# Chapter 4 Timber Design Code

CIVE480 Timber Structures
2019

University of Victoria

# 4.1 Design Method

# 1) Design goal — SAFE

- Timber design code: *O86-14 Engineering Design in Wood (CSA 2017)*

Load effect ≤ Resistance

Random variables    Random variables

**Reliability-based (or probabilistic) design**

Limit states design

# 2) Limit states design

Limit states design

Strength limit states → Maximum load-carrying capacity of the structure

Serviceability limit states → Restrict the normal use and occupancy of the structure (e.g. excessive deflection, vibration…)

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# 2) Limit states design — performance function

- Principles of reliability-based design consider all of the uncertainties involved in the design process.

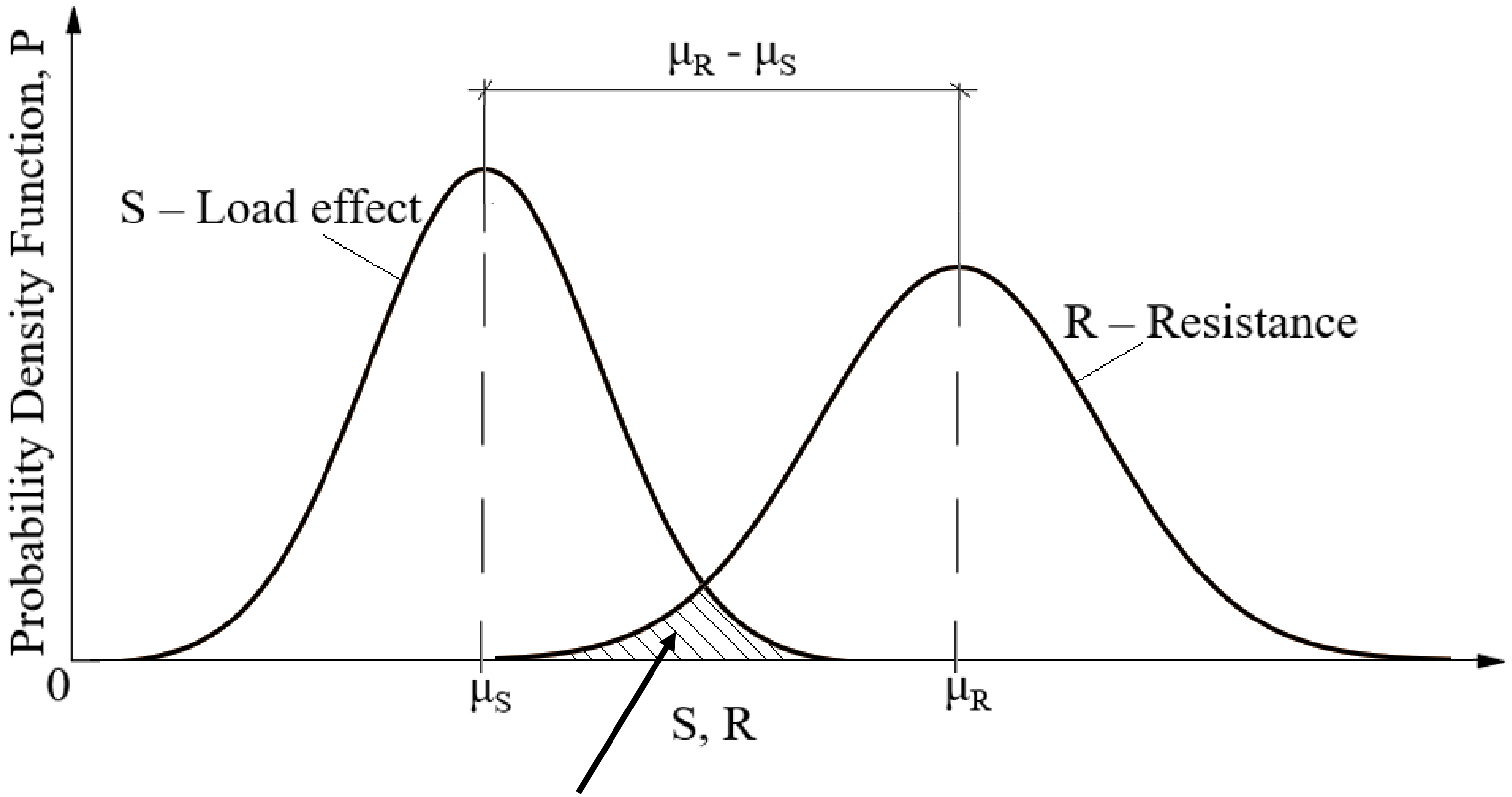
Performance function: $Z(x_1, x_2, \ldots, x_N)$, ($x_i$: design variable)

By convention: $Z = R - S$, (R: capacity, S: demand)

- The probability of non-performance: $P(Z < 0)$
- The probability of performance: $P(Z > 0)$
- Limit state: $Z = 0$

# 2) Limit states design — probability of failure

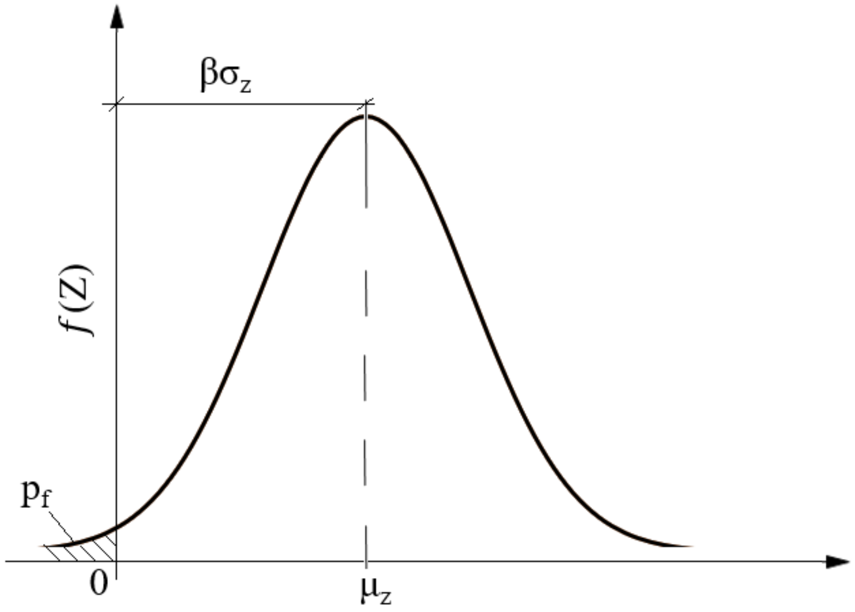
Probabilistic design
Each variable is a probability distribution (not a single value)




Shaded area stands for the probability of failure, where S > R

# 2) Limit states design — reliability index $\beta$

Performance function: Z = R-S




Probability density function of *f(Z)*

- $\mu_z$ : mean of the distribution
- $\sigma_z$ : standard deviation

Probability of failure: $p_f$

$$p_f = P(Z < 0) = \int_{-\infty}^{0} f(Z)dZ = \Phi\left(-\frac{\mu_Z}{\sigma_Z}\right)$$

$$p_f = \Phi(-\beta)$$

where

$\Phi$ is the cumulative distribution function of the standard normal distribution

$\beta = \frac{\mu_Z}{\sigma_Z}$ , is the reliability index

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# 2) Limit states design — reliability index $\beta$

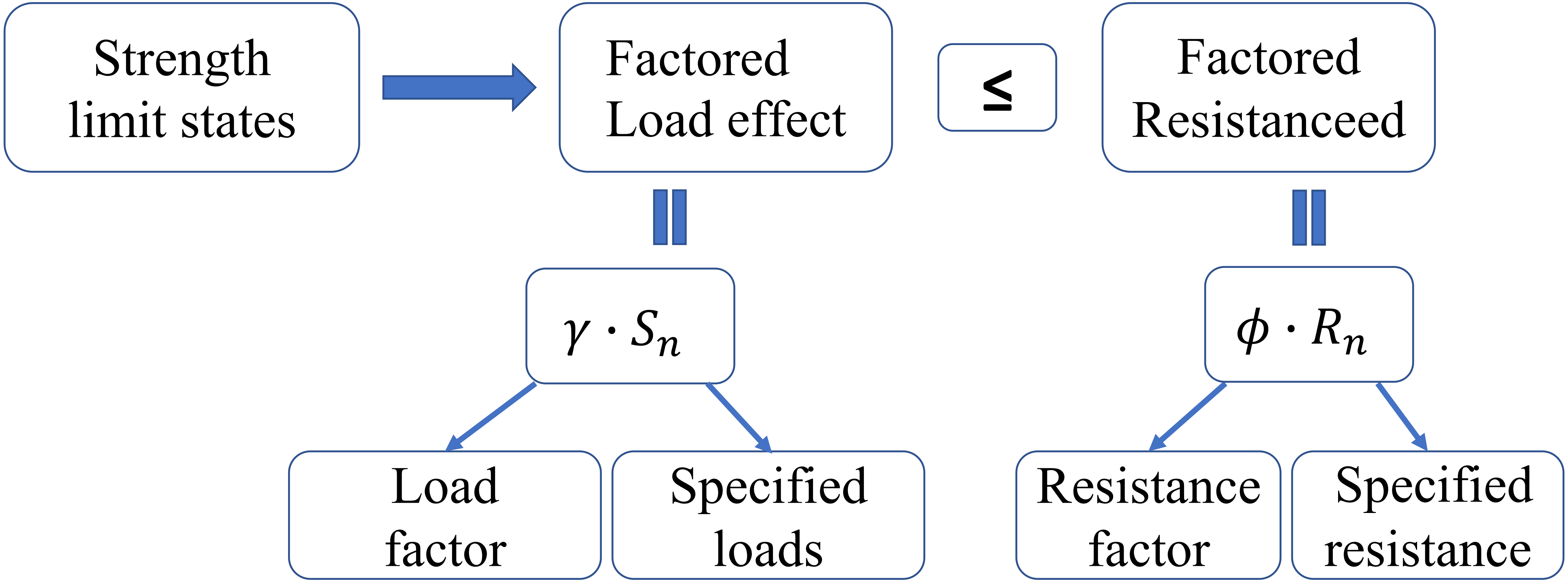
$$p_f = \Phi(-\beta)$$

There is relationship between the reliability index $\beta$ and probability of failure $p_f$:

larger $\beta$ leads to smaller $p_f$.

| **Reliability index** $\beta$ | **Probability of failure** $p_f$ |
|---|---|
| 1.0 | 0.159 |
| 2.0 | 0.0228 |
| 3.0 | 0.00135 |
| 4.0 | 0.0000316 |
| … | … |

# 2) Limit States Design — Factored load and resistance



# 2) Limit states design — load and resistance factors

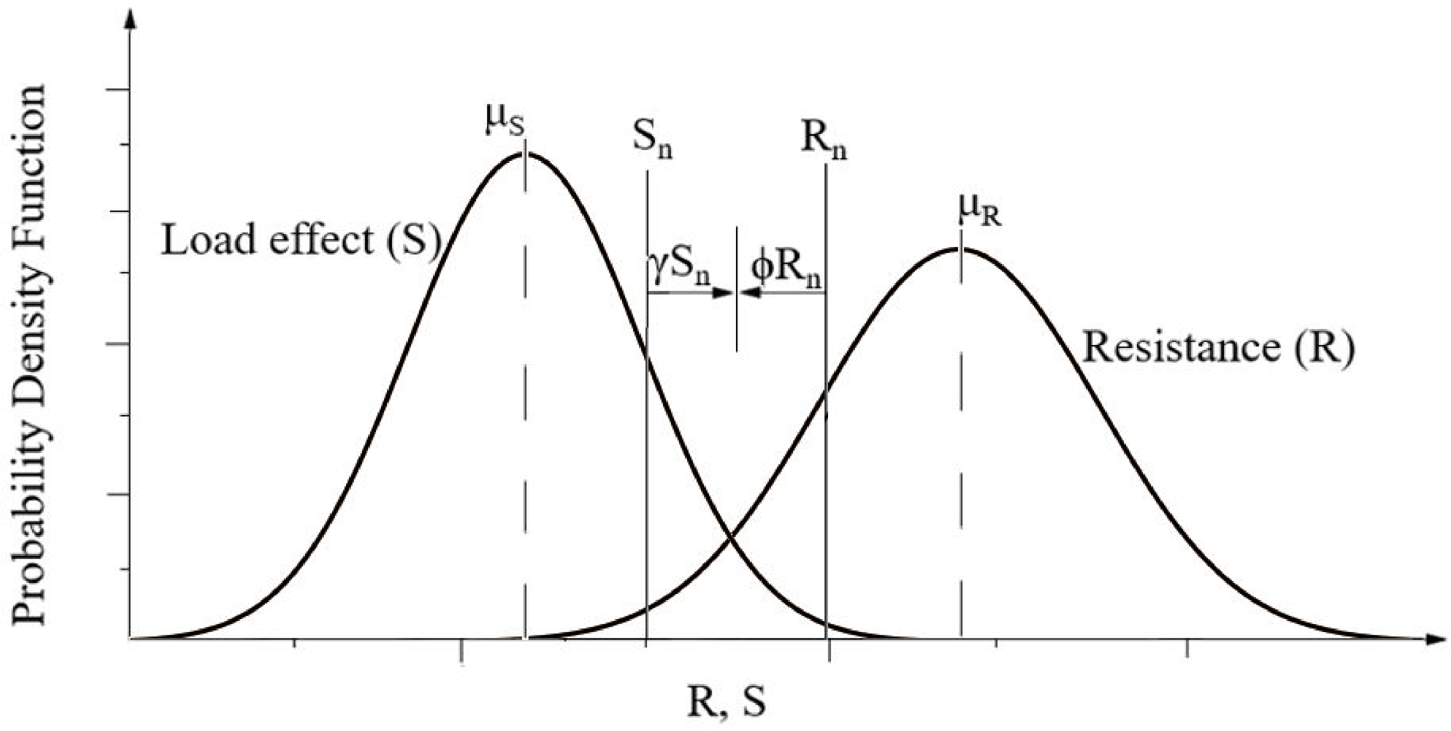
$$\gamma \cdot S_n \leq \phi \cdot R_n$$

$\gamma$: Load factor: $\gamma \geq 1$

$\phi$: Resistance factor: $\phi \leq 1$

$R_n$: Specified resistance

$S_n$: Specified load




The resistance factor $\phi$ can be calibrated to meet target reliability

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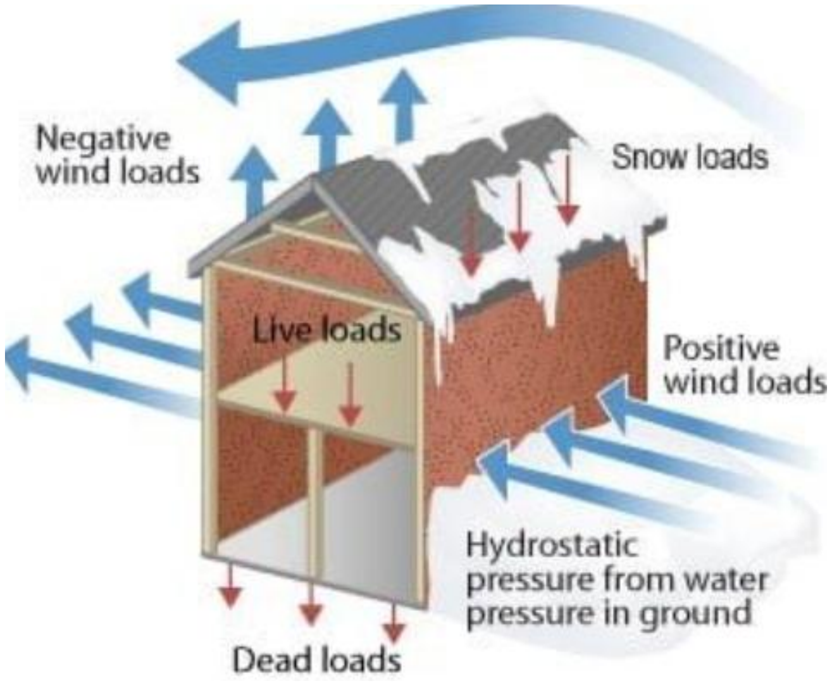
# 4.2 Load Types

# 1) Specified loads

The loads that need to be considered are as follows:

- **D** – Dead load due to **weight** of building components
- **E** – Load due to **earthquake**
- **L** – Live load due to **use and occupancy**
- **S** – Load due to **snow (ice and rain)**
- **W** – Load due to **wind**
- ……




*theconstructor.org*

# 2) Importance factors

- Depend on the type of load and the building use and occupancy.

*roofdoctorutah.com*

Applied to:

- E (earthquake)
- S (snow)
- W (wind)

# 2) Importance factors

- Depend on the type of load and the building use and occupancy.

| | **Snow Loads, $I_S$** | | **Wind Loads, $I_W$** | | **Earthquake Loads, $I_E$** | |
|---|---|---|---|---|---|---|
| Importance category | Limit State | | Limit State | | Limit State | |
| | Ultimate | Serviceability | Ultimate | Serviceability | Ultimate | Serviceability |
| Low | 0.8 | 0.9 | 0.8 | 0.75 | 0.8 | - |
| Normal | **1.0** | **0.9** | **1.0** | **0.75** | **1.0** | **-** |
| High | 1.15 | 0.9 | 1.15 | 0.75 | 1.3 | - |
| Post-Disaster | 1.25 | 0.9 | 1.25 | 0.75 | 1.5 | - |

# 2) Importance factors

<u>Importance categories:</u>

- Low — Low hazard to human life in the event of failure
- Normal — All buildings except low, high, or post-disaster
- High — Buildings **likely to be used** as post-disaster shelters (e.g. schools and community centres)
- Post-disaster —Buildings **essential** to provide services in a disaster

# 3) Load combinations — ultimate limit state

- **Most unfavourable effect** considering all possible load combinations

(principal loads only and principal loads + companion loads, *4.1.3.2. 3) of NBCC 2015*)

| Case | Principal Loads | Companion Loads |
|---|---|---|
| 1 | 1.4D | |
| 2 | (1.25D or 0.9D) + 1.5L | 1.0S or 0.4W |
| 3 | (1.25D or 0.9D) + 1.5S | 1.0L or 0.4W |
| 4 | (1.25D or 0.9D) + 1.4W | 0.5L or 0.5S |
| 5 | 1.0D + 1.0E | 0.5L + 0.25S |

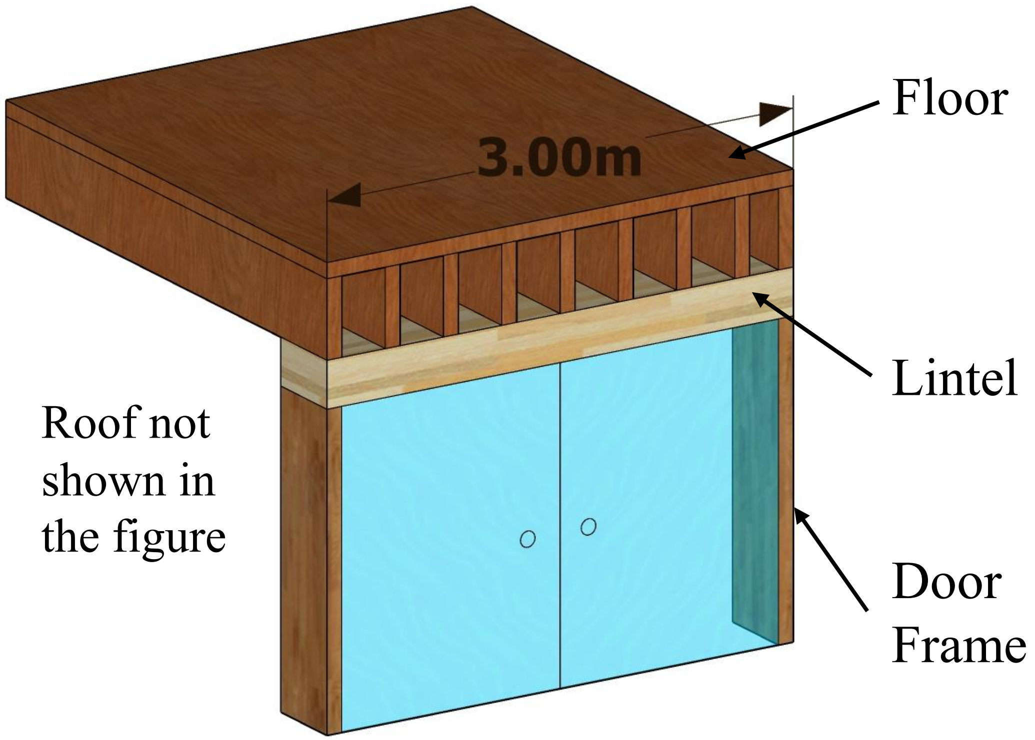
# 3) Load combinations — serviceability limit states

| Case | Principal Loads | Companion Loads |
|---|---|---|
| 1 | 1.0D | - |
| 2 | 1.0D + 1.0L | 0.5S or 0.4W |
| 3 | 1.0D + 1.0S | 0.5L or 0.4W |
| 4 | 1.0D + 1.0W | 0.5L or 0.5S |

# Example 1: Lintel loads

<u>Determine the design loads for the following conditions:</u>

- 3 meter long lintel supporting roof and one floor of a school
- Tributary width of both roof and floor = 3 m
- Specified roof dead load = 1 kPa
- Specified floor dead load = 1.5 kPa
- Minimum specified roof live load = 1.0 kPa
- Specified floor live load = 2.4 kPa
- 1 in 50 year ground snow load, $S_S$ = 1.8 kPa
- 1 in 50 year associated rain load, $S_r$ = 0.2 kPa
- Basic snow load factor, $C_b$ = 0.8
- Snow load wind exposure factor, $C_w$ = 1.0
- Snow load slope factor, $C_s$ = 1.0
- Snow load shape factor, $C_a$ = 1.0



# Solution part 1: Lintel loads

**Ultimate Limit States:**

- Uniform specified dead load

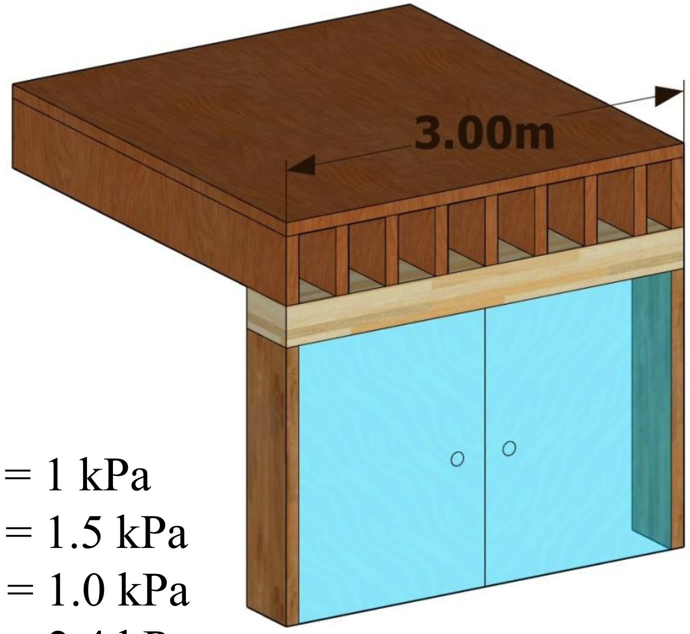
$$w_D = (1)(3) + (1.5)(3) = 7.5\,\frac{kN}{m}$$

- Uniform specified floor live load

$$w_L = (3)(2.4) = 7.2\,\frac{kN}{m}$$

- Uniform specified roof live load

$$w_L = (3)(1.0) = 3.0\,\frac{kN}{m}$$




$D_{roof}$ = 1 kPa
$D_{floor}$ = 1.5 kPa
$L_{roof}$ = 1.0 kPa
$L_{floor}$ = 2.4 kPa
Tributary width = 3 m

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# Solution part 1: Lintel loads

**Ultimate Limit States:**

- Specified snow load

$$S = I_S[S_S(C_b C_w C_S C_a) + S_r]$$
$$= 1.15[1.8(0.8 \times 1.0 \times 1.0 \times 1.0) + 0.2]$$
$$= 1.89 \text{ kPa } (\textit{4.1.6 of NBCC 2015})$$

- Uniform specified snow load *

$$w_S = (3)(1.89) = 5.67 \frac{kN}{m}$$

**Roof snow load and roof live load can be considered independently.*

# Solution part 1: Lintel loads

**Ultimate Limit States:**

- D: $w_f = (1.4)(7.5) = 10.5\,\frac{kN}{m}$
- D+S+L : $w_f = (1.25)(7.5) + (1.5)(7.2) + (1.0)(5.67) = 25.85\,\frac{kN}{m}$ [Governs]

  $w_f = (1.25)(7.5) + (1.5)(5.67) + (1.0)(7.2) = 25.08\,\frac{kN}{m}$
- D+L: $w_f = (1.25)(7.5) + 1.5(7.2 + 3.0) = 24.68\,\frac{kN}{m}$

# Solution part 2: Lintel loads

**Serviceability Limit State:**

- Specified snow load

$$S = I_S[S_S(C_b C_w C_S C_a) + S_r]$$

$$= 0.9[1.8(0.8 * 1.0 * 1.0 * 1.0 * 1.0) + 0.2]$$

$$= 1.48\ kPa$$

- Uniform specified snow load:

$$w_S = (3)(1.48) = 4.43\,\frac{kN}{m}$$

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# Solution part 2: Lintel loads

**Serviceability Limit State:**

- D: $w = 7.5\,\frac{kN}{m}$
- D+S+L: $w = 7.5 + 7.2 + (0.5)(4.43) = 16.92\,\frac{kN}{m}$

  $w = 7.5 + 4.43 + (0.5)(7.2) = 15.53\,\frac{kN}{m}$
- D+L: $w = 7.5 + 7.2 + 3.0 = 17.7\,\frac{kN}{m}$ [Governs]
- S+L: $w = 7.2 + (0.5)(4.43) = 9.41\,\frac{kN}{m}$

  $w = 4.43 + (0.5)(7.2) = 8.03\,\frac{kN}{m}$
- L: $w = 7.2 + 3.0 = 10.2\,\frac{kN}{m}$ [Governs]

# Solution part 3: Lintel loads

Use the following loads for design:

- Ultimate limit states — 10.5 kN/m for D;
  25.85 kN/m for D+S+L or D+L

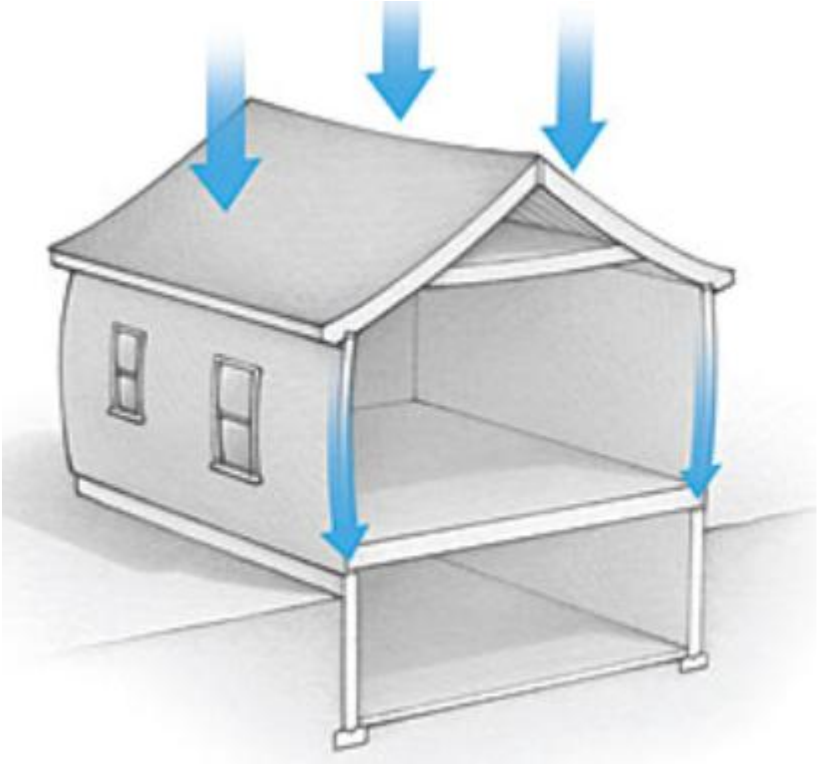
- Serviceability limit states — 7.5 kN/m for D;
  17.7 kN/m for D+S+L or D+L;
  10.2 kN/m for L or S+L

# 4.3 Design Factors

# 1) Load duration factor, $K_D$

- **Intensity** and **duration** of applied loads influence the strength of wood *(similar to fatigue in metals*)

- Strength losses even under static loading may lead to failure after a given time



*By Rob Munach*

Dead load: self weight of roofs, walls and floors

# 1) Load duration factor, $K_D$

- The specified strengths and capacities in CSA O86 are based on the **standard-term duration** of the specified loads

| Load duration | $K_D$ | Explanatory notes |
|---|---|---|
| Short term | 1.15 | Last no more than 7 days (e.g. wind, earthquake…) |
| Standard term | 1 | Between short and long term (e.g. snow, occupancy, wheel loads…) |
| Long term | 0.65 | Subjected to more or less continuous load (e.g. dead loads, fixed machinery…) |

(Table 5.3.2.2 of CSA O86)

# 1) Load duration factor — Long-term load factor

- For standard-term loads where $P_L$ is greater than $P_S$

$$K_D = 1.0 - 0.5\log(P_L/P_s) \geq 0.65$$

where:

$P_L$ = specified long-term load

$P_S$ = specified standard-term load

= S, L, S + 0.5L, or 0.5S + L, determined using importance factor equal to 1.0

# 2) Service condition factor, $K_S$

- Applied when materials are used in service conditions other than **dry**

- Strengths and capacities are multiplied by the service condition factor, $K_S$

*Greatnortherndocks.com*

Wood dock

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# 3) Preservation treatment factor $K_T$

- Exposed to conditions that cause decay or deterioration, wood should be treated with preservatives

Pressure treated timber

Dip treated timber

Preservatives only penetrate the surface of the wood, offering limited protection

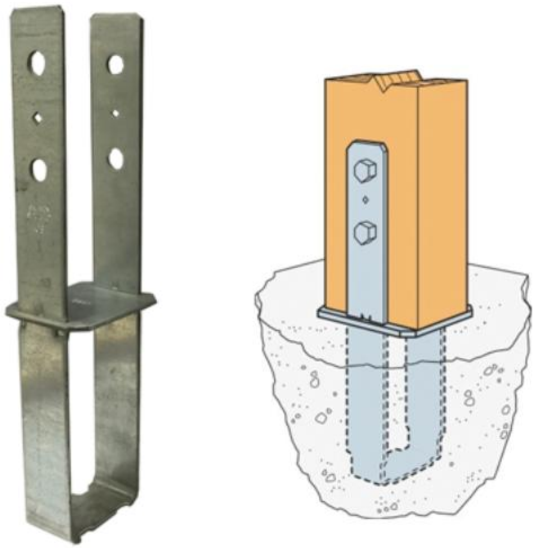
Pressure treated timber

*gardenfurnitureland.com*

Preservatives are forced deep into the wood, offering better protection

# 3) Preservation treatment factor $K_T$

- Untreated wood should not be in direct contact with masonry, concrete, or soil when moisture transfer can occur



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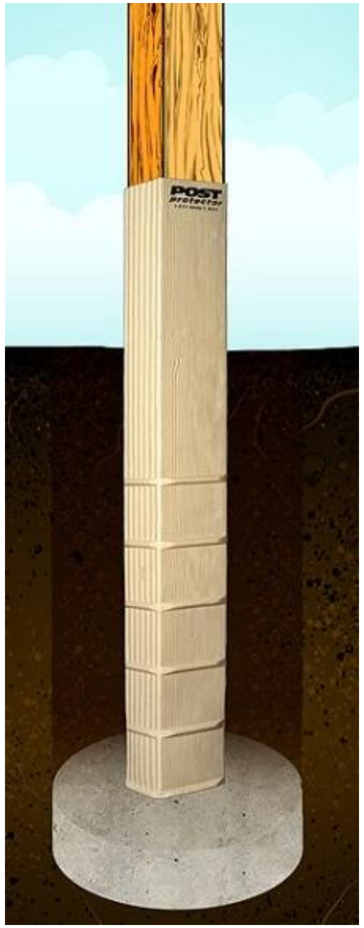
Post mounts




*postprotector.com*

Post protector

# 4) System factor, $K_H$

- Accounts for members acting as part of a system, not independently (e.g. repetitive member systems)

*Floordecorate.com*

Timber floor joist

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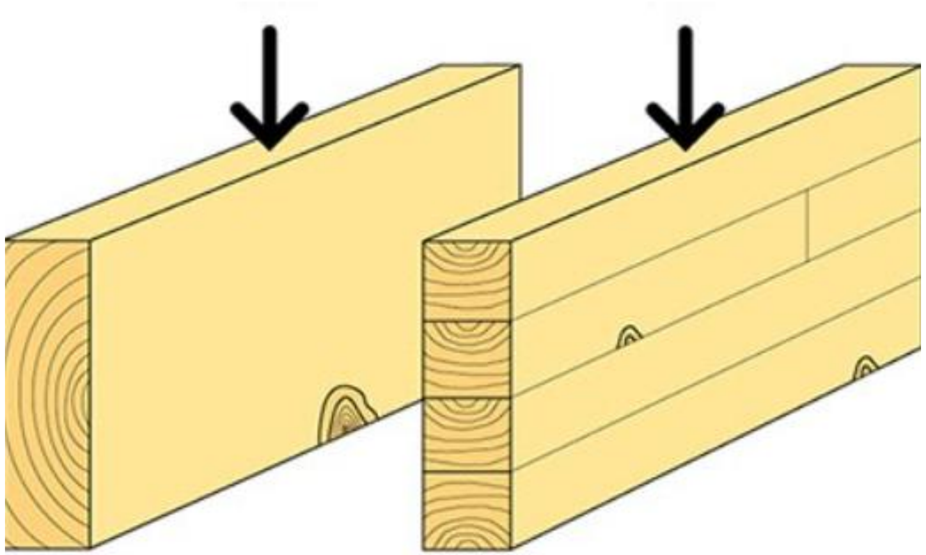
# 5) Size factor, $K_Z$

- Strength properties depend on member size and loading conditions, known as “size effect”
- A larger volume of member tends to reduce the apparent strength.



*swedishwood.com*

# 6) Serviceability limit states

- Elastic deflection (not exceed 1/180 of the span)
- Permanent deformation (upper limit of 1/360 of the span due to long term loads if the long term loads excess 50% of the load combinations for serviceability limit states.)
- Vibration (carpet, concrete topping)
- Moisture content change (design details)

# 6) Serviceability limit states — Moisture content

- Shrinkage or swelling of a wood member can be estimated using the following equation:

$$S = D(M_i - M_f)c$$

where:

- S = shrinkage or swelling in the dimensions being considered
- D = actual dimensions
- $M_i$ = the lesser of the initial moisture content or the fibre saturation point (28%)
- $M_f$ = the final moisture content
- c = shrinkage coefficient

  = for lumber (0.002 perpendicular to grain, 0.00005 parallel to the grain)

This lecture is developed based on the Wood Design Manual [1] and CSA O86-2014 [2].

# References


[1] Canadian Wood Council (CWC). 2017. *Wood design manual*. Ottawa, ON, Canada.

[2] Canadian Standards Association (CSA). 2017. *Engineering design in wood*. CSA O86-14, Toronto, ON, Canada.

[3] National Research Council (NRC). 2015. *National building code of Canada 2015*. Ottawa, ON, Canada.