COLLEGE of ENGINEERING

كلية الهندسة

تحقيق الريادة العالمية من خلال شراكة مجتمعية لبناء مجتمع المعرفة

Fundamentals of Reinforced Concrete Design

Lecture Goals

- Design Process
- Limit states
- Design Philosophy
- Loading

Design Process

- **Phase 1**: Definition of clients' needs and priorities.
  - Functional requirements
  - Aesthetic requirements
  - Budgetary requirements

Design Process

- **Phase 2**: Development of project concept
  - Develop possible layouts
  - Approximate analysis of preliminary members sizes/cost for each arrangement

Design Process

- **Phase 3**: Design of individual system
  - Structural analysis (based on preliminary design)
    - Moments
    - Shear forces
    - Axial forces

Limit States and 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

- Ultimate
- Serviceability
- Special

Ultimate Limit State

Ultimate limit state

- structural collapse of all or part of the structure (very low probability of occurrence) and loss of life can occur.
- Loss of equilibrium of a part or all of a structure as a rigid body (tipping, sliding of structure).

Ultimate Limit States

Ultimate limit state

- Rupture of critical components causing partial or complete collapse. (flexural, shear failure).

Serviceability Limit States

- Functional use of structure is disrupted, but collapse is not expected
- More often tolerated than an an ultimate limit state since less danger of loss of life.
  - Excessive crack width → leakage → corrosion of reinforcement → gradual deterioration of structure.

Special Limit States

Damage/failure caused by abnormal conditions or loading.

- Extreme earthquakes → damage/collapse
- Floods → damage/collapse

ACI Building Codes, SBC Codes

Code: Set of rules that regulates the design process, has a legal status.

The American Concrete Institute (ACI), issues building code requirements, Saudi Building Code (SBC 301 for loads, and SBC 304 for concrete structures).

Design Philosophy

Two philosophies of design:

- Working stress method focuses on conditions at service loads.
- 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.

Strength Design Method

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***.

$$\text{strength provided} \geq \begin{bmatrix} \text{strength required to} \\ \text{carry factored loads} \end{bmatrix}$$

Strength Design Method

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 as "***ultimate strength***". However, it is a code defined value for strength and not necessarily "***ultimate***". The ACI/SBC Code uses a conservative definition of strength.

Safety Provisions

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

Safety Provisions

There are three main reasons why some sort of safety factors are necessary in structural design.

[1] Variability in resistance.

[2] Variability in loading.

[3] Consequences of failure.

Variability in Resistance

- 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.

Loading

Loadings are mainly based on *ASCE Minimum Design Loads for Buildings and Other Structures (ASCE 7-98) – has been updated to ASCE 7-02*. (SBC 301).

Dead Loads

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

Dead Loads

Examples:

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

Can Be Uncertain….

- pavement thickness
- earth fill over underground structure

Live Loads

- 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.

Live Loads

See Table 2-1 from *ASCE 7-98 (SBC 301 in kn/m2)*

Private Rooms: *1.9 kN/m2*

Stairs and exit ways: 4.8 kN/m2

Storage warehouses: 6 kN/m2 (light)

12 kN/m2(heavy)

Minimum concentrated loads are also given in the codes.

TABLE 2-1 Typical Live Loads Specified in ASCE 7-98

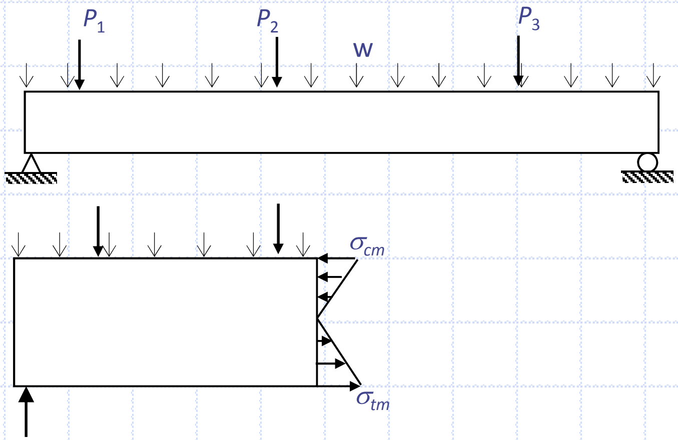
	Uniform, kN/m^2	Concentration, kN
Apartment buildings		
Private rooms and corridors serving them	1.9	
Public rooms and corridors serving them	4.8	
Office buildings		
Lobbies and first-floor corridors	4.8	8.9
Offices	2.4	8.9
Corridors above first floor	3.8	8.9
File and computer rooms shall be designed for heavier loads based on anticipated occupancy		
Schools		
Classrooms	1.9	4.45
Corridors above first floor	3.8	4.45
First-floor corridors	4.8	4.45
Stairs and exitways	4.8	
Storage warehouses		
Light	6.0	
Heavy	12.0	
Stores		
Retail		
Ground floor	4.8	4.45
Upper floors	3.6	4.45
Wholesale, all floors	6.0	4.45

Source: Based on *Minimum Design Loads for Buildings and Other Structures*, ASCE Standard ASCE 7-98, with the permission of the publisher, the American Society of Civil Engineers

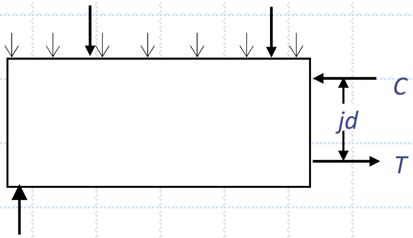
Environmental Loads

- Snow Loads
- Earthquake
- Wind
- Soil Pressure
- Ponding of Rainwater
- Temperature Differentials

Basic Design Relationship:



a) Flexural stresses on a cross section



b) Internal couple.

The beam shown in the figure will safely support the load if, at every section, the resistance of the member exceed the effects of loads:

$$R \geq \sum S \qquad (2\text{-}1)$$

The resistance, R is function of material and geometric properties.

To allow for variability in computed resistance and load effects, eq. (2-1) is rewritten as :

$$\phi R_n \geq \alpha_1 S_1 + \alpha_2 S_2 + \ldots \qquad (2\text{-}1a)$$

ϕ is strength-reduction factor less than1
α_I is load factor greater than 1
R_n stands for nominal resistance (based on specified material and geometric properties.)
S stands for load effects (based on specified loads.)

In terms of Moments:

$$\phi M_n \geq \alpha_D M_D + \alpha_L M_L + \ldots \qquad (2\text{-}2a)$$

Similar equations can be written for shear, *V*, and axial forces, *P*:

$$\phi V_n \geq \alpha_D V_D + \alpha_L V_L + \ldots \qquad (2\text{-}2b)$$

$$\phi P_n \geq \alpha_D P_D + \alpha_L P_L + \ldots \qquad (2\text{-}2c)$$

Equation (2-1) is the basic limit-states design equation. Equation (2-2a) to (2-2c) are special forms.

1.Strength Design Method in The ACI (SBC-304) Code

Strength design is a limit-state design (primarily based on ultimate limit-states.)
ACI (SBC-304) sections 9.1.1, 9.1.2

9.1.1 — Structures and structural members shall be designed to have design strengths at all sections at least equal to the required strengths calculated for the factored loads and forces in such combinations as are stipulated in this code.
9.1.2 — Members also shall meet all other requirements of this code to ensure adequate performance at service load levels.

Art. **9.1.1** $\Rightarrow$ *design strength* $\geq$ *required Strength*

design strength=$\phi\times$nominal strength, *e.g.* ϕM_n, ϕV_n, ...

required strength=load effect resulting from factored loads, M_u, V_u, ...

For Beam design, the design criteria become

$\phi M_n \geq M_u$ and $\phi V_n \geq V_u$

M_u= *factored load moment, (Moment computed from combination of factored loads)*

V_u= *factored load shear, (Shear computed from combination of factored loads)*

Selection of Design Loads

- Building codes and specifications provide conservative estimates of live-load magnitudes for various situations.
- Commonly used specifications are:
- In KSA, **SBC 301** define loads in buildings
- For highway bridges, *American Association of State Highway and Transportation Officials* (AASHTO).

Load Factors

- Load factors are numbers, almost always greater than unity, which are used to increase the estimated loads applied to structures.
- These factors account for the uncertainties involved in estimating their magnitudes.
- They also account for possibilities of combining different loads together
- ***Note: Load factors for dead loads are much smaller than the ones used for live and environmental loads because dead loads can be estimated more accurately than live and environmental loads.***

SBC Load Factors and Combinations (SBC 304 Section 9.2)

- SBC defines the critical design load effect (ultimate) as resulting from any of the following seven combinations :

$1/ U = 1.4(D + F)$

$2/ U = 1.4(D + F + T) + 1.7(L + H) + 0.5(L_r \text{ or } R)$

$3/ U = 1.2D + 1.6(L_r \text{ or } R) + (1.0L \text{ or } 0.8W)$

$4/ U = 1.2D + 1.6W + 1.0L + 0.5(L_r \text{ or } R)$

$5/ U = 1.2D + 1.0E + 1.0L$

$6/ U = 0.9D + 1.6W + 1.6H$

$7/ U = 0.9D + 1.0E + 1.6H$

D: Dead load F: Fluid load

L: Live load W : Wind load

L_r: Roof Live load R: Rain load

T: Temperature load E: Earthquake load

H : Horizontal earth load

Load factors less than unity result either from small probabilities of combinations of some load cases, or consider indirectly the upward vertical seismic / wind effects (by reducing dead load).

Alternate orientations (East-West or South-North) of wind / seismic loads, result in more than seven different combinations.

Case of Dead and Live loads only

- In this course CE363, only dead and live loads are considered, with the following SBC combinations:
- Ultimate combination: **1.4 D + 1.7 L**
- Service combination: **D + L**

Strength Reduction Factors, ϕ (SBC 304 Section 9.3)

9.3.2.1 — Tension-controlled sections

as defined in SBC 304 Sec. 10.3.4 .... 0.90

(See also SBC 304 Sec 9.3.2.7)

9.3.2.2 — Compression-controlled sections, as

defined in SBC 304 Sec 10.3.3:

(a)Members with spiral reinforcement

conforming to SBC 304 Sec 10.9.3.. 0.70

(b) Other reinforced members 0.65

9.3.2.2 — Shear and torsion 0.75