CHAPTER 1

INTRODUCTION TO CONCRETE DESIGN TO EUROCODE

Behavior of Reinforced Concrete

- RC is one of the principal materials use in many civil engineering application.
- Civil Eng. Application :
  - Construction of building, retaining walls, foundations, water retaining structures, highway and bridges.
- It is a composite material, consisting of steel reinforcing bars embedded in a hardened concrete matrix.
- These two materials have complementary properties.

Behavior of Reinforced Concrete

- **Concrete :**
  - **Highly in compressive strength but weak in tensile strength.**

- **Reinforcement (steel) :**
  - **Highly in tensile strength but weak in compressive strength.**

- **By providing steel bars in the zones within a concrete member which will subjected to tensile stresses, an economical structural material can be produced through its composite action.**

UTHM JOHOR

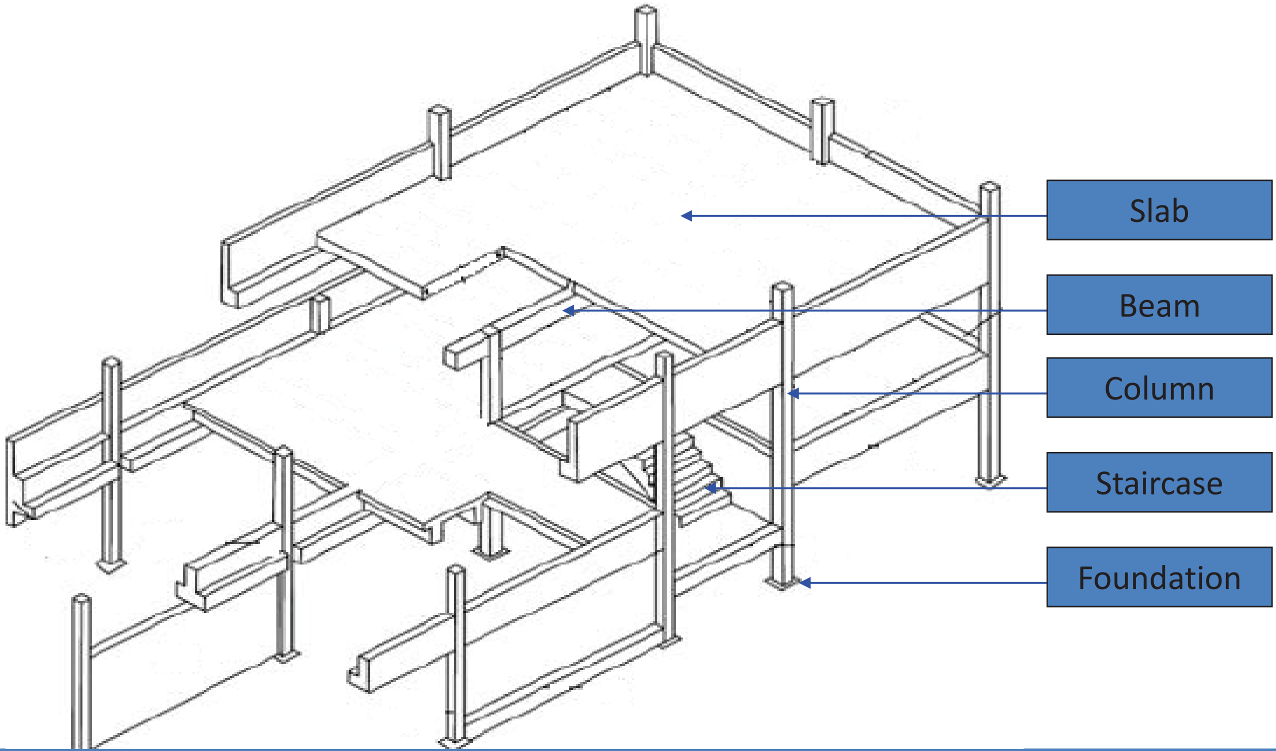
Behavior of Reinforced Concrete

www.uthm.edu.my

- **In addition, the concrete provides corrosion protection and fire resistance to the embedded steel reinforcing bars.**

With Wisdom We Explore

Reinforced Concrete Element



Code of Practice

- Document that gives recommendation for the design and construction of structures.

- It contains detailed requirement regarding actions, stresses, strengths, design principal and method of achieving the required performance of completed structure.

- The design procedures, described in this course conform to the following Eurocode (EC) published by European Committee for Standardization.

Code of Practice

- EN 1990 Eurocode 0: Basis of structural design
- EN 1991 Eurocode 1: Actions on structures
- EN 1992 Eurocode 2: Design of concrete structures

- Eurocode 2 (EC2) applies to the design of buildings and civil engineering works in plain, reinforced and prestressed concrete. EC2 comes in several parts as follows:

Eurocode 2	Title
EN 1992 Part 1-1	General rules and rules for buildings
EN 1992 Part 1-2	General rules –Structural fire design
EN 1992 Part 2	Concrete bridges –design and detailing rules
EN 1992 Part 3	Liquid retaining and containment structures

Limit State

- The purpose of design is to achieve acceptable probabilities that a structure will not become unfit for it intended use. That is, that it will not reach a limit state.
- At any way in which a structure may cease to be fit for use will constitute a limit state and the design aim is to avoid any such condition being reached during the expected life of the structure

- There are two principal types of limit state:
  - Ultimate limit state
  - Serviceability limit state

Limit State

Design situations of limit state

Persistent	Design situation during a period of the same order as the design working life of the structure. Represents normal use
Transient	Design situation during a period much shorter than the design working life of the structure. e.g. during execution or repair
Accidental	Design situation involving exceptional conditions for structure. e.g. Fire, explosion, impact etc
Seismic	Design situation involving exceptional conditions for structure during seismic event.

UTHM JOHOR
www.uthm.edu.my

Ultimate Limit State

- The conditions that structure must be able to withstand, with an adequate factor of safety of load for which it is designed to ensure the safety of the building occupants and structure itself against collapse, overturning or buckling.
- The ultimate limit state are divided into the following categories;
  - EQU — Loss of equilibrium of the structure
  - STR — Internal failure or excessive deformation of the structure or structural members
  - GEO — Failure due to excessive deformation of the ground
  - FAT — Fatigue failure of the structure or structural members

With Wisdom We Explore

www.uthm.edu.my

Ultimate Limit State

- For persistent and transient design situation under the STR limit state, the Eurocode defines three possible combination as follows;

Table A1.2(B) : Design values of actions- Ultimate limit states for persistent and transient design situation

Combination Expression	Permanent actions		Leading variable actions	Accompanying variable actions	
	Unfavourable	Favourable		Main (if any)	Others
Exp. (6.10)	$\gamma_{Gj,sup}\,G_{kj,sup}$	$\gamma_{Gj,inf}\,G_{k,j,inf}$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\ \psi_{0,i}\,Q_{k,i}$
Exp. (6.10a)	$\gamma_{Gj,sup}\,G_{kj,sup}$	$\gamma_{Gj,inf}\,G_{k,j,inf}$		$\gamma_{Q,1}\ \psi_{0,1}\,Q_{k,1}$	$\gamma_{Q,i}\ \psi_{0,i}\,Q_{k,i}$
Exp. (6.10b)	$\xi\gamma_{Gj,sup}\,G_{kj,sup}$	$\gamma_{Gj,inf}\,G_{k,j,inf}$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\ \psi_{0,i}\,Q_{k,i}$

Notes:

1. The choice between 6.10, or 6.10a and 6.10b will be in the National annex.
2. The γ and ξ values may be set by the National annex. The following values for γ and ξ are recommended when using 6.10, 6.10a and 6.10b.

$\gamma_{Gj,sup}$ = 1.35, $\gamma_{Gj,inf}$ = 1.0 $\gamma_{Q,1}$ = 1.50 where Unfavourable (0 where favourable)
$\gamma_{Q,i}$ = 1.50 where Unfavourable (0 where favourable) ξ = 0.85

www.uthm.edu.my

Serviceability Limit State

- Condition in which the structure is damaged and unsuitable for its intend purposes causing discomfort to the occupants.
- Generally the most important serviceability limit state are:
  - Deflection — The appearance of efficiency of any part of the structure must not be adversely affected by deflections.
  - Cracking — Local damage due to cracking and spalling must not affect the appearance, efficiency or durability of the structure.
- Other limit states which may be reached included consideration of durability, vibration and fire resistance of structures.

Characteristic Materials Strength

- The strength of materials upon which design is based is such strength below which results unlikely to fall.
- These are call characteristic strengths.
- It is assumed that for a given material, the variation of strength will have a normal distribution as shown in figure below.

Characteristic Materials Strength

www.uthm.edu.my

- The characteristic strength is taken as that value, below which it is unlikely that more than 5 % of the results will fails. Thus statistically,

Characteristic Strength = *Mean strength – 1.64 (Standard deviation)*

$$f_k = f_m - 1.64s$$

With Wisdom We Explore

Concrete (Clause 3.1, EC2)

- The characteristic strength f_{ck} is the 28 days cylinder strength.
- Table below shows the characteristic cylinder strength of various classes of concrete recommended for use in reinforced and prestressed concrete design.
- Class C20/25, for example, refer to cylinder/cube strength of 20 N/mm^2 and 25 N/mm^2 respectively.

UTHM JOHOR
www.uthm.edu.my

Concrete (Clause 3.1, EC2)

- Concrete strength classes and MOE

Concrete strength class	Characteristic cylinder strength f_{ck} (N/mm^2)	Characteristic cube strength $f_{ck,cube}$ (N/mm^2)	Modulus of elasticity E_{cm} (kN/mm^2)
C20/25	20	25	30
C25/30	25	30	31
C30/37	30	37	33
C35/45	35	45	34
C40/50	40	50	35
C45/55	45	55	36
C50/55	50	60	37
C55/67	55	67	38
C60/75	60	75	39

Source: Table 3.1: MS EN 1992-1-1

With Wisdom We Explore

Reinforcing steel (Clause 3.2, EC2)

- The characteristic strength of steel reinforcement is denotes by f_{yk}.
- Specified strength for high yield reinforcement given in EC2 is in the range of 400 – 600 N/mm^2.
- The most commonly use in the UK is grade 500 and grade 250 plain bar is not now recognized and no longer available for general used in UK.
- High yield (H) bars may be classified as:
  - Class A : which is normally associated with small diameter (≤ 12 mm)
  - Class B : which is most commonly used for reinforcing bars.
  - Class C : high ductility which may be used in earthquake design.

Partial Safety Factor

- Partial safety factor are importance value applied to the strength of materials and to the actions as to take into account the possible variation of constructional tolerance.
- The values adopted are based on experience and simplified calculation and considering the probability of reaching each limit state.
- Partial safety factor of materials (γ_m)

Design situation	γ_m for concrete	γ_m for reinforcing steel
Persistent & Transient	1.5	1.15
Accidental	1.2	1.0

Source: Table 2.1N: MS EN 1992-1-1

Partial Safety Factor

www.uthm.edu.my

- **Partial safety factor of action, γ_f**

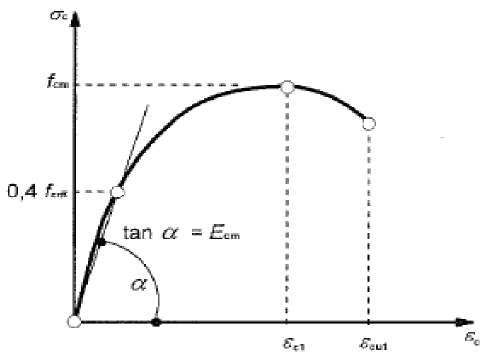
Design situation	Permanent actions (G_k)		Variable actions (Q_k)	
	Unfavourable	Favourable	Unfavourable	Favourable
Ultimate limit state				
Persistent & Transient	1.35	1.0	1.50	0
Serviceability limit state				
All	1.0		1.0	

Source: Table A1.2 & A1.4: MS EN 1990

Stress-Strain Curve of Concrete

www.uthm.edu.my

- **Concrete used mostly in compression, it compressive stress-strain curve is of primary importance.**
- **Typical stress-strain curve of concrete is shown in figure below:**

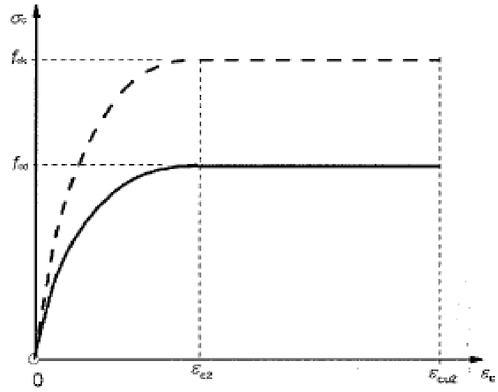


Source: Figure 3.2: MS EN 1992-1-1

- ❑ The curve is linear in very initial phase of loading.
- ❑ The curve then begin to curve to horizontal, reach the maximum stress at a strain of approximately 0.0020 and finally show a descending nature.

Stress-Strain Curve of Concrete

- **For the design of cross-section, EC2 recommended the used of idealized stress-strain curve as shown in figure below:**



Source: Figure 3.3: MS EN 1992-1-1

The curve is begin with a parabolic portion up to a strain ε_{c2}, from which point of the strain increase while the stress remain constant

UTHM JOHOR
www.uthm.edu.my

Stress-Strain Curve of Concrete

- **The ultimate design compressive stress are given by;**

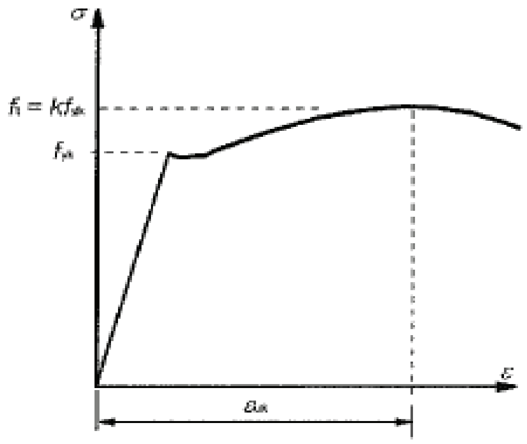
$$\frac{\alpha\, f_{ck}}{\gamma_{mc}} = \frac{0.85 f_{ck}}{1.5} = 0.567 f_{ck}$$

- **The coefficient 0.85 takes account of the difference between bending strength and the cylinder crushing strength of the concrete.**
- **The factor of 1.5 is the usual partial safety factor for the strength of concrete.**
- **The ultimate strain ε_{cu2} = 0.0035 is typical for classes of concrete ≤ C50/60.**

With Wisdom We Explore

Stress-Strain Curve of Reinforcing Steel

- **Steel is high tensile strength material.**
- **The typical stress-strain curve for hot rolled steel are shown in figure below:**

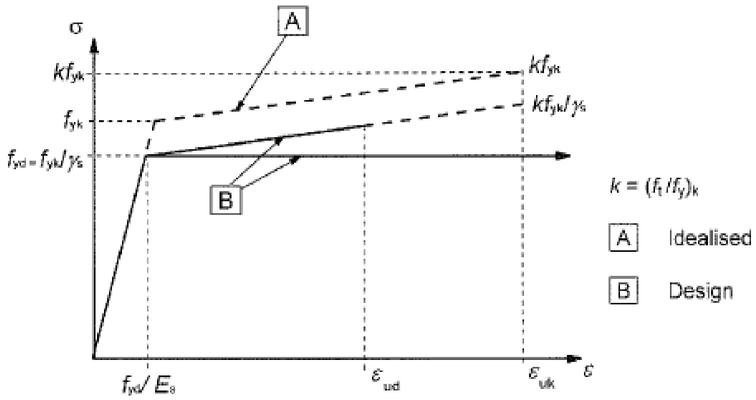


Source: Figure 3.7(a): MS EN 1992-1-1

Stress-Strain Curve of Reinforcing Steel

www.uthm.edu.my

- **For design purpose EC2 recommended the use of idealized curve shown in figure below:**



Source: Figure 3.8: MS EN 1992-1-1

With Wisdom We Explore

Stress-Strain Curve of Reinforcing Steel

- The behavior of the steel is identical in tension and compression, being linear in the elastic range up to the design yield stress.
- Design yield tensile stress can be given as;

$$\frac{f_{yk}}{\gamma_{ms}} = \frac{f_{yk}}{1.15} = 0.87 f_{yk}$$

Where;

f_{yk}	=	Characteristic yield stress
γ_{ms}	=	Partial safety factor of reinforcing steel

UTHM JOHOR
www.uthm.edu.my

Actions

- Action is the EC2 terminology for loads and imposed deformations.
- The characteristic actions are the actual loads that the structure is designed to carry.
- These are normally thought of as a maximum loads which will not be exceeded during the life of structure.
- The characteristic actions used in design and defined in EC2 are as follows;
  - Characteristic permanent action, Gk
  - Characteristic variable action, Qk
  - Characteristic wind action, Wk

With Wisdom We Explore

Characteristic Permanent Action, Gk

- **Is the selfweight of the structure, weight of finishes, ceiling and services. Examples of weight of materials as given in EC1 are shown in table below.**

Materials	Density (kN/m³)
Lightweight concrete	9.0 – 20.0
Normal weight concrete	24.0 – 25.0
Cement mortar	19.0 – 23.0
Wood	3.5 – 10.8
Plywood	4.5 – 7.0
Particle boards	7.0 – 12.0
Steel	77.0 – 78.5
Water	10.0

Source: Table A1-A5: MS EN 1991-1-1

Characteristic Variable Action, Qk

- **Cause by people, furniture, equipment etc. Which variation in magnitude with time is considered.**
- **Example of variable action as given in EC1 are shown in table below:**

Category	Example use	q_k (kN/m²)	Q_k (kN)
A1	All uses within self-contained dwelling units	1.5	2.0
A2	Bedrooms and dormitories	1.5	2.0
A3	Bedrooms in hotels and motels, hospital wards and toilets	2.0	2.0
A5	Balconies in single family dwelling units	2.5	2.0
A7	Balconies in hotels and motels	4.0 min.	2.0 at outer edge
B1	Offices for general use	2.5	2.7
C5	Assembly area without fixed seating, concert halls, bars, places of worship	5.0	3.6
D1/2	Shopping areas	4.0	3.6
E12	General storage	2.4 per m height	7.0
E17	Dense mobile stacking in warehouses	4.8 per m height (min. 15.0)	7.0
F	Gross vehicle weight ≤ 30kN	2.5	10.0

Characteristic Variable Action, Qk

- For each variable actions there are four representative values:
  - **Characteristic value, (*Qk*)** – *an upper value with an intended probability of not being exceeded or a lower value with an intended probability of being achieved, during some specific reference period*
  - **Combination value, ($\Psi_o Qk$)** – *value intended to take account of a reduced probability of the simultaneous occurrence of two or more variable actions.*
  - **Frequent value, ($\Psi_1 Qk$)** – *value such that it should be exceeded only for a short period of time and is used primarily for the serviceability limit states and also accidental limit state.*
  - **Quasi-permanent value, ($\Psi_2 Qk$)** – *value may be exceeded for a considerable period of time; alternatively it may be considered as an average loading over time. I is used for a long term affects at the SLS and also accidental and seismic ULS.*

UTHM JOHOR
Universiti Tun Hussein Onn Malaysia
www.uthm.edu.my

Characteristic Variable Action, Qk

Recommended values for Ψ action for building

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings (see EN 1991-1-1)			
Category A: domestic, residential areas	0.7	0.5	0.3
Category B: office areas	0.7	0.5	0.3
Category C: congregation areas	0.7	0.7	0.6
Category D: shopping areas	0.7	0.7	0.6
Category E: storage areas	1.0	0.9	0.8
Category F: traffic area, vehicle weight ≤ 30 kN	0.7	0.7	0.6
Category G: traffic area, 30 kN ≤ vehicle weight ≤ 200 kN	0.7	0.5	0.3
Category H: roof (see EN 1991-1-1: Cl. 3.3.2)	0.7	0	0
Wind loads on buildings (see MS 1553: 2002)	0.5	0.7	0.7
Temperature (non-fire) in buildings (see EN 1991-1-5)	0.6	0.7	0.7
* See also MS EN 1991-1-1: Clause 3.3.2(1)			

Design Action

- In order to account for variation in Loads due to:
  - Errors in the analysis and Design
  - Constructional inaccuracies
  - Possible load increases
- The characteristic loads F_k (Gk,Qk,Wk) are multiplied by the appropriate partial safety factor for loads γ_f to give the design action acting on the structure.

$$F_d = F_k \times \gamma_f$$

- Value of γ_f are given in EN 1990: Annex A1

Structural Design Process

- The first function in design is the planning carried out by the architect to determine the arrangement and layout of the building to meet the client's requirements.
- The structural engineer then determines the best structural system or forms to bring the architect's concept into being.
- Construction in different materials and with different arrangements and systems may require investigation to determine the most economical answer.
- Architect and engineer should work together at this conceptual design stage.

Structural Design Process

- **Once the building form and structural arrangement have been finalized the design problem consists of the following:**
  - **idealization of the structure into loadbearing frames and elements for analysis and design**
  - **estimation of actions**
  - **analysis to determine the maximum moments and shears for design**
  - **design of sections and reinforcement arrangements for slabs, beams, columns and foundations using the results from above**
  - **production of arrangement and detail drawings and bar schedules**