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

During an ASTM E119 standard fire endurance 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 wood stud wall assemblies 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.

A design example and a table of maximum allowable superimposed loads for common wood species groups and lumber grades follow. The calculations are based on 2005 National Design Specification for Wood Construction® (NDS®) design procedures as specified in ASTM D 6513 Standard Practice for Calculating the Superimposed Load on Wood-Frame Walls for Standard Fire-Endurance Tests.

EXAMPLE CONSTRUCTION:
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 (See Figure 1)
Insulation: 3.5” thick Mineral Wool Insulation
Sheathing: 5/8” Type X gypsum wallboard each side

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:

$$F_c = \text{reference compression design value parallel to grain} = 1,700 \text{ psi}$$

$$F_c^* = \text{reference compression design value multiplied by all applicable adjustment factors except } C_p$$

$$= F_c C_D C_M C_I C_T C_{t}$$

$$= (1,700 \text{ psi})(1.0)(1.0)(1.0)(1.15)(1.0) = 1,955 \text{ psi}$$

(Table 4.3.1, NDS 2005)
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):

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

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

\[
= 0.7915 - \sqrt{(0.7915)^2 - 0.3330} = 0.2498
\]

Where:

- \( F_{cE} \) = \( \frac{0.822 E_{min}'}{(\ell_c/d)^2} \) = \( \frac{(0.822)(690,000 \text{ psi})}{(33)^2} \) = 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
  \[ = E_{min} C_M C_t C_i C_T \text{ (Table 4.3.1, NDS 2005)} \]
  \[ = (690,000 \text{ psi})(1.0)(1.0)(1.0)(1.0) = 690,000 \text{ psi} \]
- \( C_T \) = buckling stiffness factor = 1.0
- \( \ell_c/d \) = slenderness ratio = 115.5” / 3.5” = 33
- \( c \) = 0.8 for sawn lumber

\[ F_c' = \text{adjusted compression design value parallel to grain} \]

\[ F_c' = F_{cE} C_P = (1,955 \text{ psi})(0.2498) = 488 \text{ psi} \]

\[ P_r = F_c'A = (488 \text{ psi})(5.25 \text{ in}^2) = 2,564 \text{ lb/stud} \]

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:

\[ F_{c,\perp} = \text{reference compression design value perpendicular to grain} = 625 \text{ psi} \]
\[ F_{c,\perp}' = \text{adjusted compression design value perpendicular to grain multiplied by all applicable adjustment factors except } C_p \]
\[ = F_{c,\perp} C_M C_t C_i C_b \]  
\[ = (625 \text{ psi}) (1.0)(1.0)(1.0)(1.0) = 625 \text{ psi} \]  

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

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

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:

\[ W_s = P_r \times \text{(Number of studs)} = (2,564 \text{ lb/stud})(9 \text{ studs}) = 23.1 \text{ kips} \]
Table 1. 2005 NDS Reference Design Stresses and Superimposed Loads

<table>
<thead>
<tr>
<th>Species</th>
<th>Grade</th>
<th>Size</th>
<th>$F_c$ (psi)</th>
<th>$F_{cL}$ (psi)</th>
<th>$E$ (psi)</th>
<th>$E_{min}$ (psi)</th>
<th>Stud Load (lbf/stud)</th>
<th>Total Load (lbf)</th>
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1. Reference design stresses from the 2005 NDS.
2. Stud load is calculated based on $F_c'$ using a stud length of 115.5 inches, resulting in $L/s = 33$.
3. Stud load is calculated based on $F_{cL}'$ assuming plates of the same species as the studs.
4. The tabulated total load is calculated assuming the wall contains nine studs.