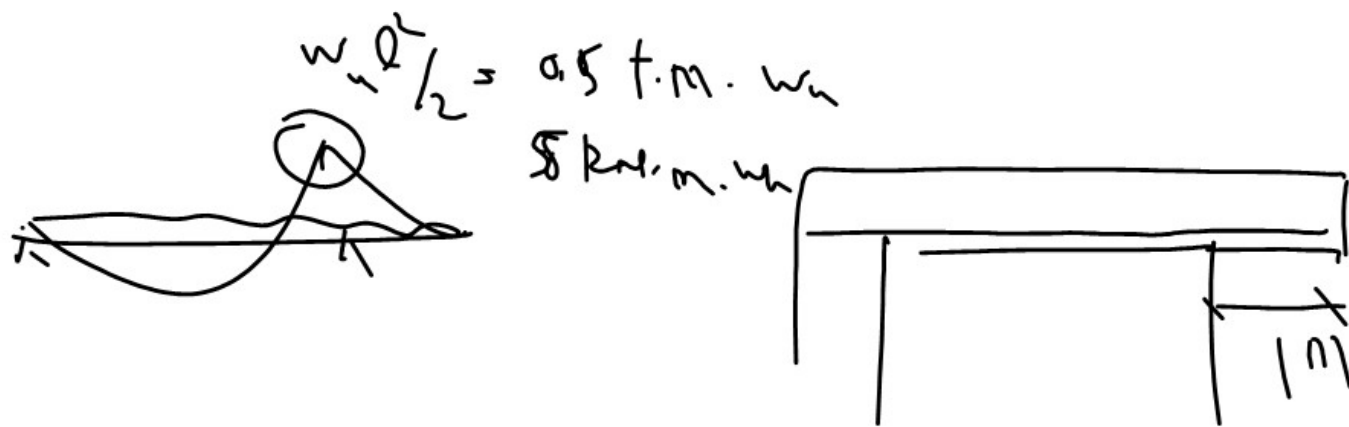
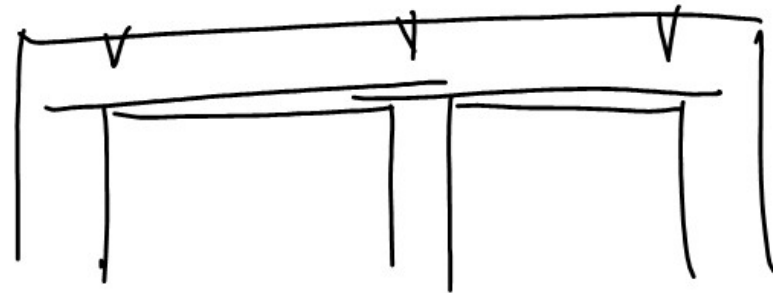
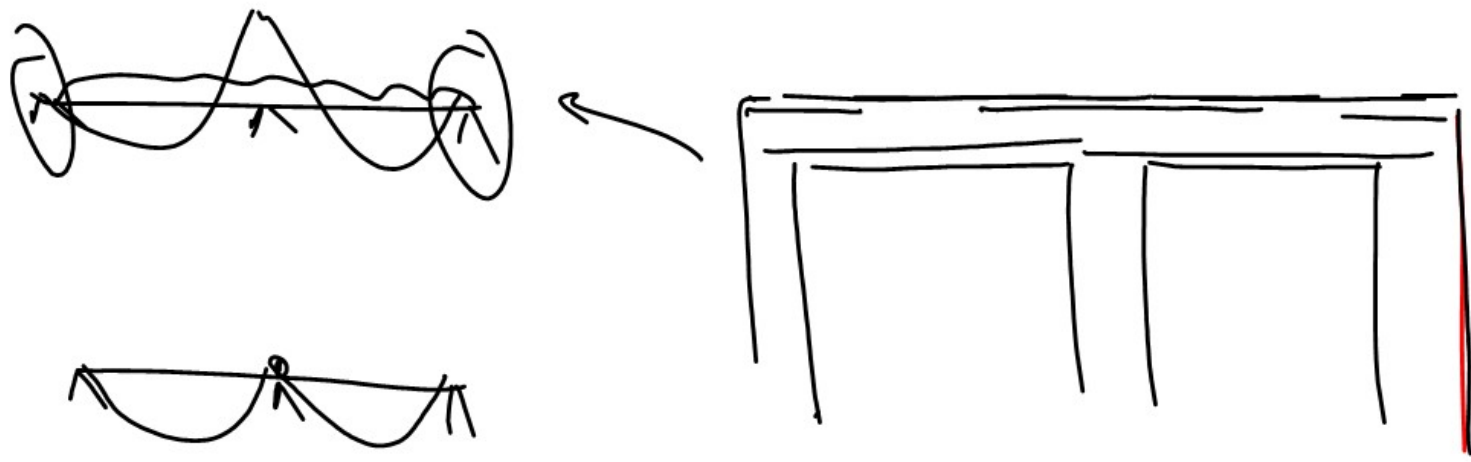
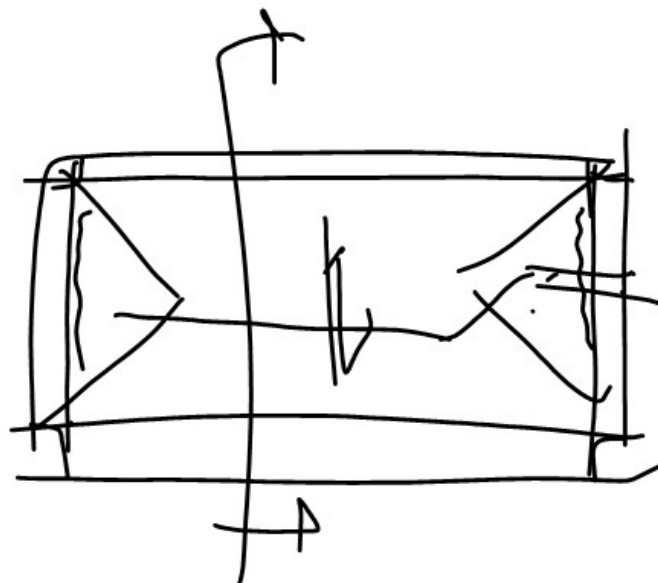
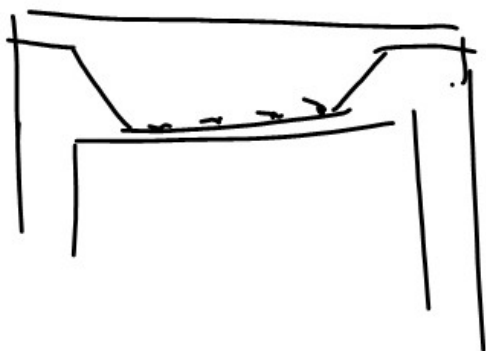
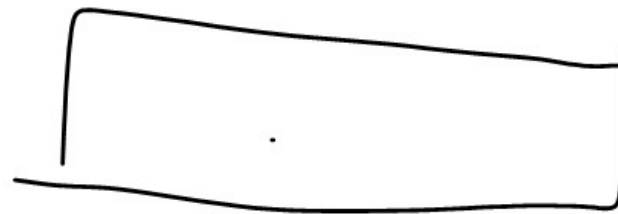




$$M_u < \phi M_{or}$$

$$\left(\begin{array}{c} \bigcirc \\ \hline \end{array} \right) \left(\begin{array}{c} X \\ \hline \end{array} \right) = \left(\begin{array}{c} X \\ \hline \end{array} \right) = 0$$



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- **Limit States Design**
 - **Strength Limit State**
 - **Serviceability Limit State**
 - **Special Limit State**
- **Limit States Design**
 - **Design Philosophy**
 - **Strength Design Method**
 - **Safety Provisions**
 - **Variability in Resistance**
 - **Variability in Loading**
 - **Consequences of Failure**
 - **Margin of Safety**

Limit State Design

Limit State:

Condition in which a structure or structural element is no longer acceptable for its intended use.

Major groups for RC structural limit states

- Strength
- Serviceability
- Special

- Structural collapse of all or part of the structure (very low probability of occurrence) and loss of life can occur (a structure will not fail as long as there is a safe load path to the foundation). Major limit states are:
 - (a) Loss of equilibrium of a part or all of a structure as a rigid body (tipping, sliding of structure...: reaction could not be developed).
 - (b) Rupture of critical components causing partial or complete collapse. (flexural, shear failure...).

(c) Progressive Collapse

- Minor local failure overloads causing adjacent members to fail until entire structure collapses.
- Structural integrity is provided by tying the structure together with correct detailing of reinforcement which provides alternative load paths to prevent localized failure.

- Functional use of structure is disrupted, but collapse is not expected. More often tolerated than a strength limit state since less danger of loss of life. Major limit states are:
 - (a) Excessive crack width leads to leakage which causes corrosion of reinforcement resulting in gradual deterioration of structure.
 - (b) Excessive deflections for normal service
 - malfunction of machinery
 - visually unacceptable
 - damage of nonstructural elements
 - changes in force distributions (no compatibility)
 - ponding on roofs leading to collapse of roof

(c) Undesirable vibrations

- Vertical: floors/ bridges
- Lateral\torsional: tall buildings

Damage/failure caused by abnormal conditions or loading.

These could be due to:

- (a) Extreme earthquakes: damage/collapse
- (b) Floods: damage/collapse
- (c) Effects of fire, explosions, or vehicular collisions.
- (d) Effects of corrosion, deterioration
- (e) Long-term physical or chemical instability

- Identify all potential modes of failure.
- Determine acceptable safety levels for normal structures building codes $\longrightarrow$ load combination factors.

- Consider the significant limit states.
 - Members are designed for strength limit states
 - Serviceability is checked.

Exceptions may include

- water tanks (crack width)
- monorails (deflection)
- Noise in auditoriums

Two philosophies of design have long prevalent.

(a) Working stress method focusing on conditions at service loads.

(b) Strength design method focusing on conditions at loads greater than the service loads when failure may be imminent.

The strength design method is deemed conceptually more realistic to establish structural safety.

In the strength method, the service loads are increased sufficiently by factors to obtain the load at which failure is considered to be “imminent”. This load is called the *factored load* or *factored service load*.

$$\text{strength provided} \geq \left[\begin{array}{l} \text{strength required to} \\ \text{carry factored loads} \end{array} \right]$$

Strength provided is computed in accordance with rules and assumptions of behavior prescribed by the building code and the strength required is obtained by performing a structural analysis using factored loads.

The “*strength provided*” has commonly referred to (wrongly) as “*ultimate strength*”. However, it is a code defined value for strength and not necessarily “*ultimate*”. The ACI Code uses a conservative definition of strength.

Structures and structural members must always be designed to carry some reserve load above what is expected under normal use.

There are three main reasons why some sorts of safety factor are necessary in structural design.

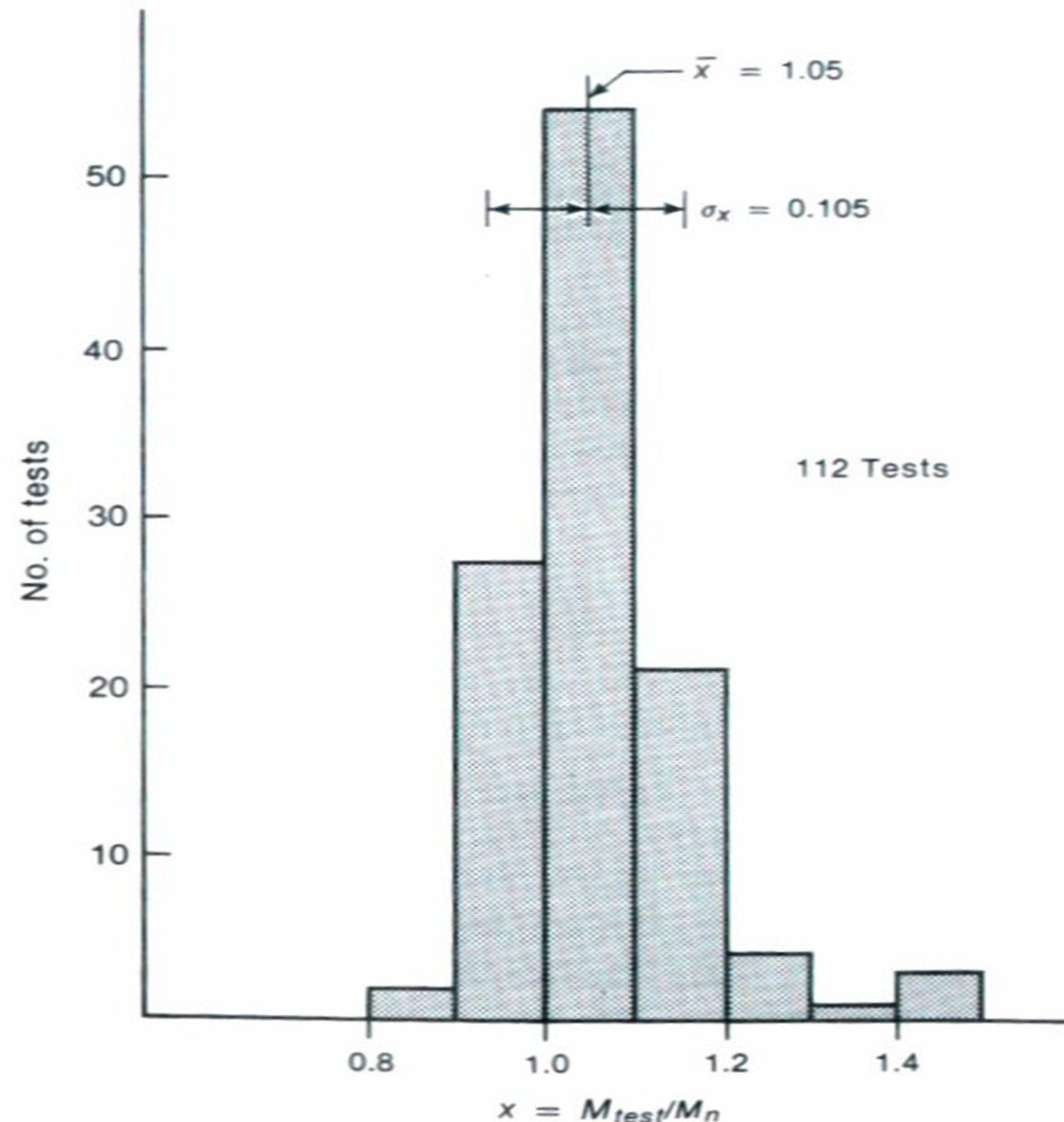
- [1] Variability in resistance.
- [2] Variability in loading.
- [3] Consequences of failure.

Variability in Resistance: R

- Variability of the strengths of concrete and reinforcement.
- Differences between the as-built dimensions and those found in structural drawings.
- Effects of simplification made in the derivation of the members resistance (i.e. simplifying assumptions).

Comparison of measured and computed failure moments based on all data for reinforced concrete beams with $f_c > 14\text{MPa}$

The variability shown is due largely to simplifying assumptions.



Frequency distribution of sustained component of live loads in offices.

In small areas:

Average = 0.65 kN/m^2

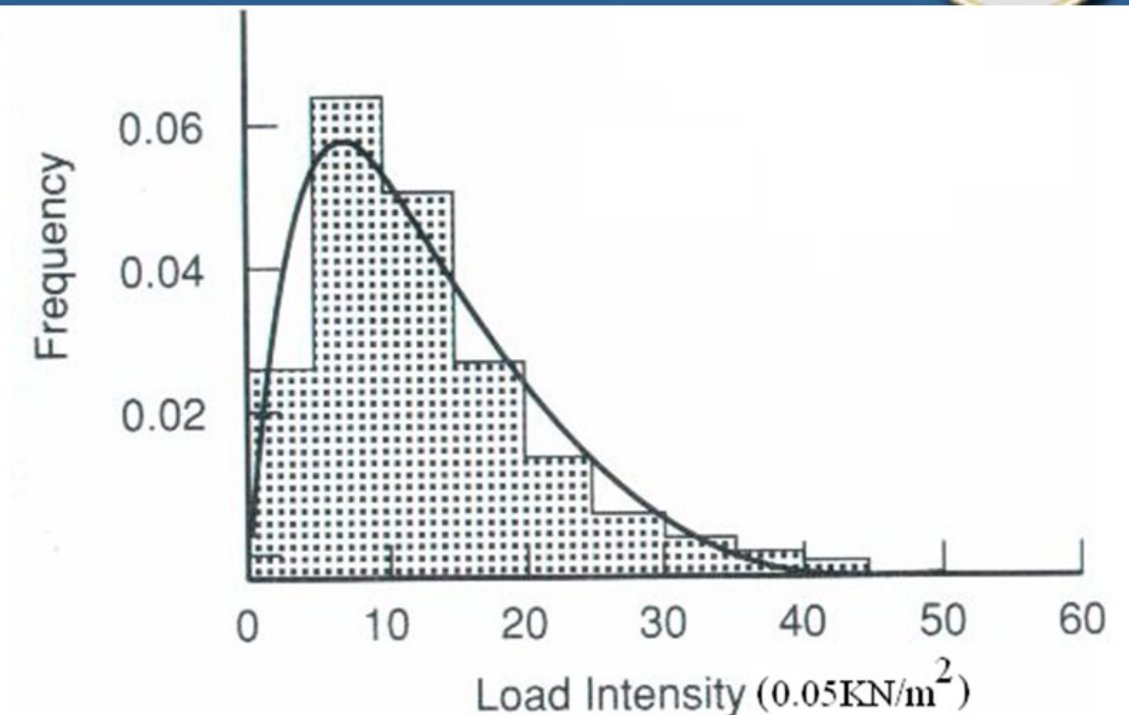
1% exceeded = 2.2 kN/m^2

Code use 2.5 kN/m^2

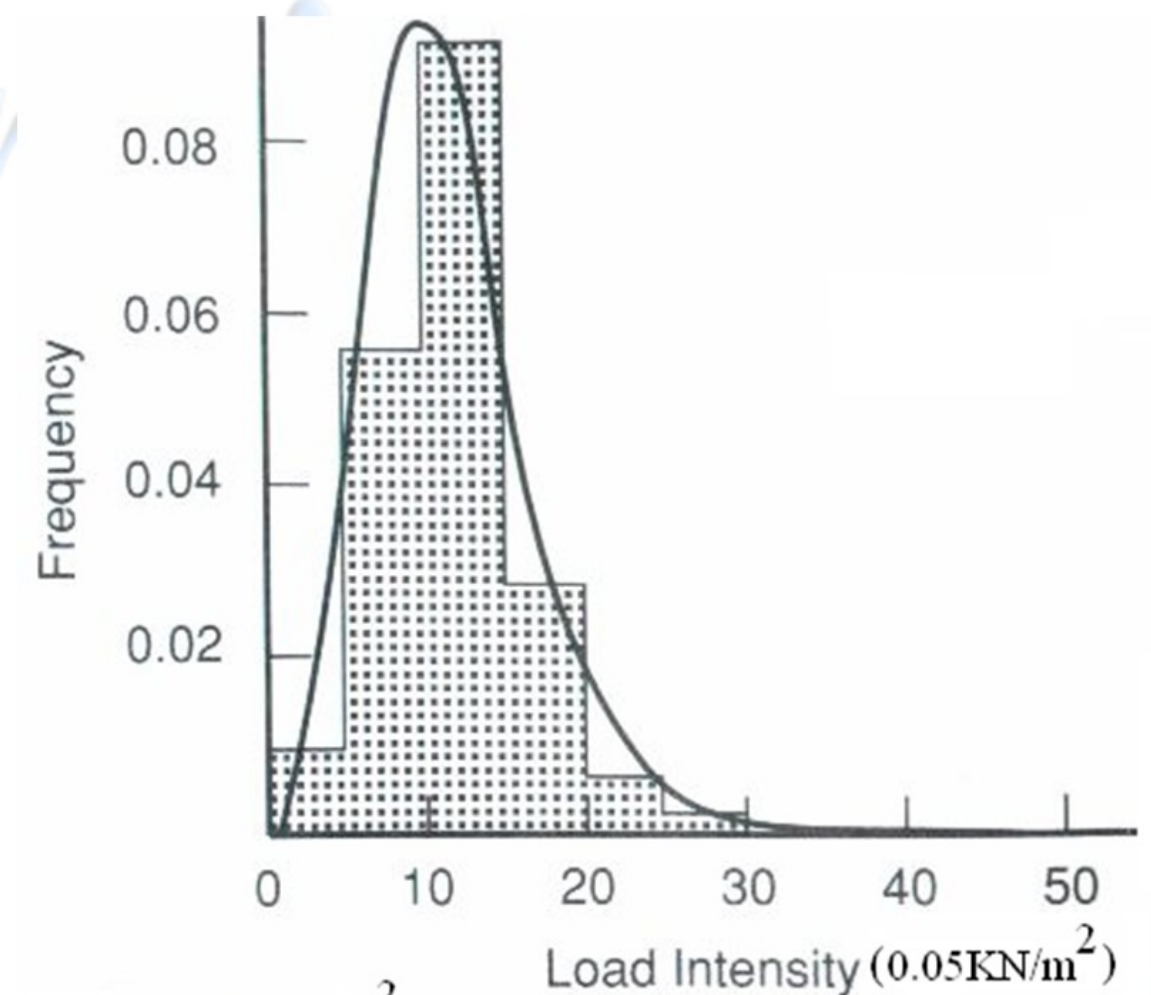
In large areas:

average almost the same, but variability decreases.

(notice that large areas can be used for parties, temporary storage...etc, thus larger LL is needed)



(a) Area = 14 m^2



(a) Area = 190 m^2

A number of subjective factors must be considered in determining an acceptable level of safety.

- Potential loss of life: larger SF for auditorium than a storage building.
- Cost of clearing the debris and replacement of the structure and its contents.
- Cost to society: collapse of a major road.
- Type of failure, warning of failure, existence of alternative load paths.

The term

$$Y = R - S$$

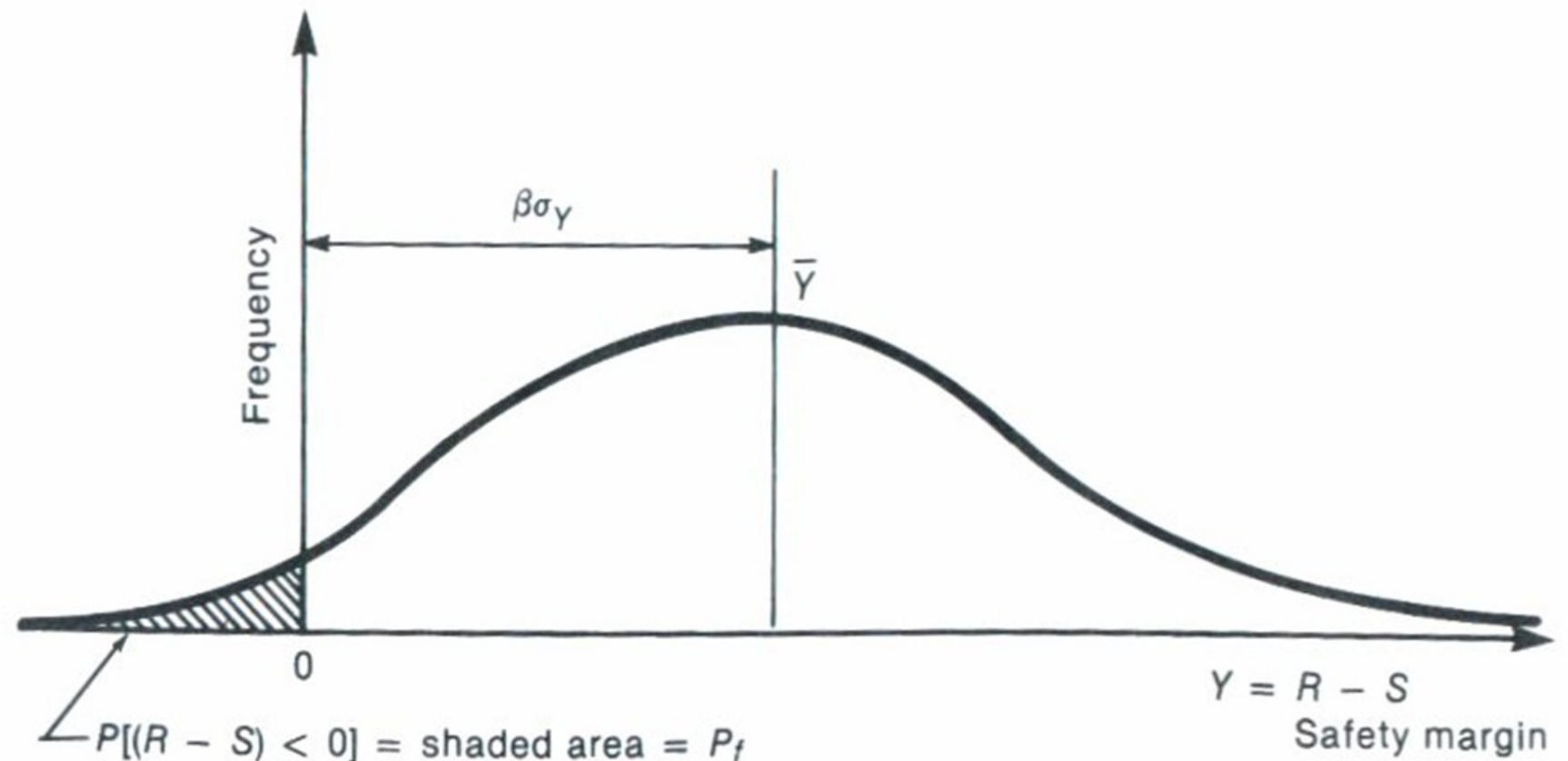
is called the safety margin.

The probability of failure is defined as:

$$P_f = \text{Probability of } [Y < 0]$$

and the safety index is

$$\beta = \frac{\bar{Y}}{\sigma_Y}$$



- Types of design can be classified as:
 - Creative
 - Development
 - Copy
- Analyze previous types showing advantages and disadvantages of each type in view of what you learned from previous two chapters.

End of chapter 2

Let Learning Continue

- Loading Specifications
- Dead Loads
- Live Loads
- Environmental Loads
- Classification of Buildings for Wind, Snow and Earthquake Loads
 - Snow Loads
 - Earthquake Loads
- Roof Loads
- Construction Loads
- Load factors

Cities in the U.S. generally base their building code on one of the three model codes:

- Uniform Building Code
- Basic Building Code (BOCA)
- Standard Building Code

These codes have been consolidated in the 2000 *International Building Code*.

Loadings in these codes are mainly based on
*ASCE Minimum Design Loads for Buildings
and Other Structures ASCE 7-10.*

- Weight of all permanent construction
- Constant magnitude and fixed location

Examples:

- Weight of the Structure
(Walls, Floors, Roofs, Ceilings, Stairways)
- Fixed Service Equipment
(HVAC, Piping Weights, Cable Tray, etc.)

- Loads produced by use and occupancy of the structure.
- Maximum loads likely to be produced by the intended use.
- Not less than the minimum uniformly distributed load given by Code.

See Table 4-1 from *ASCE 7-05*

Stairs and exitways: 4.8 kN/m^2 .

Storage warehouses: 6 kN/m^2 (light)
 12 kN/m^2 (heavy)

Minimum concentrated loads are also given in the codes.

ASCE 7-05 allows reduced live loads for members with influence area ($K_{LL} A_T$) of 38m² or more (not applied for roof):

$$L = L_o \left(0.25 + \frac{4.6}{\sqrt{K_{LL} A_T}} \right)$$

where $L \geq 0.50 L_o$ for members
supporting one floor
 $\geq 0.40 L_o$ otherwise

K_{LL} = live load element factor (Table 4.2)

=2 for beams

=4 for columns

- Snow Loads
- Earthquake
- Wind
- Soil Pressure
- Roof Loads
- Temperature Differentials
- ...etc

Based on Use Categories (I through IV)

- I** Buildings and other structures that represent a low hazard to human life in the event of a failure (such as agricultural facilities), $I=1$
- II** Buildings/structures not in categories I, III, and IV, $I=1$

III Buildings/structures that represent a substantial hazard to human life in the event of a failure (assembly halls, schools, colleges, jails, buildings containing toxic/explosive substances), $I=1.25$

IV Buildings/structures designated essential facilities (hospitals, fire and police stations, communication centers, power-generating stations), $I=1.5$

Ground Snow Loads:

- Based on historical data (not always the maximum values)
- Basic equation in codes is for flat roof snow loads
- Additional equations for drifting effects, sloped roofs, etc.
- Use ACI live load factor
- No LL reduction factor allowed
- Use 1KN/m^2 as minimum snow load, multiply it by I (importance factor)

Inertia forces caused by earthquake motion

$$\mathbf{F} = \mathbf{m} * \mathbf{a}$$

- Distribution of forces can be found using equivalent static force procedure (code, not allowed for every building) or using dynamic analysis procedures (computer applications).

- Ponding of rainwater
 - Roof must be able to support all rainwater that could accumulate in an area if primary drains were blocked.
 - Ponding Failure (steel structures):
 - Rain water ponds in area of maximum deflection
 - increases deflection
 - allows more accumulation of water → cycle continues... → potential failure
- Roof loads (like storage tanks) in addition to snow loads
- Minimum loads for workers and construction materials during erection and repair

- Construction materials
- Weight of formwork supporting weight of fresh concrete
- Basement walls
- Water tanks

The loading variations are taken into consideration by using a series of “load factors” to determine the ultimate load, U .

$$U = 1.4D$$

$$U = 1.2D + 1.6L$$

$$U = 1.2D + 1.6W + 1.0L$$

$$U = 1.2D + 1.0E + 1.0L$$

$$U = 0.9D + E; \dots \text{etc.}$$

The equations come from ACI code 9.2

D – Dead Load

L – Live Load

E – Earthquake Load

W – Wind Load

The most general equation for the ultimate load, U (M_u) that you will see is going to be:

$$U = 1.2D + 1.6L$$

- Ribbed slab construction is common in Palestine. Construct an allowable load table and an ultimate load table for common sizes of rib-construction. The table should include block (density 12KN/m^3) and eitong (density 5.5KN/m^3) of different sizes against different values of superimposed loads (1 to 4KN/m^2 in 0.5 increments).

End of chapter 3

Let Learning Continue