Calculating the Superimposed Load on Wood-Frame Walls for ASTM E119 Standard Fire-Resistance Tests

During an ASTM E119 standard fire-resistance wall test, the wall assembly is required to be subjected to a superimposed load to simulate a maximum load condition per nationally recognized structural design criteria. In the U.S., the nationally recognized structural design procedures for wood construction are contained in the *National Design Specification for Wood Construction®*. In accordance with these standard design procedures, the superimposed load applied to a 2x4 wood stud wall assembly is typically limited by the adjusted compression design stress parallel to grain of the wood stud. Thus, the maximum superimposed load for any wall being tested is the sum of the maximum allowable design loads for each stud in the wall assembly. As an alternative, ASTM E119 permits testing at less than the maximum load, however, these tests must be reported as being conducted under restricted load conditions.

Table 1 gives calculated superimposed loads for a typical 10' x 10' test assembly configuration constructed with nine (9) studs of common wood species groups and lumber grades. An example calculation is given below. The calculations are based on 2018 *National Design Specification for Wood Construction® (NDS®)* design procedures. These calculated values are also given in *ASTM D 6513 Standard Practice for Calculating the Superimposed Load on Wood-Frame Walls for Standard Fire-Endurance Tests.*

EXAMPLE CONSTRUCTION (See Figure 1):
Studs: Douglas fir – Larch (DFL) Select Structural (SS), 1.5" x 3.5" @ 16" o.c., 115.5" long
Plates: DFL SS, 1.5" x 3.5" - 1 bottom plate 120" long
- 2 top plates 120" long

Configuration: 9 studs arranged symmetrically
Insulation: 3.5" thick Mineral Wool Insulation
Sheathing: 5/8" Type X gypsum wallboard each side

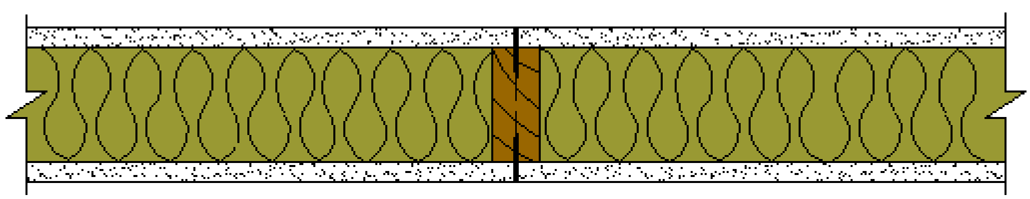

Figure 1 – Plan view of example wall cross section

CALCULATION OF SUPERIMPOSED LOAD:
Compressive resistance of the example wood stud wall loaded parallel to grain, P_r, determined in accordance with the *NDS* using Allowable Stress Design (ASD) procedures:

F_c = reference compression design value parallel to grain = 1,700 psi

F_c^* = reference compression design value multiplied by all applicable adjustment factors except C_P

= $F_c C_D C_M C_t C_F C_i$ (Table 4.3.1, NDS 2018)

$=$ (1,700 psi)(1.0)(1.0)(1.0)(1.15)(1.0) = 1,955 psi

Where:

F_c	=	reference compression design value parallel to grain = 1,700 psi
C_D	=	load duration factor = 1.0
C_M	=	wet service factor = 1.0
C_t	=	temperature factor = 1.0
C_F	=	size factor = 1.15 (for 1.5" x 3.5" studs, SS grade DFL)
C_i	=	incising factor = 1.0
C_P	=	column stability factor
A	=	area of cross-section = (3.5")(1.5") = 5.25 in^2

Due to the slenderness of the studs, the adjusted compression design stress parallel to grain is affected by the buckling resistance of each stud. For strong-axis buckling of the stud (perpendicular to the plane of wall):

$$C_P = \frac{1+(F_{cE}/F_c^*)}{2c} - \sqrt{\left[\frac{1+(F_{cE}/F_c^*)}{2c}\right]^2 - \frac{F_{cE}/F_c^*}{c}}$$

$$= \frac{1+(521/1{,}955)}{(2)(0.8)} - \sqrt{\left[\frac{1+(521/1{,}955)}{(2)(0.8)}\right]^2 - \frac{521/1{,}955}{0.8}}$$

$$= 0.7915 - \sqrt{(0.7915)^2 - 0.3330} \quad = \quad 0.2498$$

Where:

$$F_{cE} = \frac{0.822 E_{min}'}{(\ell_e/d)^2} = \frac{(0.822)(690{,}000\ psi)}{(33)^2} = 521\ psi$$

E_{min}	=	reference minimum modulus of elasticity design value = 690,000 psi
E_{min}'	=	adjusted minimum modulus of elasticity design value for beam and column stability multiplied by all applicable adjustment factors
	=	$E_{min}\, C_M\, C_t\, C_i\, C_T$ (Table 4.3.1, NDS 2018)
	=	(690,000 psi)(1.0)(1.0)(1.0)(1.0) = 690,000 psi
C_T	=	buckling stiffness factor = 1.0
ℓ_e/d	=	slenderness ratio = 115.5" / 3.5" = 33
c	=	0.8 for sawn lumber

F_c' = adjusted compression design value parallel to grain

$=$ $F_c^*\, C_P$ = (1,955 psi)(0.2498) = 488 psi

P_r = $F_c'A$ = (488 psi)(5.25 in^2) = <u>2,564 lb/stud</u>

As used in typical construction, weak-axis buckling of the stud (in the plane of the wall) is prevented by the gypsum wallboard which is fastened to the stud. Each fastener acts as a bracing point along the stud length.

Compressive resistance of wood plates loaded perpendicular to grain, Q_r, as determined in accordance with the *NDS* (ASD Method) for the Example construction:

$F_{c\perp}$ = reference compression design value perpendicular to grain = 625 psi
$F_{c\perp}'$ = adjusted compression design value perpendicular to grain multiplied by all applicable adjustment factors except C_P
= $F_{c\perp} C_M C_t C_i C_b$ (Table 4.3.1, NDS 2018)
= (625 psi)(1.0)(1.0)(1.0)(1.0) = 625 psi

Where:
C_M = wet service factor = 1.0
C_t = temperature factor = 1.0
C_i = incising factor = 1.0
C_b = bearing area factor = 1.0
A = area of cross-section = (3.5")(1.5") = 5.25 in^2

Q_r = $F_{c\perp}'A$ = (625 psi)(5.25 in^2) = 3281 lb/stud

Compression perpendicular to grain resistance does not control ($Q_r > P_r$). Accordingly, the superimposed load is limited by compression parallel to grain resistance of 2,564 lb/stud.

SUPERIMPOSED WALL LOADING:

Required Superimposed Line Load on Wall Assembly for the Example Construction:

$W_s = P_r$ (Number of studs) = (2,564 lb/stud)(9 studs) = **23.1 kips**

Table 1 - 2018 NDS Reference Design Stresses and Superimposed Loads

			2018 NDS Reference Design Stresses [1]				Superimposed Load	
Species	Grade	Size	F_c (psi)	$F_{c\perp}$ (psi)	E (psi)	E_{min} (psi)	Stud Load [2,3] (lbf/stud)	Total Load [4] (lbf)
DOUGLAS FIR-LARCH	SS	2x4	1,700	625	1,900,000	690,000	2,564	23,073
	#1	2x4	1,500	625	1,700,000	620,000	2,300	20,703
	#2	2x4	1,350	625	1,600,000	580,000	2,145	19,307
	STANDARD	2x4	1,400	625	1,400,000	510,000	1,890	17,011
	STUD	2x4	850	625	1,400,000	510,000	1,797	16,176
SOUTHERN PINE	Dense SS	2x4	2,050	660	1,900,000	690,000	2,573	23,154
	SS	2x4	1,900	565	1,800,000	660,000	2,455	22,096
	#1 Dense	2x4	1,750	660	1,800,000	660,000	2,439	21,952
	#1	2x4	1,650	565	1,600,000	580,000	2,156	19,400
	#2 Dense	2x4	1,500	660	1,600,000	580,000	2,139	19,250
	#2	2x4	1,450	565	1,400,000	510,000	1,895	17,058
	STUD	2x4	850	565	1,300,000	470,000	1,664	14,980
	STANDARD	2x4	1,300	565	1,200,000	440,000	1,640	14,759
HEM-FIR	SS	2x4	1,500	405	1,600,000	580,000	2,126	19,136
	#1	2x4	1,350	405	1,500,000	550,000	2,043	18,386
	#2	2x4	1,300	405	1,300,000	470,000	1,761	15,846
	STANDARD	2x4	1,300	405	1,200,000	440,000	1,640	14,759
	STUD	2x4	800	405	1,200,000	440,000	1,570	14,130
SPRUCE-PINE-FIR	SS	2x4	1,400	425	1,500,000	550,000	2,048	18,436
	#1/#2	2x4	1,150	425	1,400,000	510,000	1,881	16,931
	STANDARD	2x4	1,150	425	1,200,000	440,000	1,624	14,617
	STUD	2x4	725	425	1,200,000	440,000	1,548	13,931

1. Reference design stresses from the 2018 NDS.
2. Stud load is calculated based on F_c' using a stud length of 115.5 inches, resulting in $L_e/d = 33$.
3. Stud load is calculated based on $F_{c\perp}$' assuming plates of the same species as the studs.
4. The tabulated total load is calculated assuming the wall contains nine studs.