



Engineering Cleveland's First Nine-Story Mass Timber Building

INTRO

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fast + epp

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1. Project Information

2. Design Decisions
building type, grids

3. Procurement
supplier, materials

4. Design
Glulam
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Connections

overview

An architectural rendering of a modern, multi-story building with a central courtyard. The building features a grid-like facade with large windows. The courtyard is landscaped with greenery, trees, and a small water feature. The building is situated in an urban environment with other buildings and a street visible in the background.

Client

Harbor Bay Real Estate

Architect

Hartshorne Plunkard Architecture

Engineers

**Forefront Structural Engineers
Fast + Epp**

Contractor

Seagate Structures

Supplier

Binderholz

512,000 sq. ft.

9 Story on 2 Story

Type IV-B on Type I-A

Project Information



Building Type

IBC 2015

TABLE 504.3
ALLOWABLE BUILDING HEIGHT IN FEET ABOVE GRADE PLANE^a

OCCUPANCY CLASSIFICATION	TYPE OF CONSTRUCTION									
	SEE FOOTNOTES	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
R ^h	NS ^d	UL	160	65	55	65	55	65	50	40
	S13D	60	60	60	60	60	60	60	50	40
	S13R	60	60	60	60	60	60	60	60	60
	S	UL	180	85	75	85	75	85	70	60

TABLE 504.4—continued
ALLOWABLE NUMBER OF STORIES ABOVE GRADE PLANE^{a, b}

OCCUPANCY CLASSIFICATION	TYPE OF CONSTRUCTION									
	SEE FOOTNOTES	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
R-1 ^h	NS ^d	UL	11	4	4	4	4	4	3	2
	S13R	4	4						4	3
	S	UL	12	5	5	5	5	5	4	3
R-2 ^h	NS ^d	UL	11	4	4	4	4	4	3	2
	S13R	4	4						4	3
	S	UL	12	5	5	5	5	5	4	3

Design Decisions

Building Type

IBC 2015

TABLE 506.2—continued
ALLOWABLE AREA FACTOR (A_t = NS, S1, S13R, S13D or SM, as applicable) IN SQUARE FEET^{a, b}

OCCUPANCY CLASSIFICATION	SEE FOOTNOTES	TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
R-2 ^a	NS ^d	UL	UL	24,000	16,000	24,000	16,000	20,500	12,000	7,000
	S13R									
	S1	UL	UL	96,000	64,000	96,000	64,000	82,000	48,000	28,000
	SM	UL	UL	72,000	48,000	72,000	48,000	61,500	36,000	21,000

506.2.4 Mixed-occupancy, multistory buildings. Each story of a mixed-occupancy building with more than one *story above grade plane* shall individually comply with the applicable requirements of Section 508.1. For buildings with more than three *stories above grade plane*, the total building area shall be such that the aggregate sum of the ratios of the actual area of each *story* divided by the allowable area of such stories, determined in accordance with Equation 5-3 based on the applicable provisions of Section 508.1, shall not exceed three.

$$A_a = [A_t + (NS \times I_f)] \quad \text{(Equation 5-3)}$$

where:

A_a = Allowable area (square feet).

A_t = Tabular allowable area factor (NS, S13R, S13D or SM value, as applicable) in accordance with Table 506.2.

NS = Tabular allowable area factor in accordance with Table 506.2 for a nonsprinklered building (regardless of whether the building is sprinklered).

I_f = Area factor increase due to frontage (percent) as calculated in accordance with Section 506.3.

Design Decisions

+

Building Type

IBC 2021

Select Height and Area Limits by Construction Type

		I-A	I-B	IV-A	IV-B	IV-C	IV-HT
Occupancies	Value	Allowable Building Height above Grade Plane, Feet (IBC Table 504.3)					
A, B, R	S	Unlimited	180	<u>270</u>	180	<u>85</u>	85
		Allowable Number of Stories above Grade Plane (IBC Table 505.4)					
A-2, A-3, A-4	S	Unlimited	12	<u>18</u>	12	<u>6</u>	4
B	S	Unlimited	12	<u>18</u>	12	<u>9</u>	6
R-2	S	Unlimited	12	<u>18</u>	12	<u>8</u>	5
		Allowable Area Factor (At), Feet ² (IBC Table 506.2)					
A-2, A-3, A-4	SM	Unlimited	Unlimited	<u>135,000</u>	<u>90,000</u>	<u>56,250</u>	45,000
B	SM	Unlimited	Unlimited	<u>324,000</u>	<u>216,000</u>	<u>135,000</u>	108,000
R-2	SM	Unlimited	Unlimited	<u>184,500</u>	123,000	<u>76,875</u>	61,500

S is sprinklered with NFPA 13 sprinklers. SM is the multi-story allowable area factor. Underlined entries are the new additions.

Breneman, S; Timmers, M; Richardson, D; *Tall Wood Buildings in the 2021 IBC Up to 18 Stories of Mass Timber*; 2019; Woodworks Wood Products Council

Design Decisions

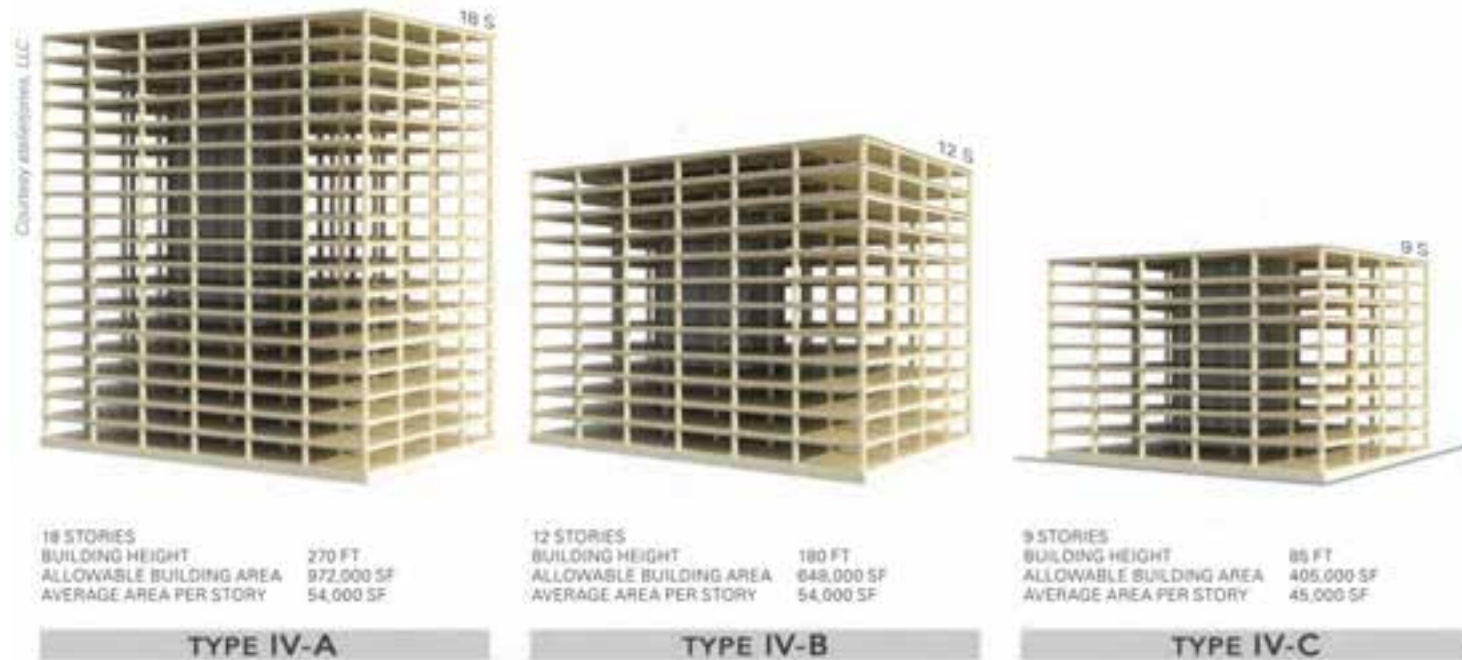


Building Type

IBC 2021

FIGURE 3

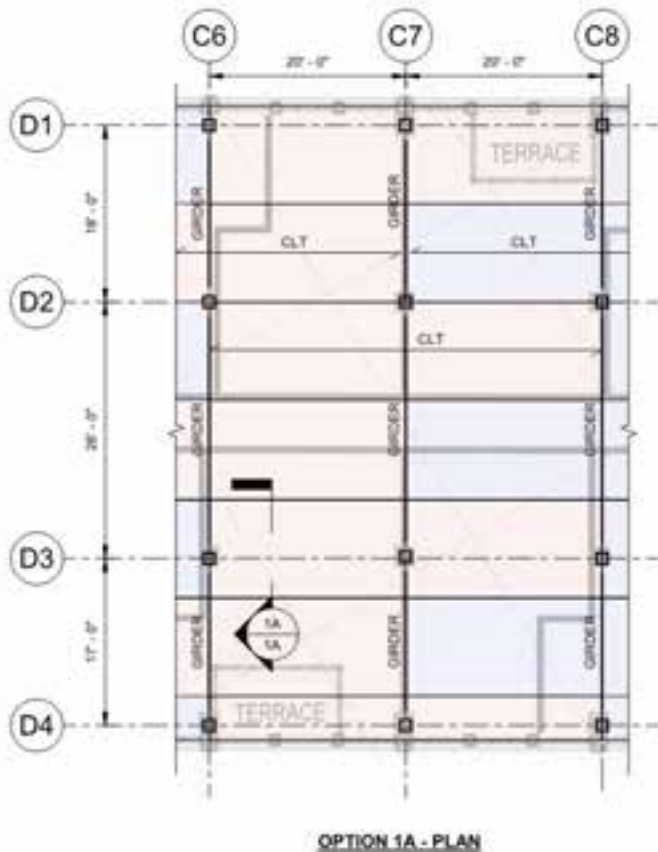
Representative Building Sizes, Business Occupancy



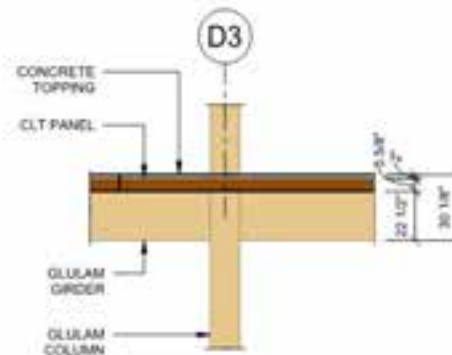
Breneman, S; Timmers, M; Richardson, D; *Tall Wood Buildings in the 2021 IBC Up to 18 Stories of Mass Timber*; 2019; Woodworks Wood Products Council
Image Courtesy atelierjones, LLC

Design Decisions

Grids



3D VISUALIZATION



SECTION 1A

RESIDENTIAL BUILDING
TYPE 4-C
DL = 55 PSF / LL = 55 PSF

OPTION 1A

TOTAL DEPTH: 30' 1 1/8"

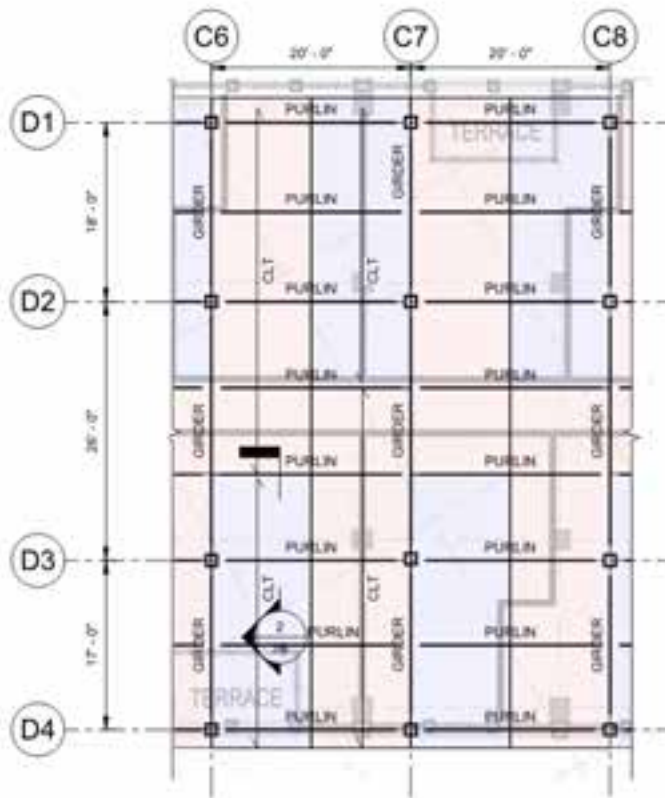
GIRDER: GLULAM 10-5" X 22-5"

CLT PANEL: 5-PLY (THK = 5.625")

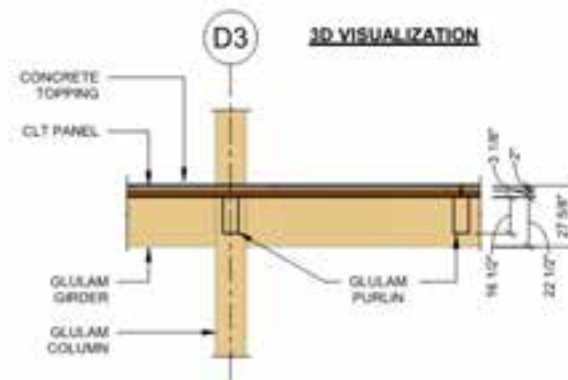
VOLUME ANALYSIS (60'X20' AREA)
TOTAL: 6.60 CU FT / SQ FT

Design Decisions

Grids



OPTION 1B - PLAN



SECTION 1B

RESIDENTIAL BUILDING
TYPE 4-C
DL = 50 PSF / LL = 55 PSF

OPTION 1B

TOTAL DEPTH: 27'-5 1/8"

GIRDER: GLULAM 10.5" X 22.5"

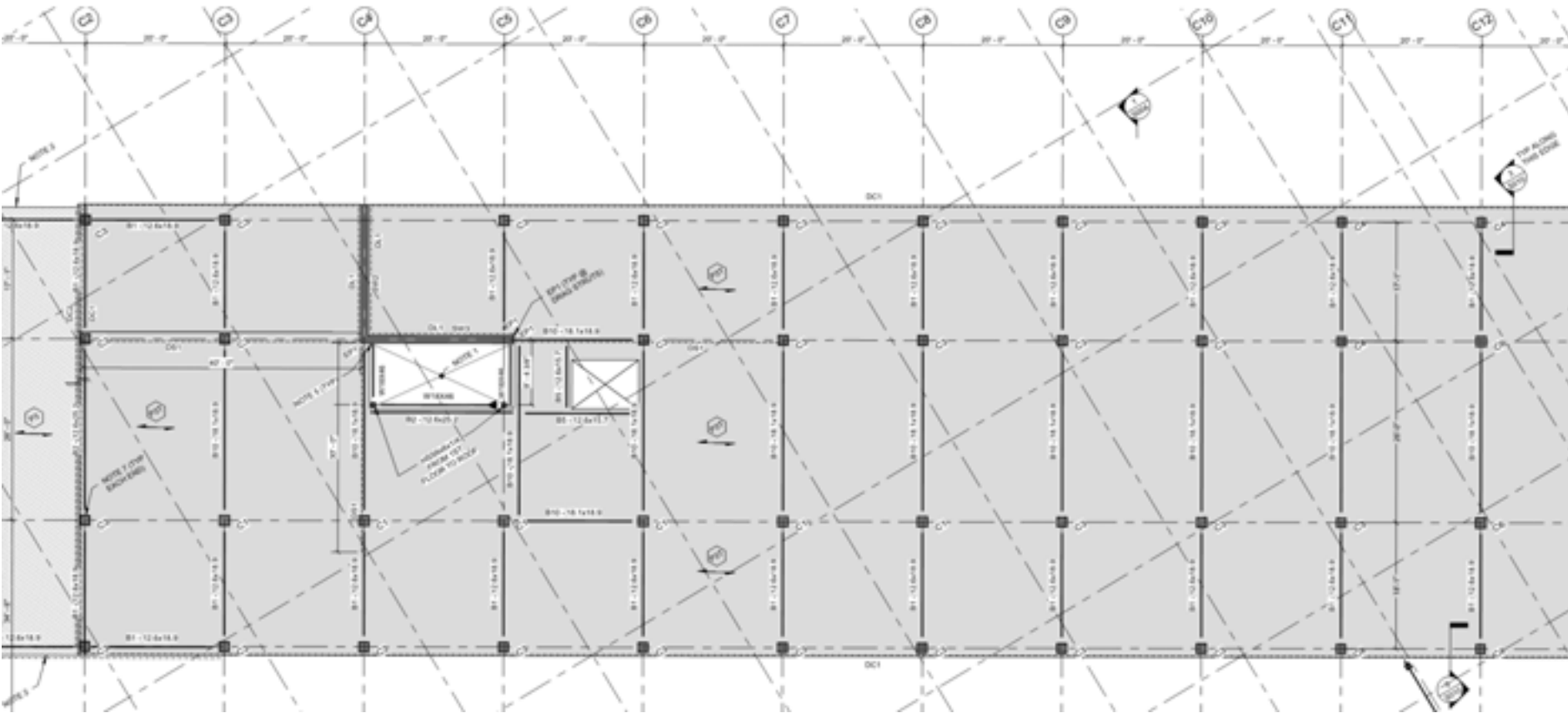
PURLIN: GLULAM 6.75" X 16.5"

CLT PANEL: 3-PLY (THK = 3.125")

VOLUME ANALYSIS (60'X20' AREA)
TOTAL: 6.50 CU FT / SQ FT

Design Decisions

Grids



Design Decisions

Suppliers



Procurement



Suppliers

Wood Species and Aesthetics

**DF, SPF, SP, Cedar, Spruce
Glulam vs. CLT, Coloring**

Supply

1 supplier for Glulam + CLT

Shipping

Ship, Truck, Material Size

Approvals

PRG320

Procurement

Suppliers
Binderholz

Wood Species
European Spruce
Fb= 1550psi

Shipping
Barge
4ft x 60ft long CLT panels

Approvals
PRG 320

Procurement

Glulam Design

Wood Species	spruce
Quality	visible quality, non-visible quality
Strength classes	GL 24c, GL 24h, GL 28c, GL 28h, GL 30c, GL 30h*, GL 32c*, GL 32h*
Layer and finger joint gluing	modified melamine resin, for categories 1-3, UV-proof and weatherproof, light
Width	60 - 280** mm (in 20 mm steps)
Height	up to 1,280 mm (in 40 mm steps)
Length	6 - 18 m
Cut to length	3.5 - 18 m

* only visible quality

** Width 60 mm is split; only in GL 24 available
width 280 mm only in GL 24 available

Design



CLT Design

Table 12 Reference Design Values on LFRD level for BBS CLT Panels in SI units

CLT Grade	Layup Designation	Major Strength Direction				Minor Strength Direction			
		$f_{b,Seff,0} \cdot 10^6$ [Nmm/m]	$E_{eff,0} \cdot 10^9$ [Nmm ² /m]	$GA_{eff,0} \cdot 10^6$ [N/m]	$V_{s,0} \cdot 10^3$ [N/m]	$f_{b,Seff,90} \cdot 10^6$ [Nmm/m]	$E_{eff,90} \cdot 10^9$ [Nmm ² /m]	$GA_{eff,90} \cdot 10^3$ [N/m]	$V_{s,90} \cdot 10^3$ [N/m]
BBS 125	60-3s	10	208	3,7	43,3	1,1	5,3	3,6	42,7
	80-3s	17	448	4,3	62,2	4,3	43	7,5	85,3
	90-3s	23	702	5,6	65,0	2,4	18	5,5	64,0
	100-3s	29	973	6,5	71,3	2,4	18	5,6	64,0
	120-3s	42	1664	7,5	86,7	4,3	43	7,3	85,3
	100-5s	24	792	7,5	82,5	9,2	139	7,3	43,3
	120-5s	31	1224	7,9	102,0	17	336	11	56,0
	140-5s	54	2536	11	105,7	9,2	139	7,8	43,3
	150-5s	61	3059	13	115,9	12	211	8,2	52,7
	160-5s	68	3648	16	126,7	15	299	8,6	62,2
	180-5s	82	4896	15	145,7	25	624	11	74,3
	200-5s	95	6336	15	165,0	37	1109	15	86,7
	220-5s	132	9712	19	168,6	25	624	12	74,3
	240-5s	152	12160	19	187,7	37	1109	15	86,7
	260-5s	10	208	3,7	43,3	1,1	5,3	3,6	42,7
	280-5s	10	208	3,7	43,3	1,1	5,3	3,6	42,7
	300-5s	248	24768	34	234,5	43	1488	15	112,7
	320-5s	274	29184	31	253,3	60	2389	17	124,4
	340-7s	304	34408	26	250,4	73	3264	22	145,7

Design

Considerations

Fire

Required Rating
Means of Protection

Vibration

User Comfort

Design



Fire

Building Type
Type IV-B

Design

Fire

Required Fire-Resistance Ratings by Construction Type (IBC Table 601)

Building Element	I-A	I-B	IV-A	IV-B	IV-C	IV-HT
Primary Structural Frame	3*	2*	3	2	2	HT
Ext. Bearing Walls	3*	2*	3	2	2	2
Int. Bearing Walls	3*	2*	3	2	2	1/HT
Floor Construction	2	2*	2	2	2	HT
Roof Construction	1½*	1*	1½	1	1	HT

**These values can be reduced based on certain conditions in IBC 403.2.1, which do not apply to Type IV buildings.*

Breneman, S; Timmers, M; Richardson, D; *Tall Wood Buildings in the 2021 IBC Up to 18 Stories of Mass Timber*; 2019; Woodworks Wood Products Council

Design



Fire

TABLE 722.7.1(1)

PROTECTION REQUIRED FROM NONCOMBUSTIBLE COVERING MATERIAL

<u>Required Fire Resistance Rating of Building Element per Tables 601 and 602 (hours)</u>	<u>Minimum Protection Required from Noncombustible Protection (minutes)</u>
<u>1</u>	<u>40</u>
<u>2</u>	<u>80</u>
<u>3 or more</u>	<u>120</u>

TABLE 722.7.1(2)

PROTECTION PROVIDED BY NONCOMBUSTIBLE COVERING MATERIAL

<u>Noncombustible Protection</u>	<u>Protection Contribution (minutes)</u>
<u>1/2 inch Type X Gypsum Board</u>	<u>25</u>
<u>5/8 inch Type X Gypsum Board</u>	<u>40</u>

Design

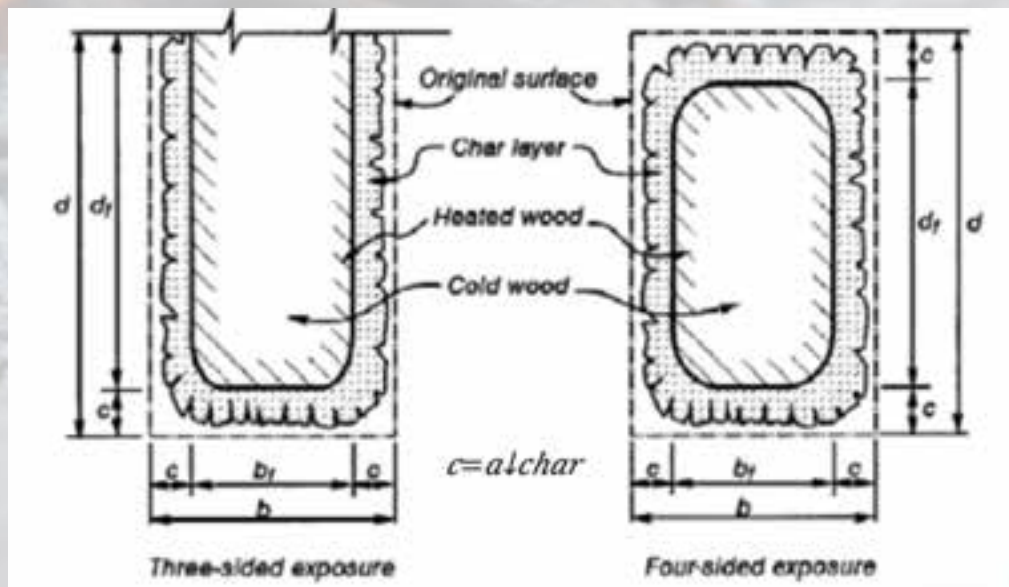
Fire

Table 16.2.1A Char Depth and Effective Char Depth (for $\beta_n = 1.5$ in./hr.)

Required Fire Resistance (hr.)	Char Depth, a_{char} (in.)	Effective Char Depth, a_{eff} (in.)
1-Hour	1.5	1.8
1½-Hour	2.1	2.5
2-Hour	2.6	3.2

Table 16.2.1B Effective Char Depths (for CLT with $\beta_n = 1.5$ in./hr.)

Required Fire Resistance (hr.)	Effective Char Depths, a_{eff} (in.)								
	lamination thicknesses, h_{lam} (in.)								
	5/8	3/4	7/8	1	1-1/4	1-3/8	1-1/2	1-3/4	2
1-Hour	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.8
1½-Hour	3.4	3.2	3.1	3.0	2.9	2.8	2.8	2.8	2.6
2-Hour	4.4	4.3	4.1	4.0	3.9	3.8	3.6	3.6	3.6



Design

Fire

Table 16.2.2 Adjustment Factors for Fire Design¹

				ASD					
				Design Stress to Member Strength Factor	Size Factor ²	Volume Factor ²	Flat Use Factor ²	Beam Stability Factor ³	Column Stability Factor ³
Bending Strength	F_b	X		2.85	C_F	C_V	C_{fu}	C_L	-
Beam Buckling Strength	F_{bE}	X		2.03	-	-	-	-	-
Tensile Strength	F_t	X		2.85	C_F	-	-	-	-
Compressive Strength	F_c	X		2.58	C_F	-	-	-	C_P
Column Buckling Strength	F_{cE}	X		2.03	-	-	-	-	-

1. See 4.3, 5.3, 8.3, and 10.3 for applicability of adjustment factors for specific products.

2. Factor shall be based on initial cross-section dimensions.

3. Factor shall be based on reduced cross-section dimensions.

FIRE:

β_n (in/hr):

1.5

Beam Label	Beam Width, in	Beam Depth, in	Volume Factor	Fire Rating	Effective Char	Charred Width	Charred Depth	LRFD Moment	ASD Fire, Moment	LRFD Shear	Moment of Inertia	Beam Width, mm	Beam Depth, mm
						2	1	k-ft	k-ft	kip			
800	12.6	23.6	1	2	3.2	6.3	20.5	261	161	62	13838	320	600
801	12.6	18.9	1	2	3.2	6.3	15.7	167	95	50	7085	320	480
802	12.6	25.2	1	2	3.2	6.3	22.0	297	187	66	16795	320	640

Design

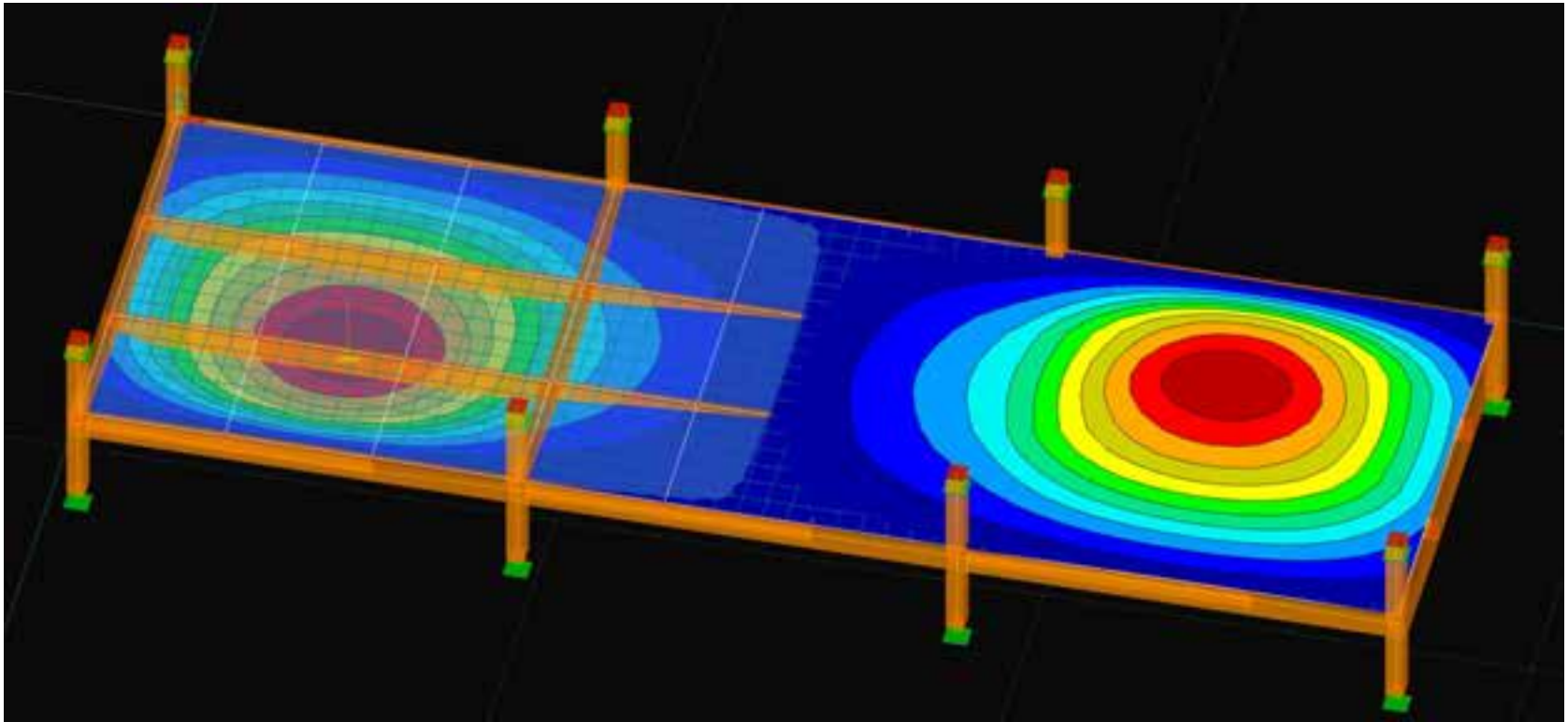
Fire

CHAR DEPTH CALCULATION

	Nominal char rate, β_n	1.5	in./hr.					
	Non-linear char rate, β_t	1.5 in./hr. ^{0.813}	$\beta t = \beta_n$, NDS 16.2-1					
	Fire-Resistance Rating (FRR):	2 hr						
Layer	t_chared off (mm)	t_char (in.)	$t_{gi} = (h_{lam}/\beta_t)^{1.23}$	$n_{lam} = (t/t_{gi})$	$a_{char} = n_{lam} h_{lam} + \beta_t (t_{gi})^{0.813}$	$a_{eff} = 1.2 a_{char}$	h_{lam}/a_{eff}	t_fire - what's left (mm)
1	0	0	1.061685948	1	2.999132298	3.598958758	0	40
2	0	0	1.061685948	1	2.999132298	3.598958758	0	40
3	0	0	0.745283357	2	3.229073277	3.874887932	0	30
4	0	0	1.061685948	1	2.999132298	3.598958758	0	40
5	15	0.59055118	0.745283357	2	3.229073277	3.874887932	0.152405	15
6	40	1.57480315	1.061685948	1	2.999132298	3.598958758	0.437572	0
7	40	1.57480315	1.061685948	1	2.999132298	3.598958758	0.437572	0

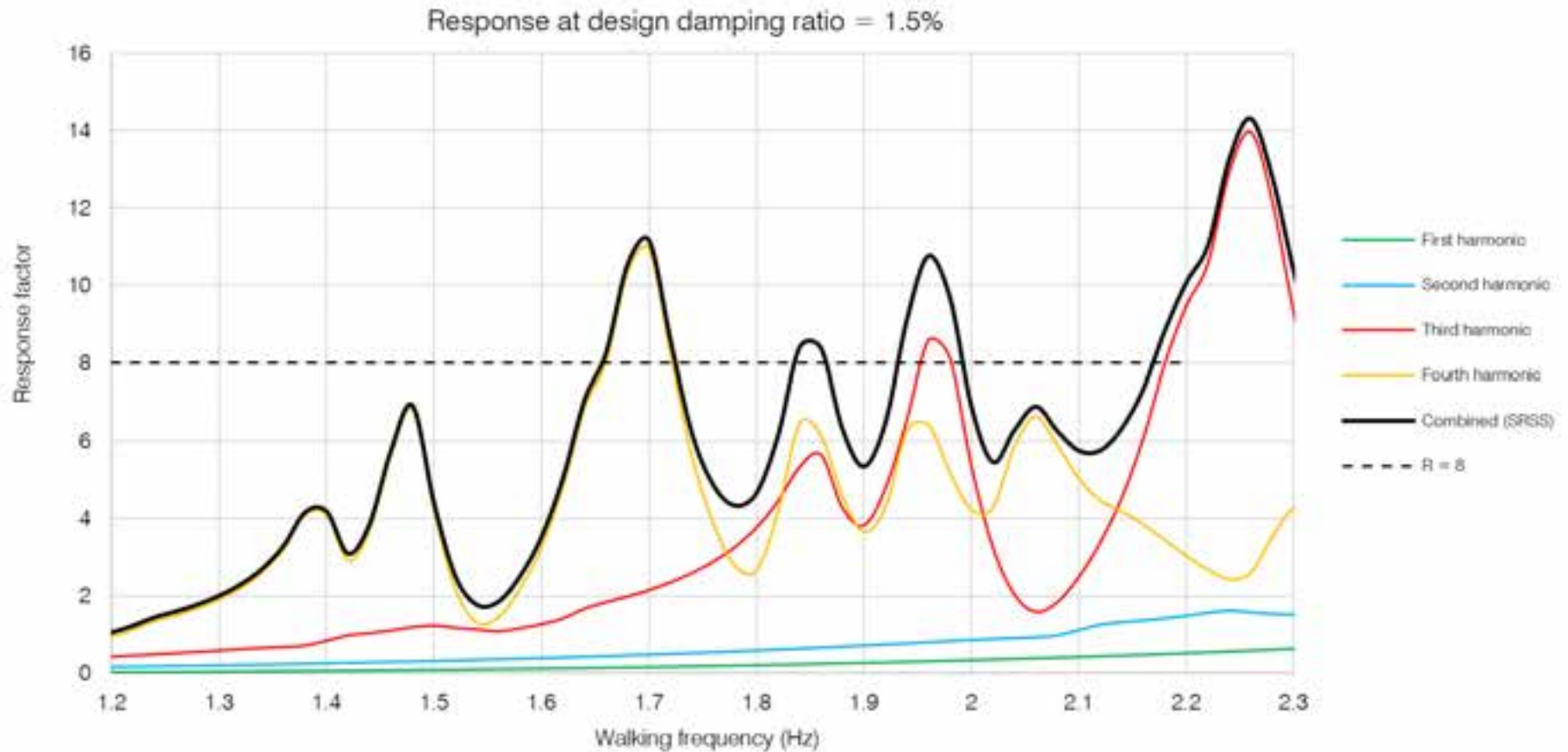
Design

Vibration



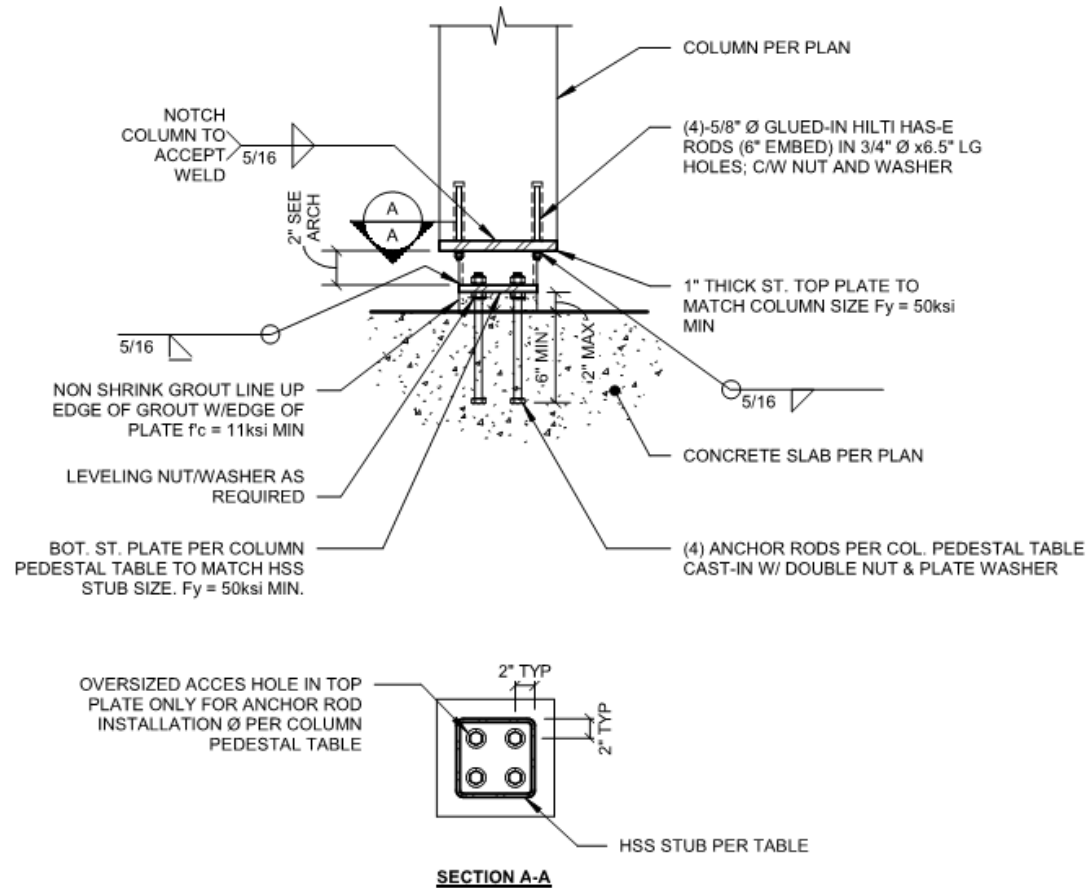
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Vibration



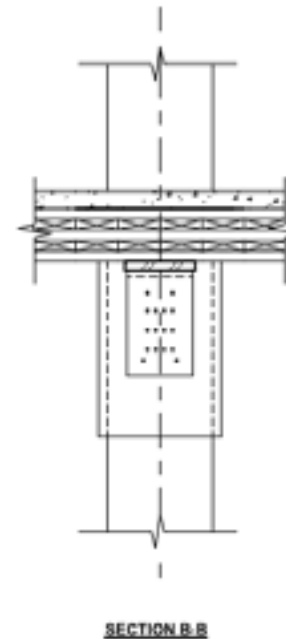
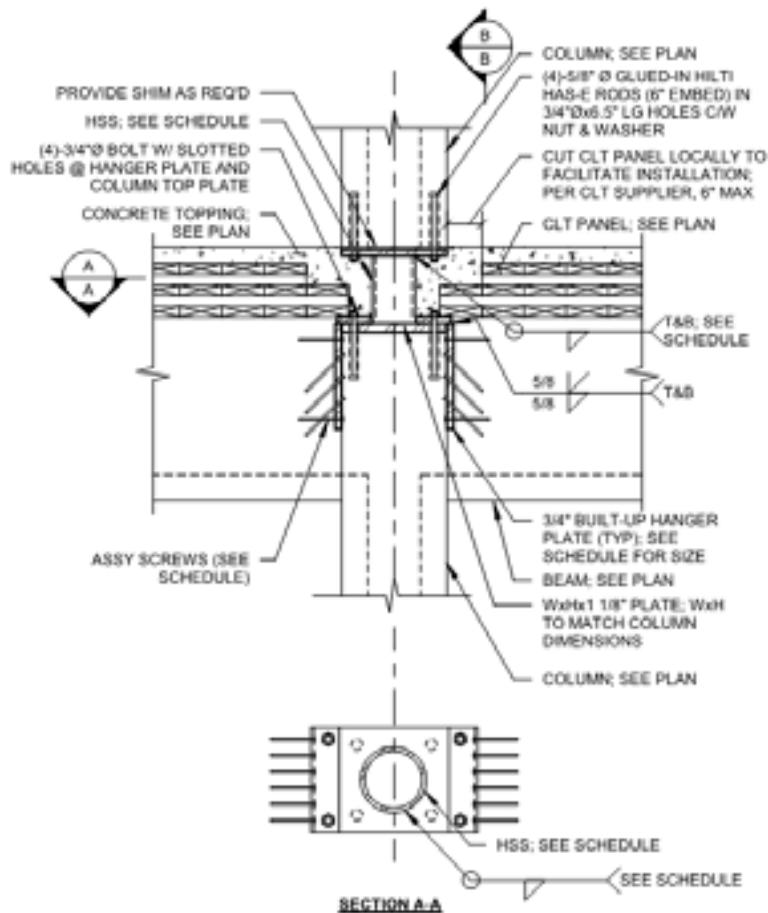
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Connections



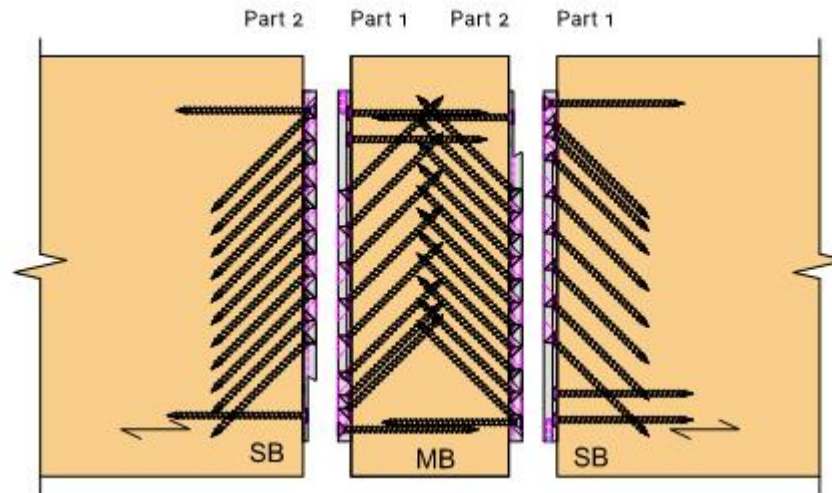
Design

Connections



Design

Connections



Design



thank
you

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