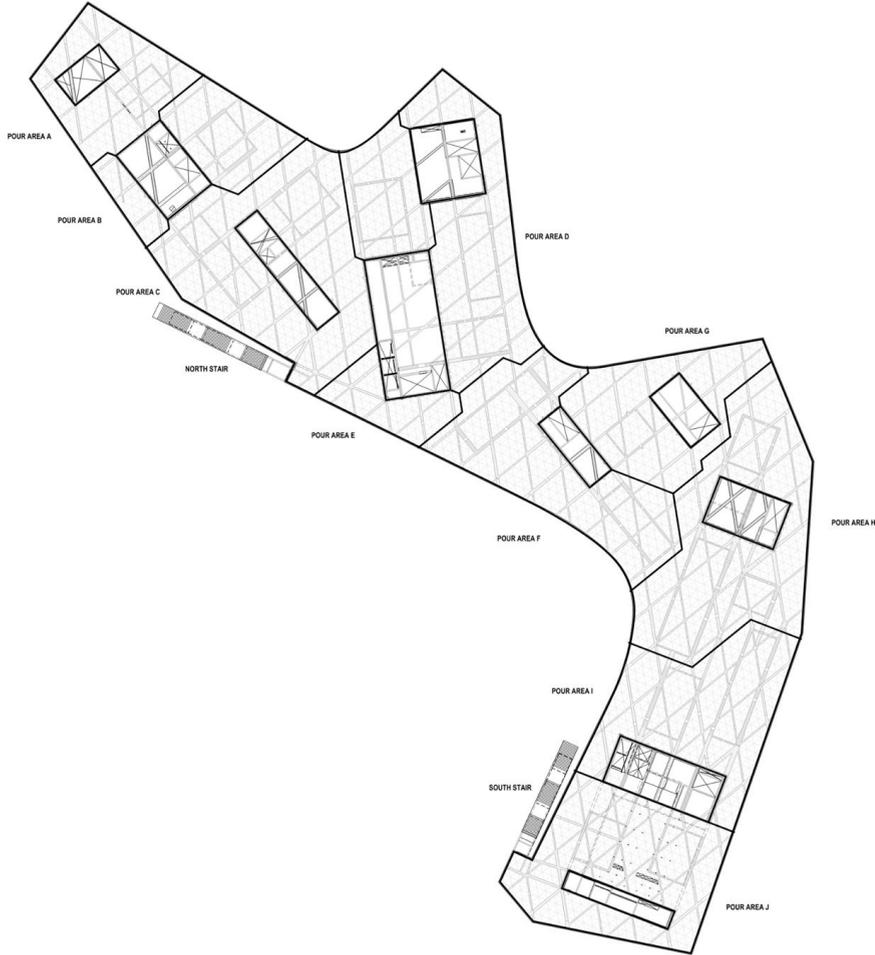


Pour upper soffit slab with delayed pour zones

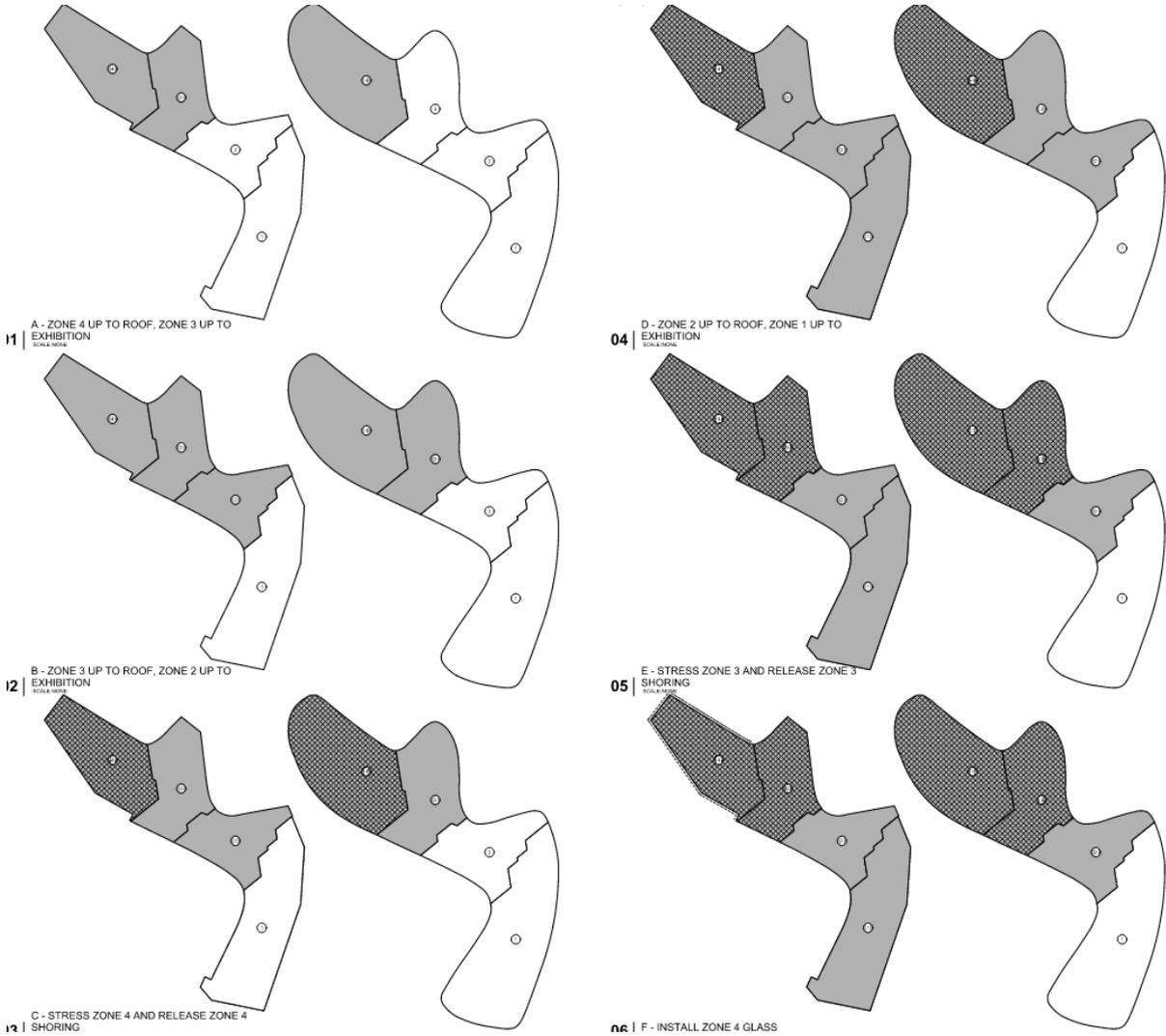


Stress wall PT

Horizontal Construction Sequence

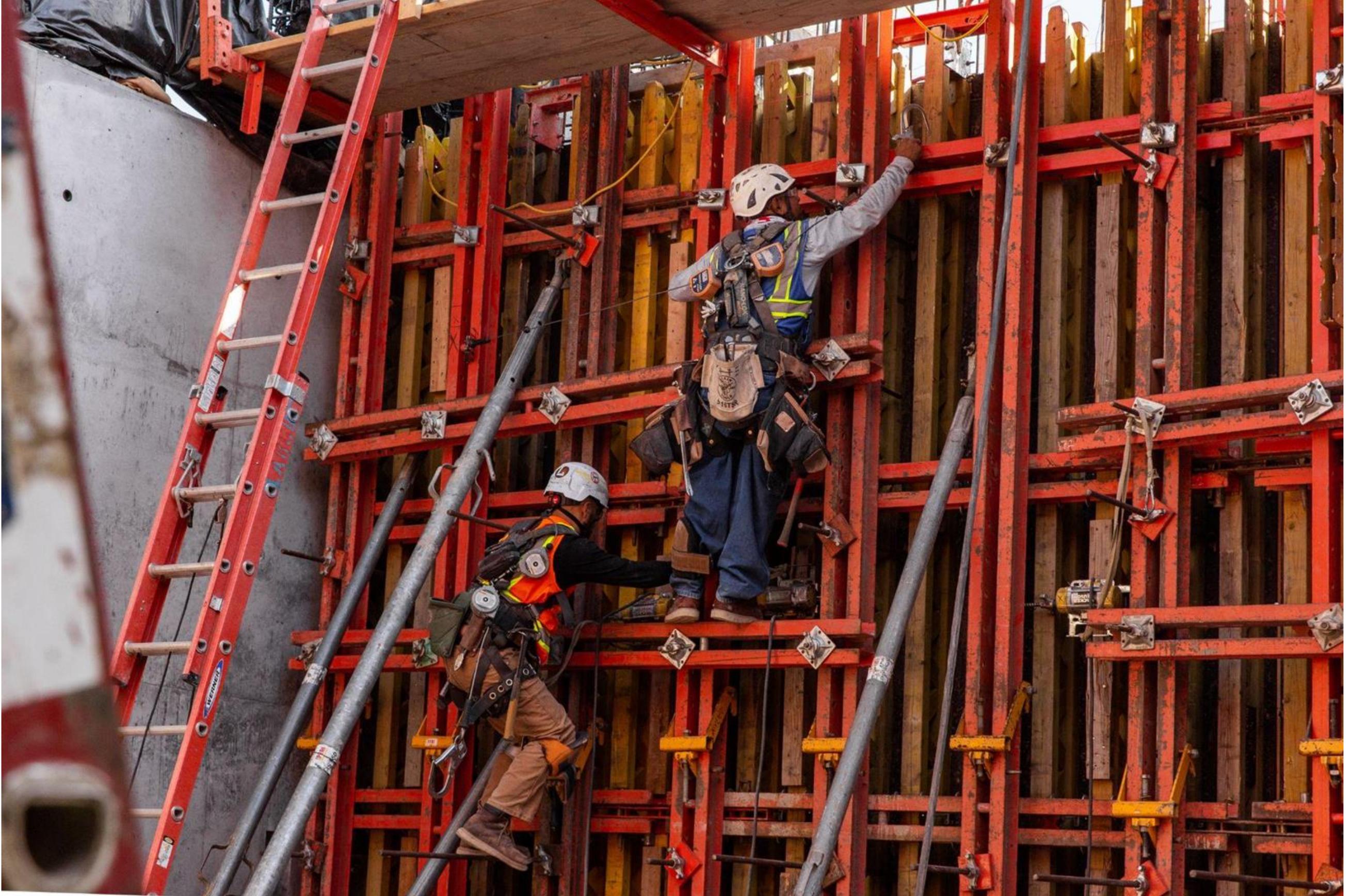


Concrete Pour Areas



PT Stressing Zones





















SOM