Applied Architectural Structures: Structural Analysis and Systems

ARCH 631

DR. ANNE NICHOLS

FALL 2013

lecture NINETEEN



wood construction and design

Wood Construction 1 Lecture 19 Applied Architectural Structures
ARCH 631

F2009abn

Timber Construction

- studs, beams
- floor diaphragms & shear walls





Wood Construction 3 Lecture 18

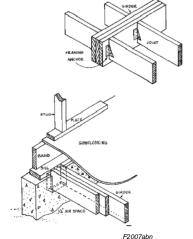
Architectural Structures III

F2007abn

Timber Construction

- all-wood framing systems
 - studs, beams, floor diaphragms, shearwalls
 - glulam arches & frames
 - post & beams
 - trusses
- composite construction
 - masonry shear walls
 - concrete
 - steel

Wood Construction 2 Lecture 18 Architectural Structures III ARCH 631



Timber Construction

- glulam arches & frames
 - manufactured or custom shapes
 - glue laminated
 - bigger members







Wood Construction 4

Architectural Structures III ARCH 631

Timber Construction

post & beam



trusses

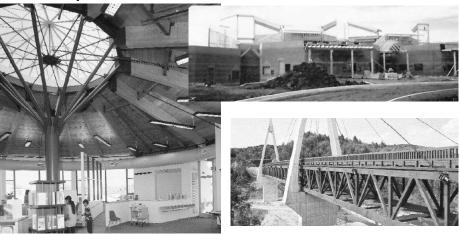


Wood Construction 5

Architectural Structures III ARCH 631 F2007abn

Timber Construction

· composite construction



Wood Construction Lecture 18 hitectural Structures I

F2007abn

Timber Construction by Code

- light-frame
 - light loads
 - -2x's
 - floor joists 2x6, 2x8,
 2x10, 2x12 typical at spacings of 12", 16", 24"



- normal spans of 20-25 ft or 6-7.5 m
- plywood spans between joists
- stud or load-bearing masonry walls
- limited to around 3 stories -fire safety

Timber Construction by Code

- heavy timber
 - member size rated for fire resistance
 - solid or built-up sections
 - beams spaced 4', 6' or8' apart or 1, 2 or 2.5 m



- normal spans of 10-20 ft or 3-6 m
- timber columns or load-bearing masonry walls
- knee-bracing common

Wood Construction 7 Architecture 18

Architectural Structures III
ARCH 631

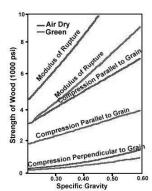
F2007abn

Wood Construction 8

Architectural Structures III ARCH 631

Timber

- lightweight : strength ~ like steel
- strengths vary
 - by wood type
 - by direction
 - by "flaws"
- size varies by tree growth
- manufactured wood
 - assembles pieces
 - adhesives



Wood Construction 9 Lecture 18 Architectural Structures III ARCH 631 F2007abn

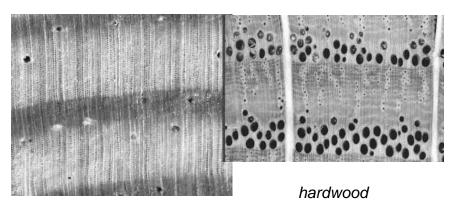
ARCH 631

Wood Properties

- moisture
 - exchanges with air easily
 - excessive drying causes warping and shrinkage
 - strength varies some
- temperature
 - steam
 - volatile products
 - combustion

Wood Properties

cell structure and density



softwood

Wood Construction 10 Lecture 18 Architectural Structures III ARCH 631 F2007abn

Wood Properties

- load duration
 - short duration
 - higher loads
 - normal duration
 - > 10 years
- creep
 - additional
 deformation with no additional load



Wood Construction 11 Lecture 18 Architectural Structures III
ARCH 631

F2007abn

Wood Construction 12 Lecture 18 Architectural Structures III ARCH 631

Wood Properties

- strength
 - allowable design loads are given with respect to <u>direction</u> of loading
 - wood is <u>weakest</u> in <u>shear</u> parallel to the grain
 - wood is <u>strongest</u> in <u>compression</u> and <u>tension</u> parallel to grain





Wood Construction 13 Lecture 18 Architectural Structures III ARCH 631

Lumber Grading

- light-framing
 - construction

visual

- standard
- utility

mechanical

- economy
- structural light-framing
 - select structural
 - no. 1, 2, & 3



Wood Construction 14

Architectural Structures III ARCH 631 F2007abn

Engineered Wood

- plywood
 - veneers at different orientations
 - glued together
 - split resistant
 - higher and uniform strength
 - limited shrinkage and swelling
 - used for sheathing, shear walls, diaphragms

Engineered Wood

- glued-laminated timber
 - glulam
 - short pieces glued together
 - straight or curved
 - grain direction parallel
 - higher strength
 - more expensive than sawn timber
 - large members (up to 100 feet!)
 - flexible forms



Wood Construction 15 Lecture 18 Architectural Structures III
ARCH 631

F2007abn

Wood Construction 16

Architectural Structures III ARCH 631

Engineered Wood

- I sections
 - beams
- other products
 - pressed veneer strip panels (Parallam)



- wood fibers
 - Hardieboard: cement & wood

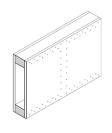
Wood Construction 17

Architectural Structures III

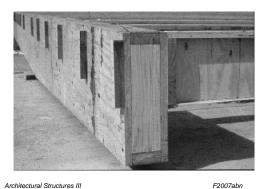
F2007abn

Timber Elements

- built-up box sections
 - built-up beams
 - usually site-fabricated
 - bigger spans



Wood Construction 19 Lecture 18

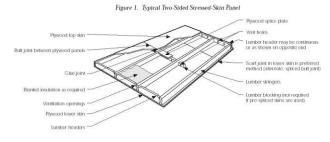


Architectural Structures III ARCH 631

Timber Elements

- stressed-skin elements
 - modular built-up "plates"
 - typically used for floors or roofs





Wood Construction 18 Architectural Structures III F2007abn

Timber Elements

- trusses
 - long spans
 - versatile
 - common in roofs





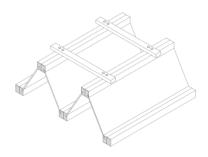


Architectural Structures III ARCH 631

F2007abr

Timber Elements

- folded plates and arch panels
 - usually of plywood



Wood Construction 21

Architectural Structures III ARCH 631 F2007abn

tension-induced

torsional buckling

Timber Elements

- beams
 - joists
 - girders
 - lateral bracing
 - deflection
 - elastic
 - creep

Hardwood finish flooring
Plywood subfloor

Drywall ceiling
Drywall ceiling
16"
16"

Figure 5.2 Typical joist floor construction.

Wood Construction 23 Lecture 18

Architectural Structures III F2007abri ARCH 631

Timber Elements

- arches and lamellas
 - arches commonly laminated timber
 - long spans
 - usually only for roofs

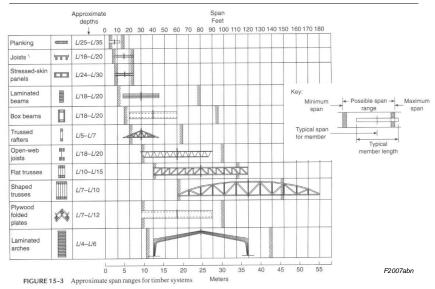






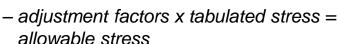
F2007abn

Approximate Depths



Wood Design

- National Design Specification
 - National Forest Products Association
 - ASD & LRFD (combined 2005)



- adjustment factors terms, C with subscript
- i.e, bending:

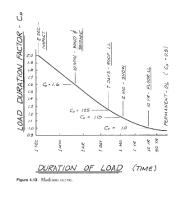
 $f_b \le F_b' = F_b \times (product \ of \ adjustment \ factors)$

Wood Construction 25 Lecture 18 Applied Architectural Structures ARCH 631 F2007abn

Adjustment Factors

- terms
 - $-C_D = load duration factor$
 - $-C_M$ = wet service factor
 - 1.0 dry ≤ 16% MC
 - $-C_F = size factor$
 - visually graded sawn lumber and round timber > 12" depth

$$C_F = (12/d)^{\frac{1}{9}} \le 1.0$$



Allowable Stresses

- design values
 - F_b: bending stress
 - $-F_t$: tensile stress | strong
 - − F_v: horizontal shear stress
 - $-F_{c\perp}$: compression stress (perpendicular to grain)
 - F_c: compression stress (parallel to grain) strong
 - E: modulus of elasticity
 - $-F_p$: bearing stress (parallel to grain)

y rallel to grain)

Wood Construction 26 Lecture 18 Architectural Structures III

Adjustment Factors

- terms
 - $-C_{fu}$ = flat use factor
 - not decking
 - $-C_i = incising factor$
 - · increase depth for pressure treatment
 - $-C_t = temperature factor$
 - · lose strength at high temperatures



Wood Construction 27

Architectural Structures III

F2007abn

Wood Construction 28 Lecture 19 Applied Architectural Structures ARCH 631 F2012abn

Adjustment Factors

- terms
 - $-C_r$ = repetitive member factor
 - 1.15 for more than 3 joists, < 24" o.c., or connected by load-distributing element
 - $-C_H$ = shear stress factor
 - splitting
 - $-C_v = volume\ factor\ for\ glulam$
 - replaces C_F for timber
 - $-C_L$ = beam stability factor
 - · beams without full lateral support

Wood Construction 29 Lecture 18 Architectural Structures III ARCH 631 F2007abr

Deflection Limits

relies on Uniform Building Code specs

Use	LL only	DL+LL
Roof beams:		
Industrial	L/180	L/120
Commercial		
plaster ceiling	L/240	L/180
no plaster	L/360	L/240
Floor beams:		
Ordinary Usage	L/360	L/240

Architectural Structures III F2007abri

Load Combinations

- design loads, take the bigger of
 - (dead loads)/0.9
 - (dead loads + any possible combination of live loads)/C_D
- deflection limits
 - no load factors
 - for stiffer members:
 - $\Delta_T \max from \ LL + 0.5(DL)$
 - · for instantaneous deflection



Wood Construction 30

Architectural Structures III ARCH 631 F2007abn

Wood Beam Design - Glulam

- find M
- determine allowable stress
 - Pinus Radiata (man.) basic working stress (MPa)

			Timberbond G	ilulam		
Moisture content	Bending parallel F'b	Compression parallel F'c	Tension parallel F'c	Shear in beam F's	Compression perpendicular F'p	Modular elasticity E(GPa)
			F11			
16%	13.8	12.5	8.3	1.9	4.3	12.0
			Engineeri	ng		
16%	12.1	11.7	7.3	1.8	4.0	11.0
			No.1 Fram	ing		
16%	10.6	10.9	6.4	1.8	4.0	9.0
			No.2 Fram	ing		
16%	8.2	10.0	4.9	1.8	4.0	8.0

Wood Construction 32 Lecture 18 Architectural Structures III ARCH 631

Wood Beam Design - Glulam

- calculate S_{required}
- choose width and height so that bh²/6 > S_{req'd}
- evaluateV, ∆, T
- considerbracing,connections

Wood Construction 33 Lecture 18

Technical Information

STANDARD SIZES OF STRAIGHT GLULAM MEMBERS

Beam Width (mm)			Beam Depth (mm)		
Nominal Dimension	Premium finish	Utility & Standard finish	No. of Laminations	Beam Depth	
50	38	40	1	45	
75	63	65	2	90	
100	88	90	3	135	
125	110	113	4	180	
150	133	135	5	225	
200	178	180	6	270	
225	203	205	7	315	
250	228	230	8	360	
300	278	280	9	405	
			10	450	
		[11	495	
		[12	540	
		[etc	etc	

Architectural Structures III F2007abn Wood Cor ARCH 631 Lecture 11

Allowable Wood Stress

$$F_c' = F_c(C_D)(C_M)(C_t)(C_F)(C_D)$$

• where:

 F_c = compressive strength parallel to grain

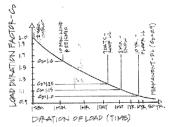
 C_D = load duration factor

 C_M = wet service factor (1.0 dry)

 C_t = temperature factor

 C_{E} = size factor

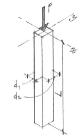
 $C_p = column \ stability \ factor$



Wood Columns

- slenderness ratio = L/d_{min} = L/d₁
 - $-d_1 = smaller dimension$
 - $-\ell_e/d \le 50 \text{ (max)}$

$$f_c = \frac{P}{A} \le F_c'$$

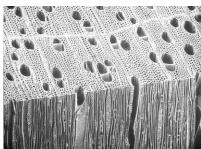


 where F'_c is the allowable compressive strength parallel to the grain

Wood Construction 34 Lecture 18 Architectural Structures III ARCH 631 F2007abn

Strength Factors

- wood properties and load duration, C_D
 - short duration
 - higher loads
 - normal duration
 - > 10 years



- stability, C_p
 - combination curve tables

$$F_c' = F_c^* C_p = (F_c C_D) C_p$$

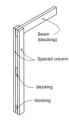
Wood Construction 36 Lecture 18 Architectural Structures III ARCH 631

C_p Charts

Sawed C _p 0.000 0.010 0.020 0.030 0.040 0.049 0.059 0.069	Clu-Lam C _p 0.000 0.010 0.020 0.030 0.040 0.050 0.060 0.069		0.40 0.41 0.42 0.43 0.44 0.45 0.46	Sawed C _p 0.360 0.367 0.375 0.383 0.390 0.398	$C_p \cdot F_c^*$ F_C Glu-Lam C_p 0.377 0.386 0.394 0.403 0.411 0.420		0.80 0.81 0.82 0.83	Sawed C _p 0.610 0.614 0.619 0.623	C _p 0.667 0.672 0.678 0.683	-	$\frac{F_{CE}}{F_C}^*$ 1.20 1.22 1.24	Sawed <i>C_p</i> 0.750 0.755 0.760	Glu-Lam C _p 0.822 0.826 0.831
0.000 0.010 0.020 0.030 0.040 0.049 0.059	0.000 0.010 0.020 0.030 0.040 0.050 0.060		0.40 0.41 0.42 0.43 0.44 0.45	0.360 0.367 0.375 0.383 0.390 0.398	0.377 0.386 0.394 0.403 0.411		0.80 0.81 0.82 0.83	0.610 0.614 0.619 0.623	0.667 0.672 0.678 0.683	-	1.20 1.22 1.24	0.750 0.755	0.822 0.826 0.831
0.010 0.020 0.030 0.040 0.049 0.059	0.010 0.020 0.030 0.040 0.050 0.060		0.41 0.42 0.43 0.44 0.45	0.367 0.375 0.383 0.390 0.398	0.386 0.394 0.403 0.411		0.81 0.82 0.83	0.614 0.619 0.623	0.672 0.678 0.683		1.22 1.24	0.755	0.826 0.831
0.020 0.030 0.040 0.049 0.059	0.020 0.030 0.040 0.050 0.060		0.42 0.43 0.44 0.45	0.375 0.383 0.390 0.398	0.394 0.403 0.411		0.82 0.83	0.619 0.623	0.678 0.683		1.24		0.831
0.030 0.040 0.049 0.059	0.030 0.040 0.050 0.060		0.43 0.44 0.45	0.383 0.390 0.398	0.403 0.411		0.83	0.623	0.683			0.760	
0.040 0.049 0.059	0.040 0.050 0.060		0.44 0.45	0.390 0.398	0.411								
0.049 0.059	0.050 0.060		0.45	0.398			0.04		0.000		1.26	0.764	0.836
0.059	0.060				0.420		0.84	0.628	0.688		1.28	0.769	0.840
			0.46				0.85	0.632	0.693		1.30	0.773	0.844
0.069	0.060		0.40	0.405	0.428		0.86	0.637	0.698		1.32	0.777	0.848
	0.069		0.47	0.412	0.436		0.87	0.641	0.703		1.34	0.781	0.852
0.079	0.079		0.48	0.419	0.444		0.88	0.645	0.708		1.36	0.785	0.855
0.088	0.089		0.49	0.427	0.453		0.89	0.649	0.713		1.38	0.789	0.859
0.098	0.099		0.50	0.434	0.461		0.90	0.653	0.718		1.40	0.793	0.862
0.107	0.109		0.51	0.441	0.469		0.91	0.658	0.722		1.42	0.796	0.865
0.117	0.118		0.52	0.448	0.477		0.92	0.661	0.727		1.44	0.800	0.868
0.126	0.128		0.53	0.454	0.484		0.93	0.665	0.731		1.46	0.803	0.871
0.136	0.138		0.54	0.461	0.492		0.94	0.669	0.735		1.48	0.807	0.874
0.145	0.147		0.55	0.468	0.500		0.95	0.673	0.740		1.50	0.810	0.877
0.154	0.157		0.56	0.474	0.508		0.96	0.677	0.744		1.52	0.813	0.879
0.164	0.167		0.57	0.481	0.515		0.97	0.680	0.748		1.54	0.816	0.882
0.173	0.176		0.58	0.487	0.523		0.98	0.684	0.752		1.56	0.819	0.884
0.182	0.186		0.59	0.494	0.530		0.99	0.688	0.756		1.58	0.822	0.887
	0.107 0.117 0.126 0.136 0.145 0.154 0.164	0.107 0.109 0.117 0.118 0.126 0.128 0.136 0.138 0.145 0.147 0.154 0.157 0.164 0.167 0.173 0.176 0.182 0.186	0.107 0.109 0.117 0.118 0.126 0.128 0.136 0.138 0.145 0.147 0.154 0.157 0.164 0.167 0.173 0.176 0.182 0.186	0.107 0.109 0.51 0.117 0.118 0.52 0.126 0.128 0.53 0.136 0.138 0.54 0.145 0.147 0.55 0.154 0.157 0.56 0.164 0.167 0.58 0.173 0.176 0.58 0.182 0.186 0.59	0.107 0.109 0.51 0.441 0.117 0.118 0.52 0.448 0.126 0.128 0.53 0.454 0.136 0.138 0.54 0.461 0.145 0.147 0.55 0.468 0.154 0.157 0.56 0.474 0.164 0.167 0.57 0.481 0.173 0.176 0.58 0.487 0.182 0.186 0.59 0.494	0.107 0.109 0.51 0.441 0.469 0.117 0.118 0.52 0.448 0.477 0.126 0.128 0.53 0.454 0.484 0.136 0.136 0.138 0.54 0.461 0.492 0.145 0.157 0.56 0.474 0.508 0.164 0.167 0.57 0.481 0.515 0.173 0.176 0.58 0.487 0.523 0.182 0.186 0.59 0.494 0.530 37	0.107 0.109 0.51 0.441 0.469 0.117 0.118 0.52 0.448 0.477 0.126 0.128 0.53 0.454 0.484 0.473 0.136 0.138 0.54 0.461 0.492 0.145 0.147 0.55 0.468 0.500 0.154 0.167 0.56 0.474 0.508 0.164 0.167 0.57 0.481 0.515 0.173 0.176 0.58 0.487 0.523 0.182 0.186 0.59 0.494 0.530 0.37	0.107 0.109 0.51 0.441 0.469 0.91 0.117 0.118 0.52 0.448 0.477 0.92 0.126 0.128 0.53 0.454 0.467 0.93 0.136 0.138 0.54 0.461 0.492 0.94 0.145 0.147 0.55 0.468 0.500 0.95 0.154 0.157 0.56 0.474 0.508 0.96 0.164 0.167 0.57 0.481 0.515 0.97 0.173 0.176 0.58 0.487 0.523 0.98 0.182 0.186 0.59 0.494 0.530 0.99	0.107 0.109 0.51 0.441 0.469 0.91 0.658 0.117 0.118 0.52 0.448 0.477 0.92 0.661 0.126 0.128 0.53 0.454 0.484 0.93 0.665 0.136 0.138 0.54 0.461 0.492 0.94 0.669 0.145 0.147 0.500 0.95 0.673 0.154 0.157 0.56 0.474 0.508 0.96 0.677 0.164 0.167 0.57 0.481 0.515 0.97 0.680 0.173 0.176 0.58 0.487 0.523 0.98 0.684 0.182 0.186 0.186 0.500 0.530 0.99 0.688 37 Architectural Structures III	0.107 0.109 0.51 0.441 0.469 0.91 0.658 0.722 0.117 0.118 0.52 0.448 0.477 0.92 0.661 0.727 0.126 0.128 0.53 0.454 0.484 0.93 0.665 0.735 0.136 0.138 0.54 0.461 0.492 0.94 0.669 0.735 0.145 0.147 0.500 0.95 0.673 0.740 0.154 0.157 0.56 0.474 0.508 0.96 0.677 0.748 0.164 0.167 0.57 0.481 0.515 0.97 0.680 0.748 0.173 0.176 0.58 0.487 0.523 0.98 0.684 0.752 0.182 0.186 0.189 0.530 0.99 0.688 0.756 Architectural Structures III	0.107 0.109 0.51 0.441 0.469 0.91 0.658 0.722 0.117 0.118 0.52 0.448 0.477 0.92 0.661 0.722 0.126 0.128 0.53 0.454 0.484 0.93 0.665 0.731 0.136 0.138 0.54 0.461 0.492 0.94 0.669 0.735 0.145 0.147 0.55 0.468 0.500 0.95 0.673 0.740 0.154 0.157 0.56 0.474 0.508 0.96 0.677 0.744 0.164 0.167 0.57 0.481 0.515 0.97 0.680 0.748 0.173 0.176 0.58 0.487 0.523 0.98 0.684 0.752 0.182 0.186 0.186 0.530 0.99 0.688 0.756 Architectural Structures III	0.107 0.109 0.51 0.441 0.469 0.91 0.658 0.722 1.42 0.117 0.118 0.52 0.448 0.477 0.92 0.661 0.727 1.44 0.126 0.128 0.53 0.454 0.484 0.93 0.665 0.731 1.46 0.136 0.138 0.54 0.461 0.492 0.94 0.669 0.735 1.48 0.145 0.147 0.55 0.468 0.500 0.95 0.673 0.740 1.50 0.154 0.157 0.56 0.474 0.508 0.96 0.677 0.744 1.52 0.164 0.167 0.57 0.481 0.515 0.97 0.680 0.748 1.54 0.173 0.176 0.58 0.487 0.523 0.98 0.684 0.752 1.56 0.173 0.186 0.186 0.590 0.530 0.99 0.688 0.756 1.58 37	0.107 0.109 0.51 0.441 0.469 0.91 0.658 0.722 1.42 0.796 0.117 0.118 0.52 0.448 0.477 0.92 0.661 0.727 1.44 0.803 0.128 0.52 0.448 0.493 0.665 0.731 1.46 0.803 0.136 0.138 0.54 0.461 0.492 0.94 0.669 0.735 1.48 0.803 0.145 0.147 0.55 0.468 0.500 0.95 0.673 0.740 1.50 0.810 0.154 0.157 0.56 0.474 0.508 0.96 0.677 0.744 1.52 0.813 0.164 0.167 0.55 0.481 0.515 0.97 0.680 0.748 1.54 0.816 0.173 0.176 0.58 0.487 0.523 0.98 0.684 0.752 1.56 0.819 0.182 0.186 0.189 0.530 0.99

Procedure

- 2. select a section
 - if P & A known, set stress at limit
 - solve for ℓ_e , L, or d_{min}
 - if P & ℓ_e known,
 - find A, or d_{min}
- 3. continue from 2 until F_c satisfied

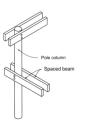


Procedure

- 1. obtain F_c
 - find ℓ_e /d or assume (ℓ_e /d \leq 50)
 - compute $F_{cE} = \frac{K_{cE}E}{\binom{l_e/d}{2}}$
 - K_{cE}=0.3 sawn
 - $K_{cE} = 0.418 \text{ glu-lam}$
 - compute $F_c^* \approx F_c C_D$
 - find F_{cE}/F_c^* and get C_p

$$F_c' = F_c^* C_p$$

Wood Construction 38 Architectural Structures III
Lecture 18 ARCH 631

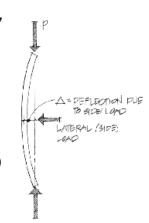


F2007abn

Eccentric Loading Stress Limit

- in reality, as the column flexes, the moment increases
- P-∆ effect

$$\frac{f_a}{F_a} + \frac{f_b \times (Magnification\ factor)}{F_{bx}} \le 1.0$$



Wood Construction 39 Lecture 18 Architectural Structures III
ARCH 631

F2007abn

Wood Construction 40

Architectural Structures III ARCH 631

Column with Bending Design

interaction equation

$$\left[\frac{f_{c}}{F'_{c}}\right]^{2} + \frac{f_{bx}}{F'_{bx}\left[1 - \frac{f_{c}}{F_{cEx}}\right]} \le 1.0$$

() term – magnification factor for P-∆ F'_{bx} – allowable bending strength



Wood Construction 41

Architectural Structures III ARCH 631

F2007abn

Wood Construction 42 Lecture 18

Architectural Structures III ARCH 631

Construction Requirements - Wood

- if not treated
 - height above exposed ground
 - 18" joists, 12" girders
 - in masonry or concrete
 - provide ½" air space
- foundation sills must be treated
- structural members
 - must be protected from exposure to weather and water



Structural Supervision

- review changes in shop drawings!
- inspection of construction
 - verify compliance with plans
- some materials require more
 - variability of materials
 - sampling and testing



F2007abr

Construction Requirements - Wood

- crawl space ventilation
- fire stops
 - walls
 - at ceiling and floor and every 10' along
 - interconnections
 - soffits and dropped ceilings
 - concealed spaces
 - · access for passage of fire
 - · stairways & between floors and roof



Wood Construction 43 Lecture 18

Architectural Structures III ARCH 631

F2007abn

Wood Construction 44 Lecture 18

Architectural Structures III ARCH 631