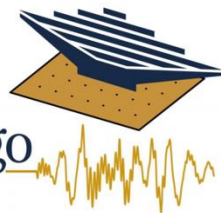




NHERI@
UC San Diego



American
Iron and Steel
Institute



PAPER ID#: 96

Structural Design Narrative of the CFS-NHERI 10-story Test Building for Multi-dimensional Shake Table Testing

Amanpreet Singh, Dr. Tara C. Hutchinson – *Univ. of California San Diego*

Dr. Shahab Torabian, Dr. Benjamin W. Schafer – *Johns Hopkins Univ.*

Dr. Kara D. Peterman – *Univ. of Massachusetts Amherst*

Lynn Padgett – *ClarkDietrich Engineering Services*, Harry Jones – *DCI Engineers*

JOHNS HOPKINS
UNIVERSITY

UC San Diego

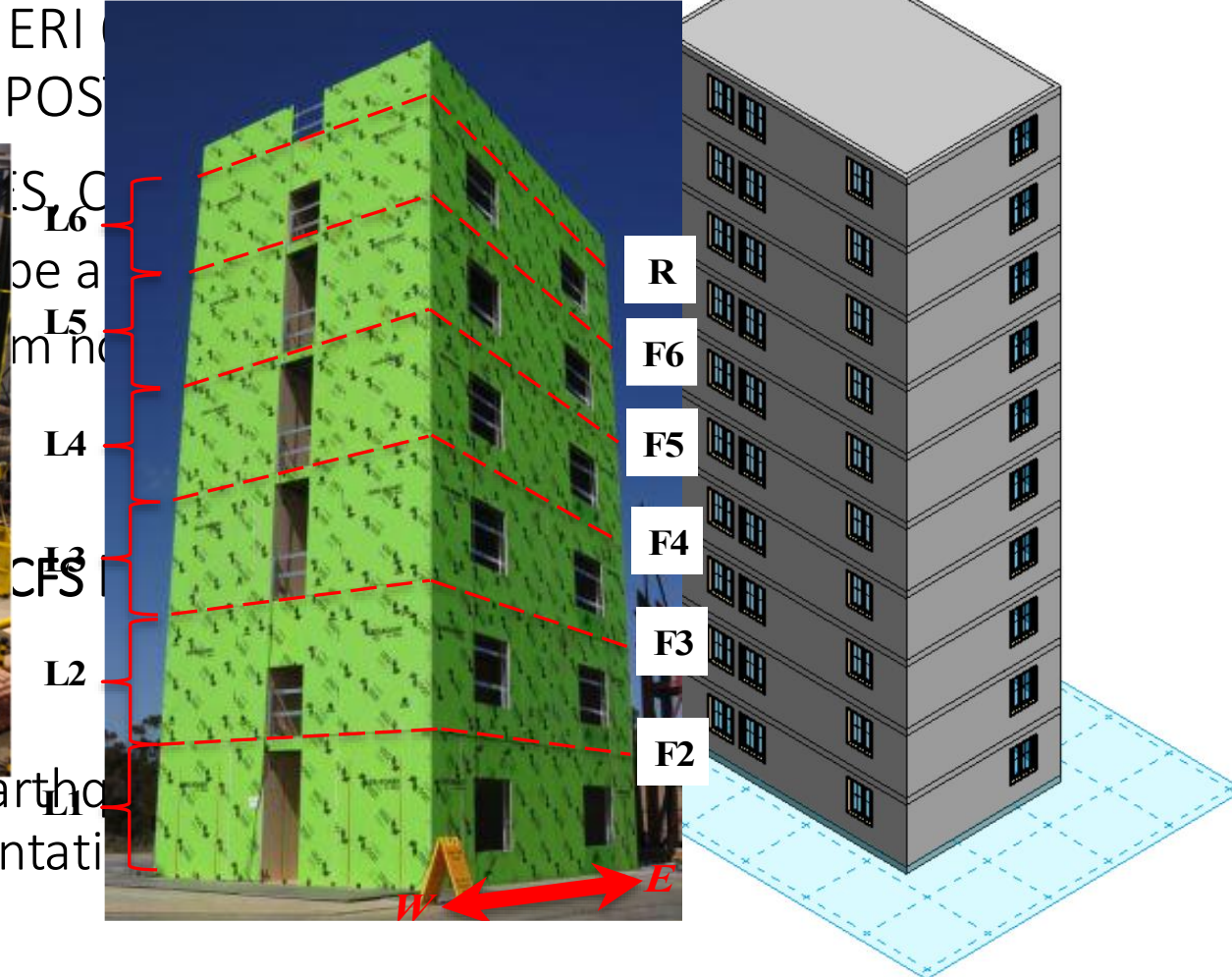
UMassAmherst



CFS-NHERI COLLOQUIUM
2022

CFS-NHERI Building Test: *Planned for 2024*

- 10-story CFS framed building test at the NHERI High Performance Outdoor Shake Table (LHPOS)
- Previous work
 - Demonstrated the feasibility of testing a full-scale CFS building on a shake table
 - High performance of CFS buildings under seismic loading
- CFS-NHERI Building Test
 - Provide experimental data for validation of CFS building performance
 - Investigate the seismic response of a full-scale CFS building
 - Multi-directional seismic response, post-earthquake damage assessment, and post-fire earthquake performance documentation
 - Code improvements



NHERI@UC San Diego: *Upgraded 6DOF configuration*



Platen size	12.2 m × 7.6 m (40 ft × 25 ft)		
Frequency Bandwidth	0 – 33 Hz		
Vertical Payload Capacity	20 MN (4,500 kip)		
	Horizontal X	Horizontal Y	Vertical Z
Peak Translational Displacement	±0.89 m (±35 in)	±0.38 m (±15 in)	±0.127 m (±5 in)
Peak Translational Velocity	2.5 m/sec (100 in/sec)	2.0 m/sec (80 in/sec)	0.6 m/sec (25 in/sec)
Peak Translational Force*	10.6 MN (2,380 kip)	8.38 MN (1,890 kip)	54.8 MN** (12,300 kip)
Peak Rotation*	2.2 deg	1.5 deg	4.0 deg
Peak Rotational Velocity*	21.0 deg/sec	12.4 deg/sec	40.5 deg/sec
Peak Moment*	37.2 MN-m (27,400 kip-ft)	49.0 MN-m (36,200 kip-ft)	47.0 MN-m (34,600 kip-ft)
Overturning Moment Capacity	45.1 MN-m (33,200 kip-ft)	50.0 MN-m (36,900 kip-ft)	

* peak demand obtained during sinusoidal motions

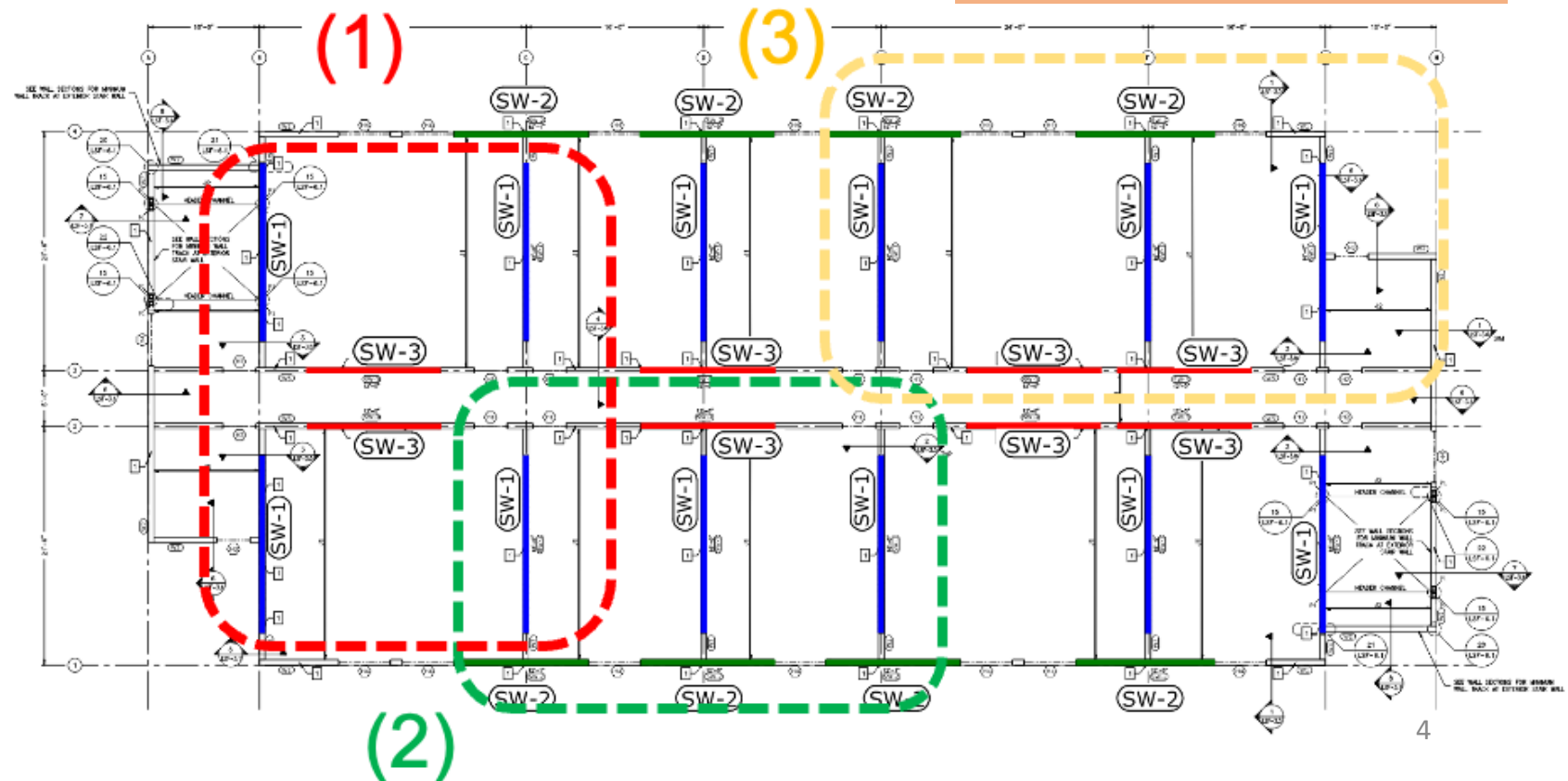
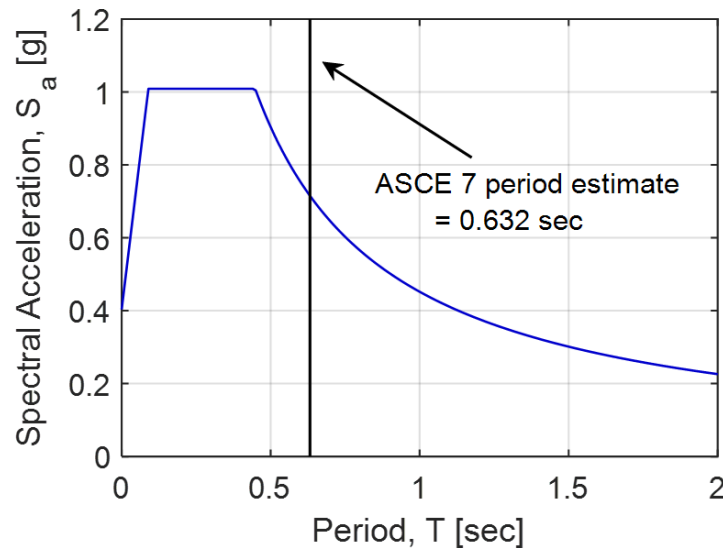
** peak compressive force in the compression-only vertical actuators

**Table loaded with
rigid payload of
1,100 kips (5 MN)**

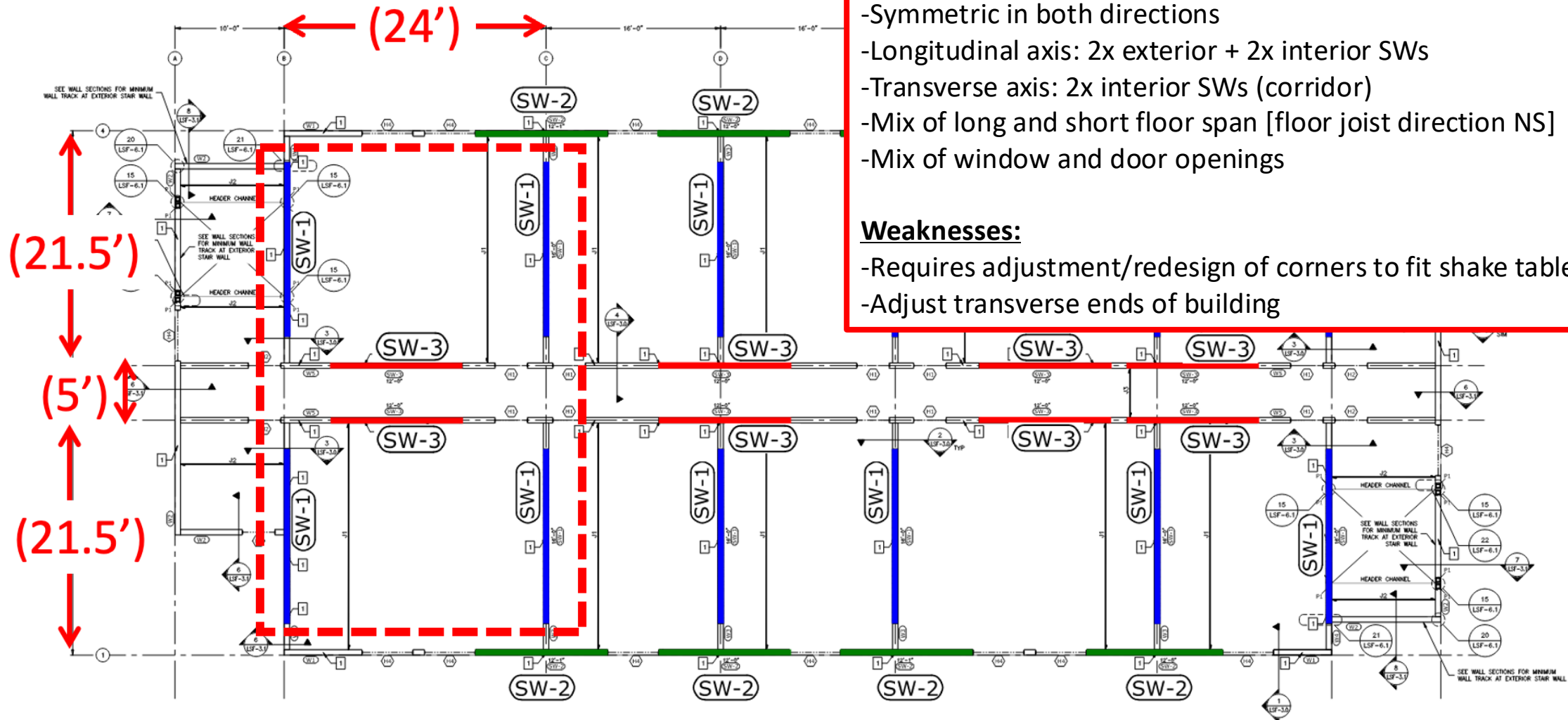
Archetype Building

- Test building design guided by larger archetype building (plan area = 116ft x 48ft)
- Design location = Irvine, CA ($S_{DS} = 1.009g$, $S_{D1} = 0.452g$)
- Lateral force resisting system = steel sheet sheathed SWs
- Ledger framing for floor-to-wall connections
- $R = 6.5$, $\Omega_o = 3.0$, $C_d = 4.0$

Test building to fit shake table platen area 40ft x 25ft



Archetype Building: *Slice Option 1*



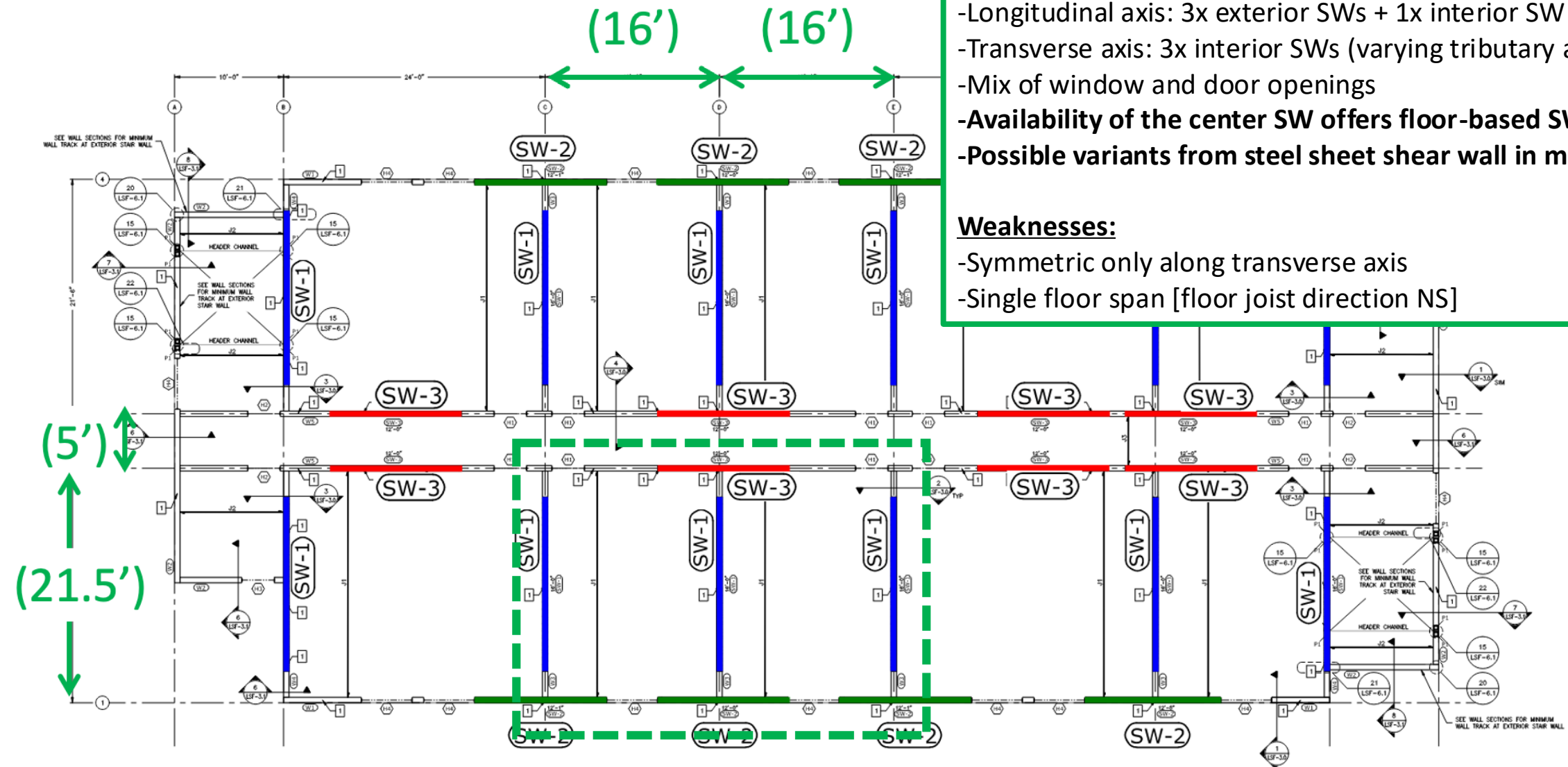
Strengths:

- Symmetric in both directions
- Longitudinal axis: 2x exterior + 2x interior SWs
- Transverse axis: 2x interior SWs (corridor)
- Mix of long and short floor span [floor joist direction NS]
- Mix of window and door openings

Weaknesses:

- Requires adjustment/redesign of corners to fit shake table
- Adjust transverse ends of building

Archetype Building: *Slice Option 2*



Strengths:

- Longitudinal axis: 3x exterior SWs + 1x interior SW (corridor)
- Transverse axis: 3x interior SWs (varying tributary area)
- Mix of window and door openings
- Availability of the center SW offers floor-based SW comparison**
- Possible variants from steel sheet shear wall in middle SW**

Weaknesses:

- Symmetric only along transverse axis
- Single floor span [floor joist direction NS]

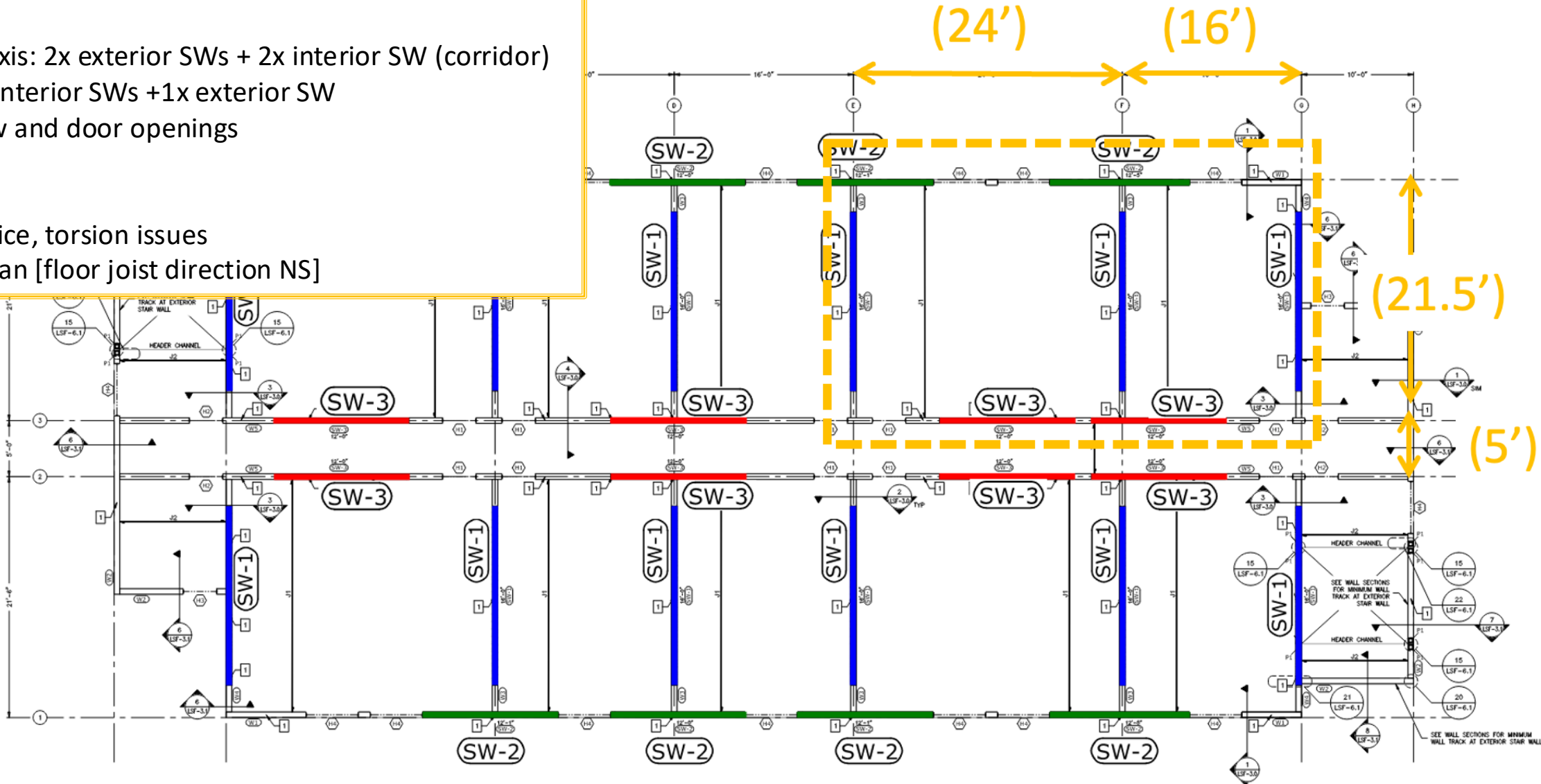
Archetype Building: *Slice Option 3*

Strengths:

- Longitudinal axis: 2x exterior SWs + 2x interior SW (corridor)
- Trans axis: 2x interior SWs + 1x exterior SW
- Mix of window and door openings

Weaknesses:

- Asymmetric slice, torsion issues
- Single floor span [floor joist direction NS]



Shear Walls: *Story-to-story Detail Options*

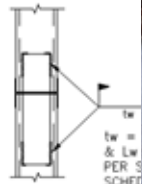
- Hold-down: direct (through track) chord stud connection



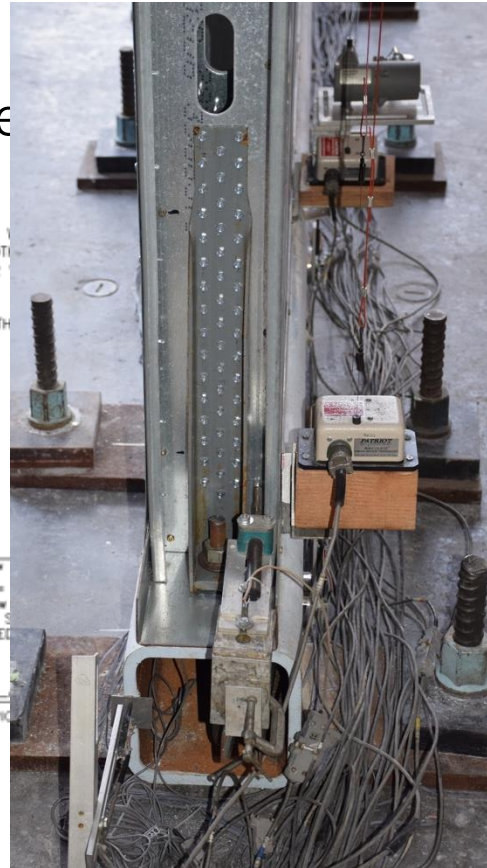
Hold-down on CFS chord stud (**CFS-NEES**)

- Plate

HOLDOWN
(TYPICAL BOTTOM SHEAR)
TRIM WALL TRACK TO
PLATE TO PASS TH



7 PL
TYPICAL

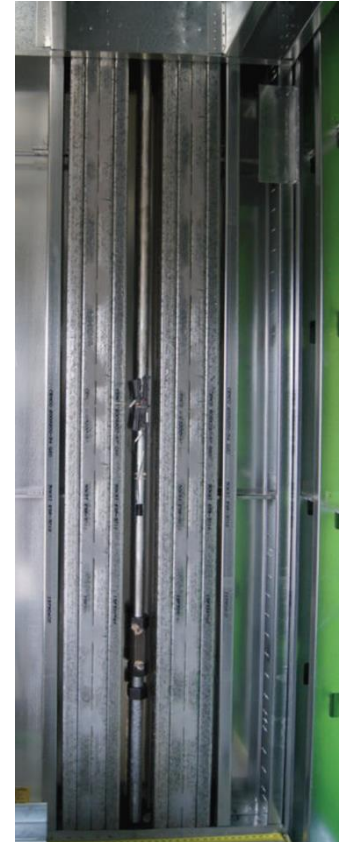


Shear walls with hold-downs and tie-rods
(**CFS-NHERI wall-line tests**)

- Tension tie-rod: continuous connection



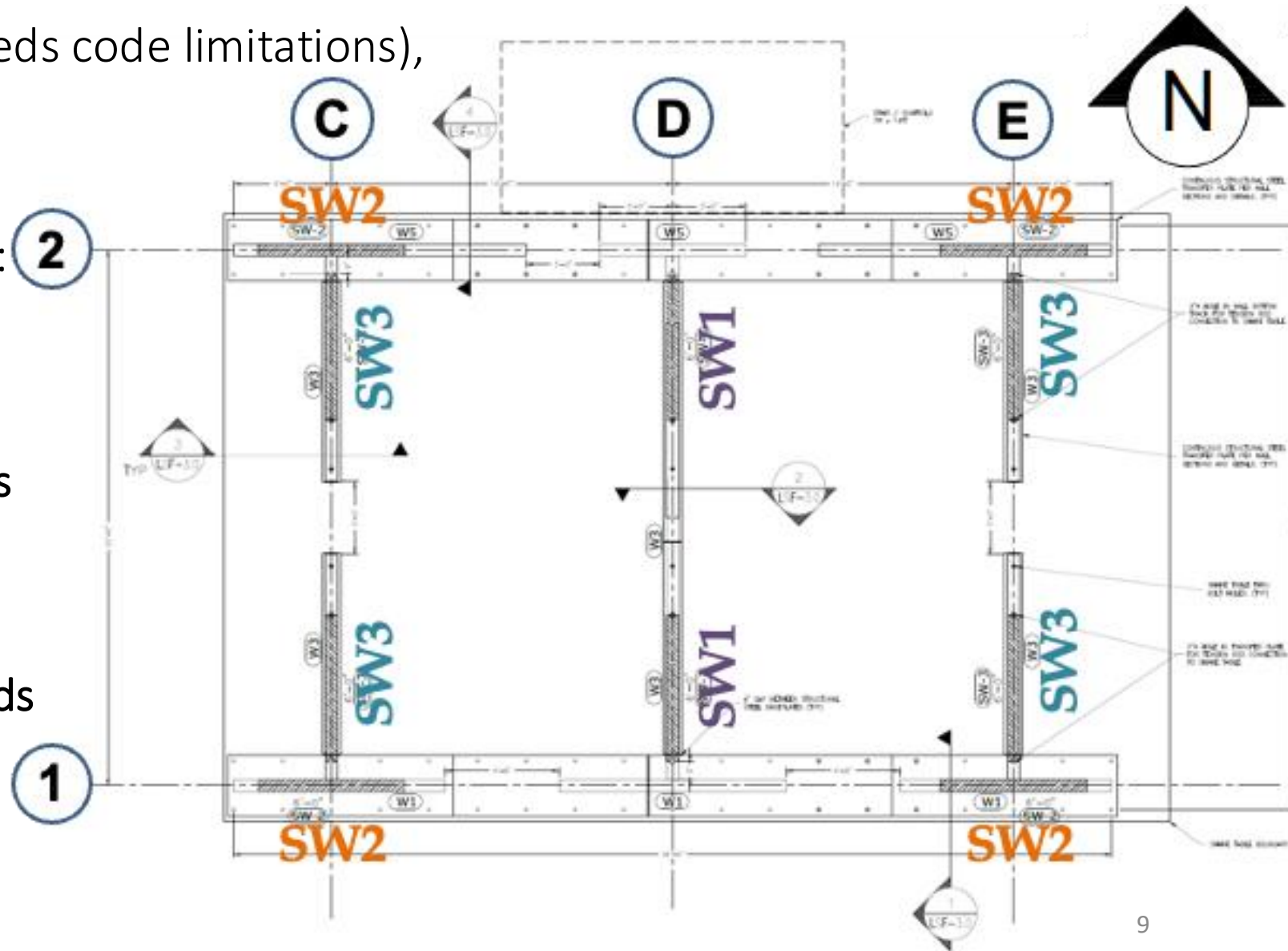
B7 1 3/8" ATR (10')
1 3/8" - 1 3/4" GR8 CPL
NT-GR8-14
PL 4.5" x 8" x 1 1/2" (ϕ = 2")
B7 1 3/4" ZROD (10')
1 3/4" GR8 CPL
NT-GR8-14
PL 4.5" x 8" x 1 1/2" (ϕ = 2")



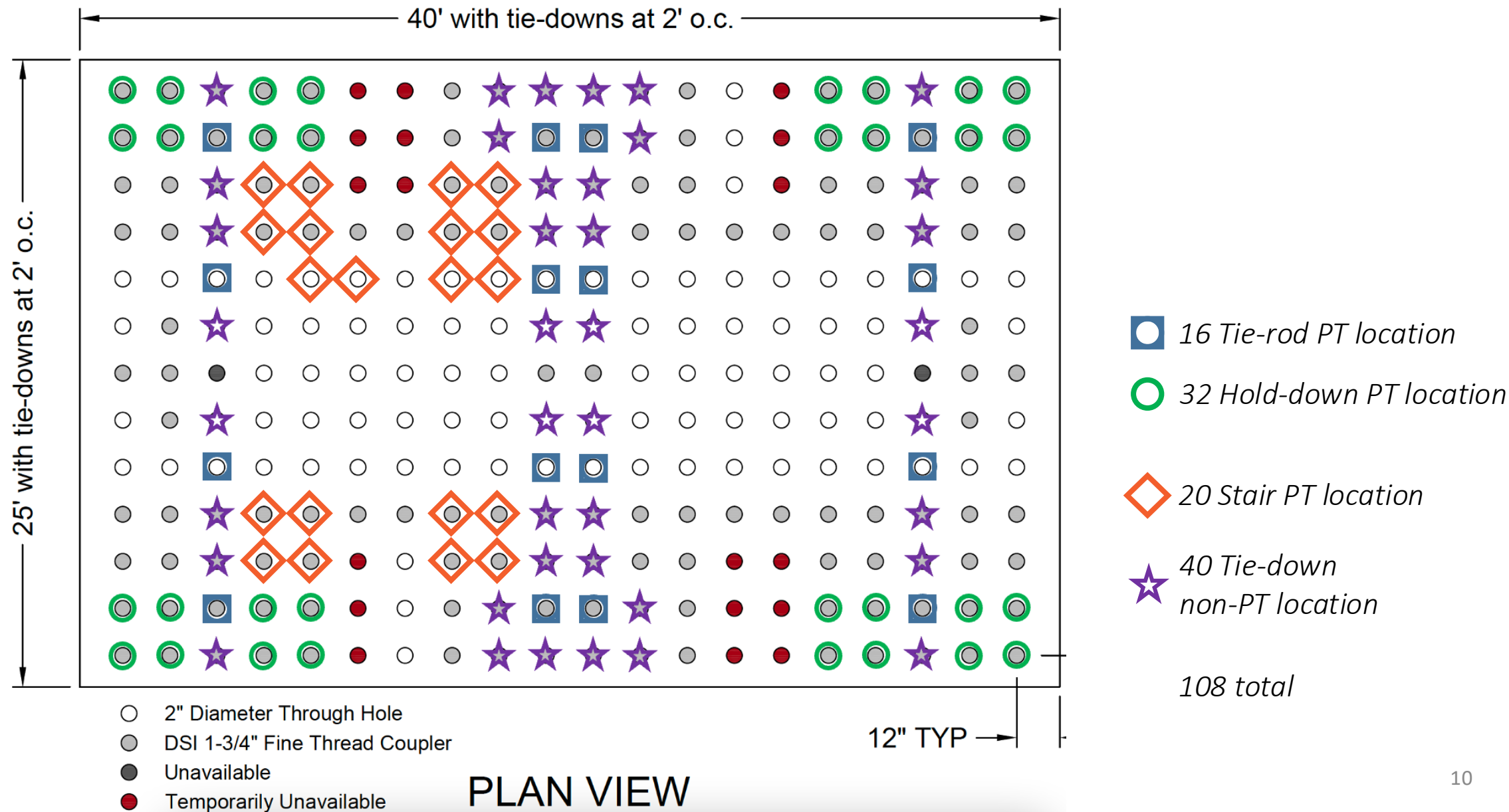
Tie-rods between CFS chord stud (**CFS-HUD**)

Test Building: *Overview*

- Building height = 100ft (exceeds code limitations),
Story height = 10ft
- Plan area = 38ft x 22.5ft
- Lateral force resisting system:
6ft long steel sheet sheathed CFS shear walls
 - *Longitudinal walls (E-W):*
Holdowns or plate holdowns
attached to stud packs
or HSS member.
 - *Transverse walls (N-S):*
Floor-to-floor tension tie-rods
with **built-up stud packs**



Test Building: *Shake table tie-down plan*



Test Building: *Seismic Load Calculation*

ROOF DEAD LOAD DEVELOPMENT	
COMPONENT	DEAD LOAD
ROOFING MEMBRANE	1.50 psf
RIGID INSULATION	5.00 psf
3/4 CEMENT PANEL ROOF DECK	5.30 psf
CFS ROOF JOIST	3.00 psf
INSULATION	1.00 psf
5/8" GYP. BOARD W/FURRING	3.00 psf
MECHANICAL	5.00 psf
TOTAL:	23.80 psf

FLOOR DEAD LOAD DEVELOPMENT	
COMPONENT	DEAD LOAD
FINISH FLOORING	3.00 psf
3/4 CEMENT PANEL SUBFLOOR	5.30 psf
CFS FLOOR JOIST	3.50 psf
INSULATION	1.00 psf
5/8" GYP. BOARD W/FURRING	3.00 psf
MECHANICAL / OTHER	5.00 psf
TOTAL:	20.80 psf

EXTERIOR WALL DEAD LOAD DEVELOPMENT	
COMPONENT	DEAD LOAD
EIFS CLADDING	2.50 psf
5/8 EXTERIOR GYPSUM	3.00 psf
CFS WALL STUDS	3.50 psf
INSULATION	1.00 psf
5/8" GYP. BOARD	2.50 psf
MISC	2.00 psf
TOTAL:	14.50 psf

INTERIOR WALL DEAD LOAD DEVELOPMENT	
COMPONENT	DEAD LOAD
5/8 GYP. BOARD	2.50 psf
CFS WALL STUDS	3.50 psf
INSULATION	1.00 psf
5/8" GYP. BOARD	2.50 psf
MISC	2.00 psf
TOTAL:	11.50 psf

Level	Elevation, h_x (ft)	Weight (psf)	Floor Area (sf)	Weight, w_x (kips)	Story Force, F_x & F_y (kips)
Roof	100	24.0	855	20.5	4.397
10	90	41.9	855	35.8	6.853
9	80	41.9	855	35.8	6.044
8	70	41.9	855	35.8	5.242
7	60	41.9	855	35.8	4.448
6	50	41.9	855	35.8	3.662
5	40	41.9	855	35.8	2.887
4	30	41.9	855	35.8	2.124
3	20	41.9	855	35.8	1.379
2	10	41.9	855	35.8	0.659
Total Seismic Weight, $W =$				342.6	

Total Seismic Weight, $W = 342.6$ kip

Seismic Response Coefficient, $C_s = 0.110$

Seismic Base Shear, $V = 37.7$ kip

Shear Wall Details: *Longitudinal (E-W) Direction*

SHEAR WALL SCHEDULE *										
SHEARWALL TYPE (DETAILS)	(1)	(2)	END POSTS		HOLDOWNS AT BOTTOM OF WALL (TOP OF LEVEL BELOW)			SHEATHING		BOTTOM CONNECTION
	LEVEL	SHEAR WALL MINIMUM ON-CENTER STUD & TRACK MATERIAL	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
			END POSTS MEMBER	PROFILE	TYPE	DETAIL (BOTTOM OF WALL)	THREADED ROD ANCHOR	TYPE	FASTENER PATTERN	WALL BOTTOM TO TOP TRACK FASTENERS
SW-2 1 & CORRIDOR W5 WALL RIDLINES 1 & 2	10	43-MIL (33 KSI) MIN	(1) 600S250-43 (33 KSI)	MP1.1	USP S/PHD4 (8) #14 SCREWS	5/LSF-5.0	Traditional hold-downs connected to CFS member		6 / 12	#12 SCREW AT 24" ON-CENTER
	9	43-MIL (33 KSI) MIN	(1) 600HDS300-54 (50 KSI)	MP1.6	CD8 (17) #14 SCREWS	5/LSF-5.0			4 / 12	#12 SCREW AT 9" ON-CENTER
	8	43-MIL (33 KSI) MIN	(1) 600HDS300-97 (50 KSI)	MP1.6	CD10 (23) #14 SCREWS	5/LSF-5.0	7/8"Ø F1554 Gr36 (2) HVY HN's & FW's	27 MIL STEEL SHEET (33Ksi)	2 / 12	#12 SCREW AT 12" ON-CENTER
	7	54-MIL (50 KSI) MIN	(2) 600HDS300-68 (50 KSI)	MP1.8	(2) CD15 (30) #14 SCREWS	6/LSF-5.0	1"Ø F1554 Gr36, (2) HVY HN's & FW's	33 MIL STEEL SHEET (33Ksi BLOCKED)	4 / 12	#12 SCREW AT 9" ON-CENTER
	6	54-MIL (50 KSI) MIN	HSS 6 x 6 x $\frac{3}{16}$ (A500 GR.B)	MPC.1	$\frac{1}{4}$ " x 5"w A36 PLATE, $tw=\frac{3}{16}$ Lw=4"	7/LSF-5.0	--	33 MIL STEEL SHEET (33Ksi BLOCKED)	3 / 12	#12 SCREW AT 9" ON-CENTER
	5	54-MIL (50 KSI) MIN	HSS 6 x 6 x $\frac{3}{16}$ (A500 GR.B)	MPC.1	$\frac{3}{8}$ " x 5"w A36 PLATE, $tw=\frac{1}{4}$ " Lw=4"	7/LSF-5.0	--	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
		54-MIL (50 KSI) MIN	HSS 6 x 6 x $\frac{1}{4}$ (A500 GR.B)	MPC.1	$\frac{1}{2}$ " x 5"w A36 PLATE, $tw=\frac{5}{16}$ Lw=4"	7/LSF-5.0		33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
		54-MIL (50 KSI) MIN	HSS 6 x 6 x $\frac{5}{16}$ (A500 GR.B)	MPC.1	$\frac{1}{2}$ " x 5"w A572 Gr50 PL, $tw=\frac{3}{8}$ Lw=5"	7/LSF-5.0		33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
	2	68-MIL (50 KSI) MIN	HSS 6 x 6 x $\frac{3}{8}$ (A500 GR.B)	MPC.1	$\frac{1}{2}$ " x 5"w A572 Gr50 PL, $tw=\frac{3}{8}$ Lw=5"	7/LSF-5.0	--	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	#12 SCREW AT 6" ON-CENTER
EX	1	97-MIL (50 KSI) MIN	HSS 6 x 6 x $\frac{3}{8}$ (A500 GR.B)	MPC.1	(4) $\frac{5}{16}$ " x 5"w Weld HSS @ Transfer PL	8/LSF-5.0	--	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	3/8" DIA x 1" Gr5 HEX HEAD CAP SCREW AT 6" OC TO BASEPLATE

HSS member as chord stud

Heavier gauge CFS studs at lower levels

Plate hold-downs welded to HSS member

Thicker sheet and tighter spacing at lower levels

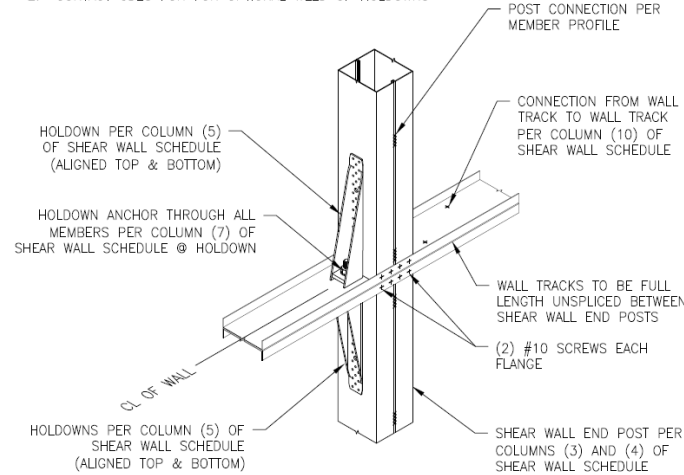
Tie-down Details: *Longitudinal (E-W) Direction*

SHEAR WALL SCHEDULE *

END POSTS		HOLDOWNS AT BOTTOM OF WALL (TOP OF LEVEL BELOW)		
(3)	(4)	(5)	(6)	(7)
END POSTS MEMBER	PROFILE	TYPE	DETAIL (BOTTOM OF WALL)	THREADED ROD ANCHOR
(1) 600S250-43 (33 KSI)	MP1.1	USP S/PHD4 (8) #14 SCREWS	5/LSF-5.0	5/8"Ø F1554 Gr36, (2) HVY HN's & FW's
(1) 600HDS300-54 (50 KSI)	MP1.6	CD8 (17) #14 SCREWS	5/LSF-5.0	7/8"Ø F1554 Gr36, (2) HVY HN's & FW's
(1) 600HDS300-97 (50 KSI)	MP1.6	CD10 (23) #14 SCREWS	5/LSF-5.0	7/8"Ø F1554 Gr36, (2) HVY HN's & FW's
(2) 600HDS300-68 (50 KSI)	MP1.8	(2) CD15 (30) #14 SCREWS	6/LSF-5.0	1"Ø F1554 Gr36, (2) HVY HN's & FW's
1 HSS 6 x 6 x $\frac{3}{16}$ (A500 GR.B)	MPC.1	$\frac{1}{4}$ " x 5"w A36 PLATE, tw= $\frac{3}{16}$ Lw=4"	7/LSF-5.0	-- 1
HSS 6 x 6 x $\frac{3}{16}$ (A500 GR.B)	MPC.1	$\frac{3}{8}$ " x 5"w A36 PLATE, tw= $\frac{1}{4}$ Lw=4"	7/LSF-5.0	--
HSS 6 x 6 x $\frac{1}{4}$ (A500 GR.B)	MPC.1	$\frac{1}{2}$ " x 5"w A36 PLATE, tw= $\frac{5}{16}$ Lw=4"	7/LSF-5.0	--
HSS 6 x 6 x $\frac{5}{16}$ (A500 GR.B)	MPC.1	$\frac{3}{2}$ " x 5"w A572 Gr50 PL, tw= $\frac{3}{8}$ Lw=5"	7/LSF-5.0	--
1 HSS 6 x 6 x $\frac{3}{8}$ (A500 GR.B)	MPC.1	$\frac{3}{2}$ " x 5"w A572 Gr50 PL, tw= $\frac{3}{8}$ Lw=5"	7/LSF-5.0	--
HSS 6 x 6 x $\frac{3}{8}$ (A500 GR.B)	MPC.1	(4) $\frac{5}{16}$ " x 5"w Weld HSS @ Transfer PL 1	8/LSF-5.0	--

NOTES:

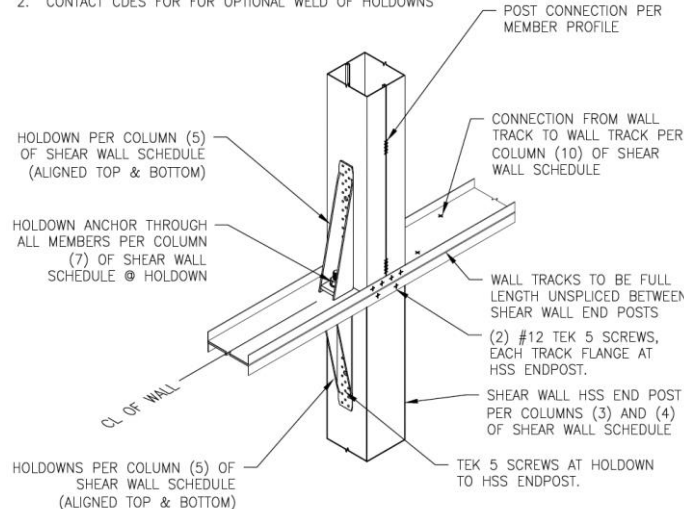
- HOLDOWNS MAY OCCUR ON ONE (AS SHOWN) OR BOTH SIDES OF END POST. REFER TO SHEAR WALL SCHEDULE FOR HOLDOWN REQUIREMENTS.
- CONTACT CDES FOR FOR OPTIONAL WELD OF HOLDOWNS



5 HOLDOWN AT LSF END-POST
TYPICAL

NOTES:

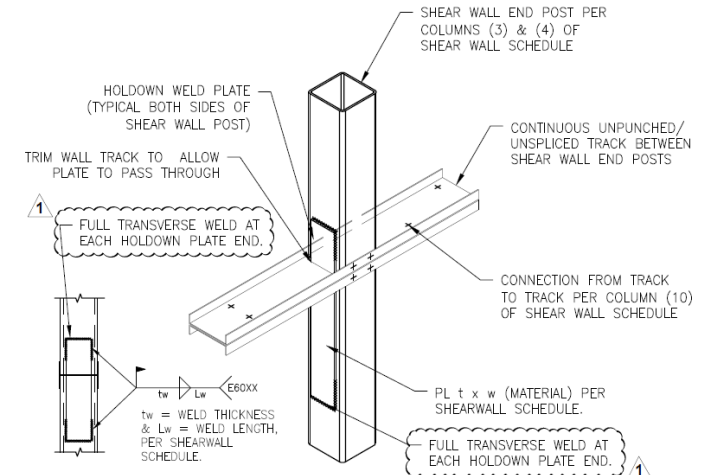
- HOLDOWNS MAY OCCUR ON ONE (AS SHOWN) OR BOTH SIDES OF END POST. REFER TO SHEAR WALL SCHEDULE FOR HOLDOWN REQUIREMENTS.
- CONTACT CDES FOR FOR OPTIONAL WELD OF HOLDOWNS



6 HOLDOWN AT HSS END-POST
TYPICAL

NOTES:

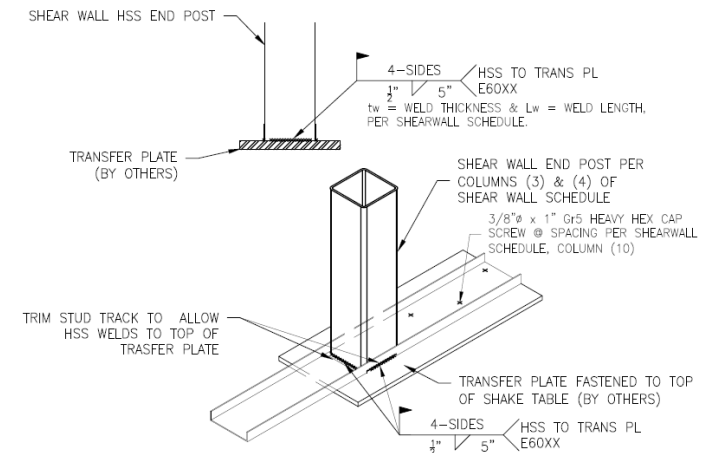
- CLEAN ALL AREAS PRIOR TO WELDING
- CLEAN & DRY ALL AREAS AFTER WELDING AND COAT WITH ZINC RICH PAINT



7 PLATE HOLDOWN AT HSS END-POST
TYPICAL

NOTES:

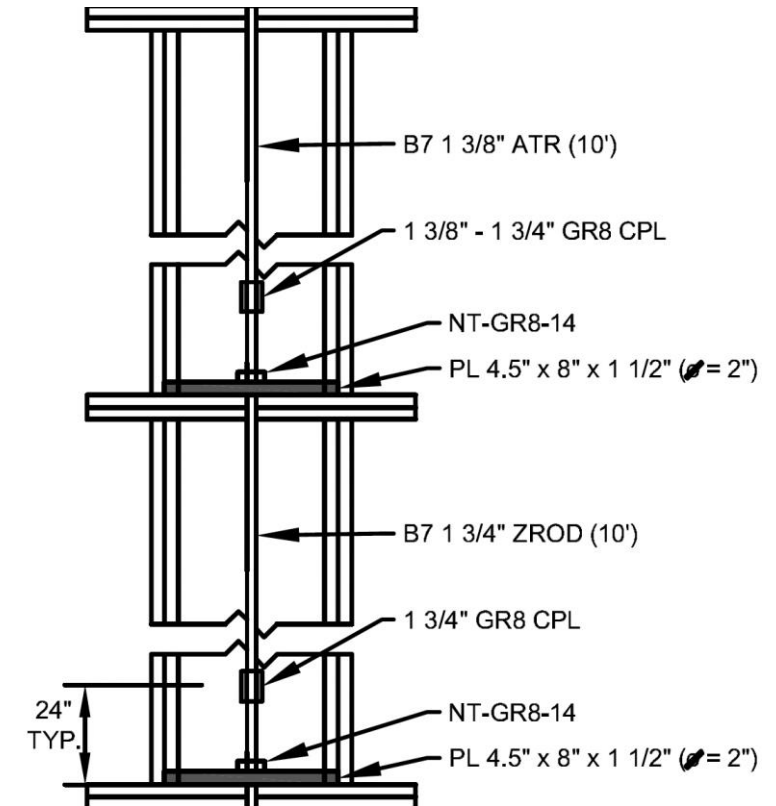
- CLEAN ALL AREAS PRIOR TO WELDING
- CLEAN & DRY ALL AREAS AFTER WELDING AND COAT WITH ZINC RICH PAINT



8 HOLDOWN GUSSET FROM HSS TO EMBED.
TYPICAL

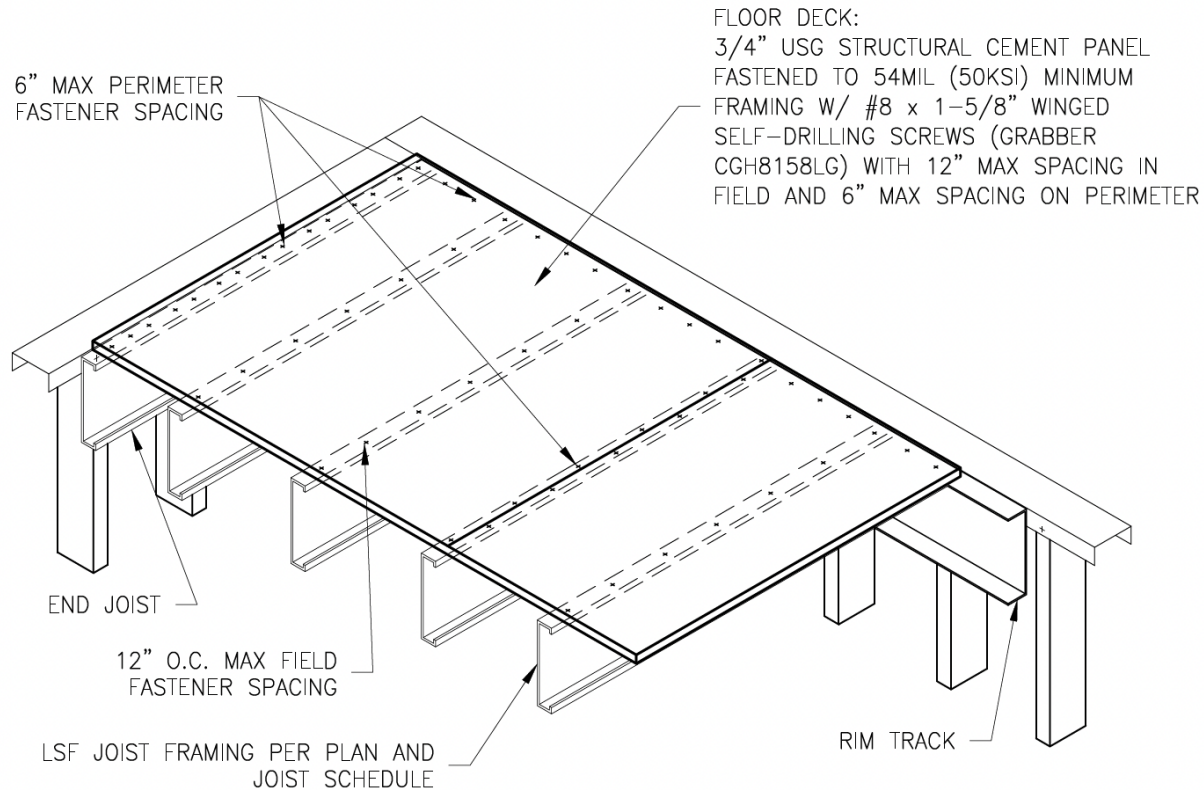
Shear Wall Details: *Transverse (N-S) Direction*

SHEARWALL TYPE (DETAILS)	(1)	(2)	SHEATHING		COMPRESSION STUD PACKS EACH SIDE OF TENSION ROD	TENSION TIE-ROD GRADE & DIAMETER (inch)
	LEVEL	SHEAR WALL MINIMUM ON-CENTER STUD & TRACK MATERIAL	(8)	(9)		
			TYPE	FASTENER PATTERN		
SW-1 INTERIOR WALL AT W3 GRIDLINE D	10	43-MIL (33 KSI) MIN	27 MIL STEEL SHEET (33Ksi)	6 / 12	600S162-43 Single	A36 5/8"
	9	43-MIL (33 KSI) MIN	27 MIL STEEL SHEET (33Ksi)	6 / 12	600S200-43 Single	A36 3/4"
	8	43-MIL (33 KSI) MIN	27 MIL STEEL SHEET (33Ksi)	4 / 12	600S162-68 Single	A36 1-1/8"
	7	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	6 / 12	600S200-54 Boxed	A36 1-1/2"
	6	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	4 / 12	600S200-68 Boxed	A36 1-3/4"
	5	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	4 / 12	600S162-97 Boxed	B7 1-3/4"
	4	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	3 / 12	600S250-97 Boxed	B7 1-3/4"
	3	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	3 / 12	600S200-97 3-Ply	B7 1-3/4"
	2	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	600S200-118 3-Ply	B7 2"
	1	54-MIL (50 KSI) MIN	33 MIL STEEL SHEET (33Ksi BLOCKED)	2 / 12	600S200-118 3-Ply	B7 2"



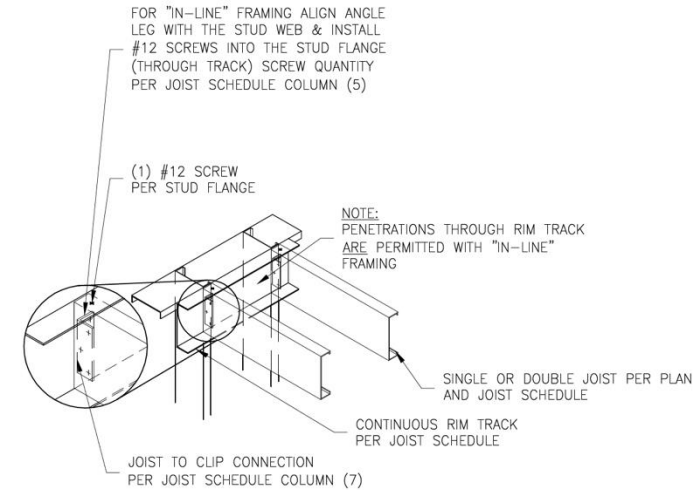
For tie-rod detail representation only
Not CFS-NHERI drawing

Floor and Diaphragm Details

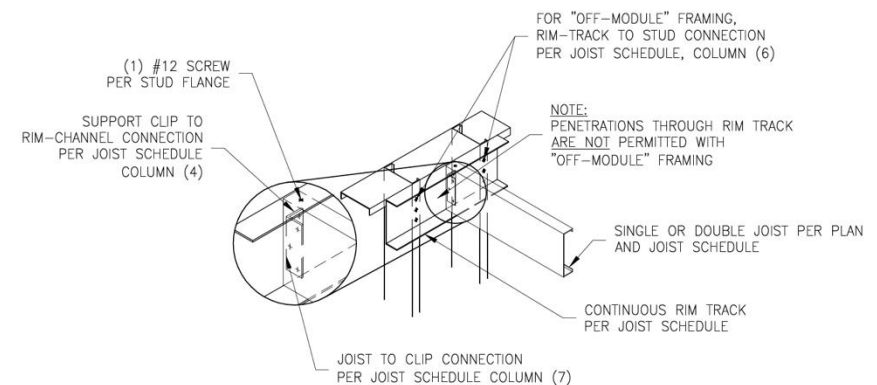


6 FLOOR DECK CONNECTION TO FRAMING

Ref. Plan Notes from Structural Plans



A TYPICAL "IN-LINE" JOIST-TO-RIM TRACK CONNECTION



B TYPICAL "OFF-MODULE" JOIST-TO-RIM TRACK CONNECTION

4 JOIST AND END-JOIST CONNECTIONS

TYPICAL UNLESS NOTED OTHERWISE

CFS-NHERI Building Test: *Near-term Activities*

- Finalize design (final iteration), shop drawings
- Material takeoffs and donations/procurement/delivery
- Development of testing protocol:
 - Sequence of increasing intensity earthquake tests, progressive damage to specimen
 - Ongoing numerical modeling (OpenSeesPy) for seed motion selection & scale factors
 - Fire tests for post-earthquake fire performance and post-fire earthquake (aftershocks)
- Development of instrumentation plans

Questions/Comments?

PAPER ID#: 96



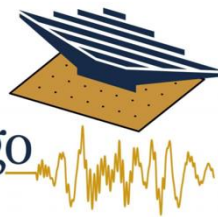
ams082@eng.ucsd.edu



@Amanpreet Singh



NHERI@
UC San Diego



American
Iron and Steel
Institute

SFIA
STEEL FRAMING INDUSTRY ASSOCIATION

JOHNS HOPKINS
UNIVERSITY

UC San Diego

UMass**Amherst**


ClarkDietrich.

EDCI
ENGINEERS