REINFORCED CONCRETE DESIGN 1

Introduction & General Design Consideration

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Topic 1 : Introduction to Reinforced Concrete Design

i. Reinforced concrete materials
ii. Limit state design
iii. Characteristic load and strength
iv. Partial safety factor
v. Code of practice
vi. Properties of concrete and steel

Lesson Outcomes

At the end of this lesson, students should be able to:

- Define and explain reinforced concrete materials
- Define and explain the limit state design (ultimate & serviceability limit state)
- Identify characteristic load and strength, partial safety factors
- Define and explain properties of concrete and steel

Objectives of Structural Design

To provide a structure which throughout its intended life span:

- Possess an acceptable margin of safety against collapse whilst in use;
- Serviceable and perform its intended purpose whilst in use;
- Sufficiently strong (robust) to cater for subjected loadings
- Economic to construct (construction cost)
- Economic to maintain (maintenance cost)

Design Objectives (Keywords)

- Safe and reliable
- Fulfill its purposes
- Strong and durable
- Economic
- User comfort
- Maintainability

Design Process

1. Classify structures into frames and elements
2. Estimate the loads
3. Analyse/calculate the maximum moments, shear etc.
4. Design the section and reinforcement required
5. Produce detail drawing

What is Reinforced Concrete?

- A composite material that combines **concrete with steel reinforcements**.

- The combination of these materials provide a **strong durable** building material that could cater for both **compressive and tensile stress**.

- Concrete and steel reinforcement act together to resist forces.

Communitising Technology

Concrete

- Composite material composed of aggregate (sand & gravel) chemically bounded together by hydrated Portland cement.
- The aggregate generally is graded in size from sand to gravel, with the maximum gravel size in structural concrete commonly being 20mm (although 10mm or 40mm may be used)

Properties of Concrete and Steel

PROPERTIES	CONCRETE	STEEL
STRENGTH IN TENSION	POOR	GOOD
STRENGTH IN COMPRESSION	GOOD	GOOD (BUT SLENDER BARS WILL BUCKLE)
STRENGTH IN SHEAR	FAIR	GOOD
DURABILITY	GOOD	CORRODES IF UNPROTECTED
FIRE RESISTANCE	GOOD	POOR – SUFFERS RAPID LOSS OF STRENGTH AT HIGH TEMPERATURES

Advantages & Disadvantages of Reinforced Concrete

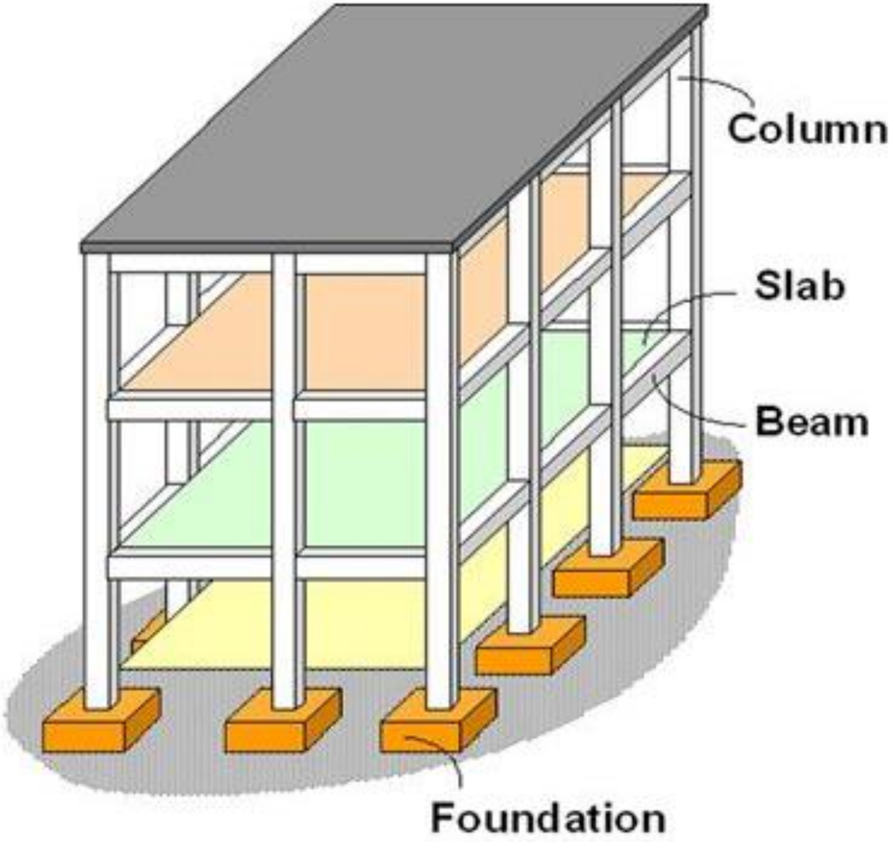
ADVANTAGES	DISADVANTAGES
1. Ability to be casted	1. Low Tensile Strength
2. Economical	2. Low Ductility
3. Durable/Impermeable	3. Volume Instability
4. Fire Resistance	4. Low Strength-weight Ratio
5. Energy Efficient	
6. On Site Fabrication	
7. Aesthetic Properties	

Typical Reinforced Concrete Element

- Beams – horizontal members carrying lateral loads
- Slabs – horizontal plate elements carrying lateral loads
- Columns – vertical members carrying primarily axial load, but generally subjected to axial load and moment
- Walls – vertical plate elements resisting vertical, lateral or in-plane loads
- Bases and foundations – pads or strips supported directly on the ground that spread the loads from columns or walls so that the can be supported by the ground

Typical Reinforced Concrete Element

Typical Reinforced Concrete Frame Building

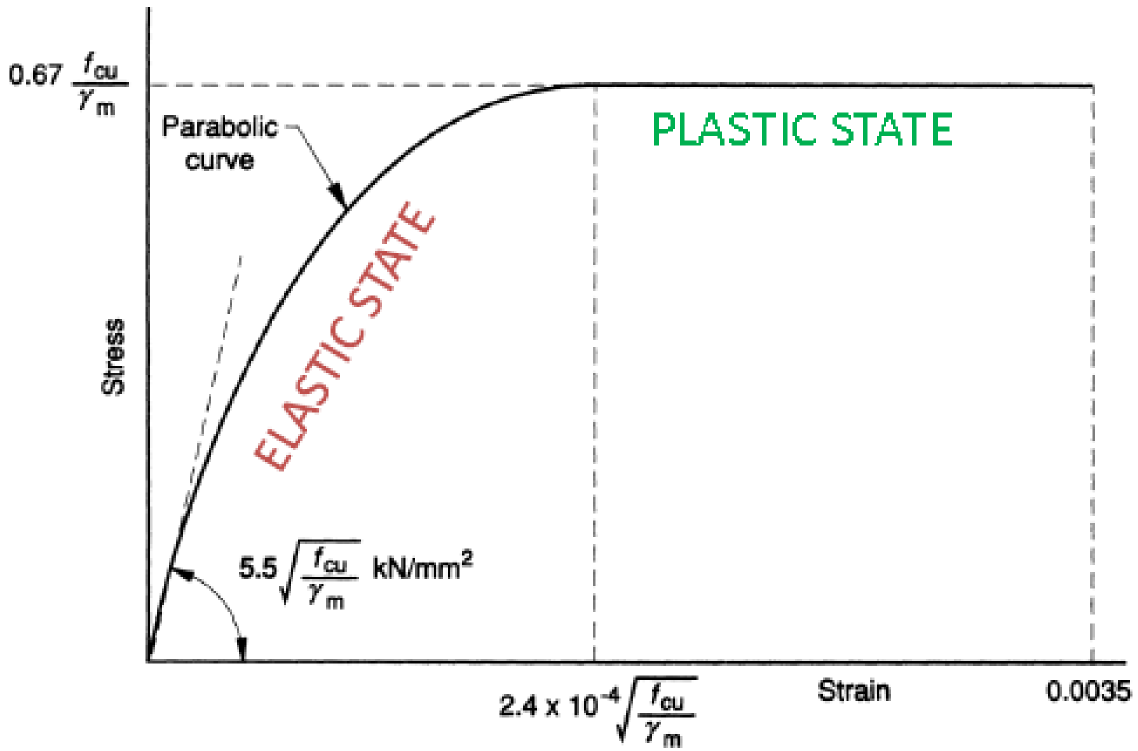


Source: http://www.concretecoalition.org/wpcontent/uploads/2013/08/RC_frame.jpg

Material Properties (Concrete)

- Concrete is a variable material
- As the load is applied, the ratio between the stresses and strains is approximately linear at first and the concrete behaves almost as an “elastic material”.
- Eventually, the curve becomes no longer linear and it behaves more as a “plastic material”.

Stress – Strain Curve (Concrete)



http://anbeal.co.uk/wpimages/wp8123ba8e_00.png

- Typical stress-strain curve for concrete in compression
- Concrete's strength generally increases with age.

Concrete's Compressive Strength, f_{ck}

- Concrete strength is assessed by measuring the crushing strength of cubes and cylinders made from the mix.
- The samples are then cured and tested after 28 days according to standard procedures.
- The strength of concrete is identified by its "class":

❑ **Example :**

Class 25/30

- **The characteristic cylinder crushing strength (f_{ck}) of 25 N/mm^2 and cube strength of 30 N/mm^2**

Strength Classes of Concrete

CLASS	f_{ck} (N/mm^2)	USAGE
C16/20	16	Plain Concrete
C20/25	20	Reinforced Concrete
C25/30	25	Reinforced Concrete
C28/35	28	Pre-stressed concrete / Reinforced Concrete subjected to chlorides
C30/37	30	Reinforced Concrete

There are higher strengths of concrete. These are just examples that are commonly used.

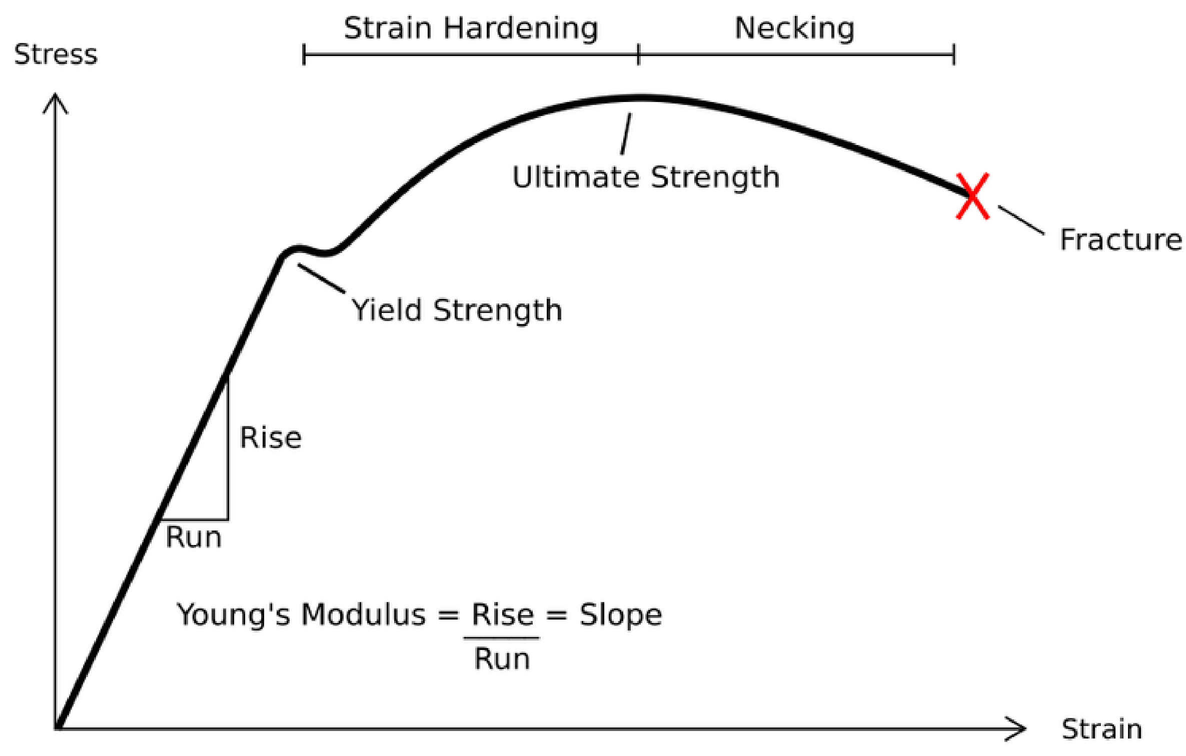
Concrete's Tensile Strength, f_t

- In reinforced concrete design, the tensile strength of concrete is normally assumed to be "zero".

Material Properties (Steel)

- Types of steel:
  - Hot rolled high yield steel
  - Cold worked high yield steel
- The specified characteristic strength, f_{yk} is 500 N/mm^2
- The bars are commonly identified by H (for high yield steel)

Stress – Strain Curve (Steel)



Source: https://commons.wikimedia.org/wiki/File:Stress_Strain_Ductile_Material.png

Simplified Stress – Strain Curve (Steel)

- In reinforced concrete design, a linear elastic-plastic is considered for both tension and compression condition.
- Reinforcing bar still has a considerable margin of safety within its maximum load-carrying capacity beyond the yield point.
- Modulus of elasticity of steel, Es can be taken as 200 kN/mm^2

Limit State Design

OBJECTIVES OF DESIGN:

- to achieve acceptable probabilities that a structure will not become unfit for its intended use
- In other words: “It will not reach its limit state”
- There are **two principle types of limit states:**
  - Ultimate limit state (ULS)
  - Serviceability limit state (SLS)

Ultimate Limit State (ULS)

DEFINITION:

- •This requires the structure to be able to withstand, with **an adequate factor of safety against collapse**, designed to ensure **safety** of the occupants and the safety of the structure itself.

- The possibility of buckling, overturning and accidental damage (eg: explosion) has to be taken into account.

Serviceability Limit State (SLS)

Generally, **the most important SLS are:**

1. **Deflection** (the appearance/efficiency of the structure or the comfort of the occupants should not be affected)
2. **Cracking** (must not affect the appearance, efficiency or durability of the structure)
3. **Durability** (must be considered in terms of the proposed life of the structure and its conditions of exposure)

Other limit states are:

– Excessive vibration, fatigue, fire resistance

Code of Practice

- A document about the best practice by engineers and also experienced researchers.
- Current code of practice in Malaysia is the Eurocode 2.
- For reinforced concrete design, these are the codes of practice being used:
  - **BS EN 1990 : 2002**
    - Eurocode : Basis of Structural Design
  - **BS EN 1991-1-1 : 2002**
    - Eurocode 1 : Actions on structures (densities, self-weight, imposed loads for buildings)
  - **BS EN 1992-1-1 : 2004**
    - Eurocode 2 : Design of concrete structures

Actions

- The set of applied forces (or loads) for which a structure is to be designed.
- The standard loadings are given in BS EN 1991 : Eurocode 1 – Actions on Structures
- The actions(loads) on a structure are divided into two types:
  - **Permanent actions, Gk**
  - **Variable actions, Q_k**

Permanent Action, G_k

- Actions which are normally constant during the structures life.
- Include the weight of the structure itself and all static components.

- Examples:
  - Self-weight of all permanent structures such as beams, columns, floors, wall, roofs and finishes.
  - Permanent partitions

Variable Action, Q_k

- These actions are more difficult to determine accurately.
- Estimates are based on standard codes of practice or past experience.
- The values adopted are based on observations and measurements and it is less accurate than the assessment of dead loads.
- Examples:
  - Weights of buildings occupants, furniture, machinery, and retained earth or water.

The standard values can be obtained from EN 1991-1-1:2002 (Actions on Structures)

Wind Load, W_k

- Although wind load is a variable action, it is kept in a separate category.

- Since the partial factors of safety are specified and the load combinations on the structure are considered.

Partial Factor of Safety

- Allowance of **possible variations** such as constructional tolerances.

- This is applied to the strength of materials and actions.

Partial Factor of Safety for Material, γ_m

$$\text{Design strength} = \frac{\text{characteristic strength } (f_k)}{\text{partial factor of safety } (\gamma_m)}$$

- To cater for **errors during construction** or manufacturing process.
  - **Steel** : manufactured in a factory with stringent care (smaller partial factor of safety)
  - **Concrete**: Constructed on site (leads to higher partial factor of safety)

Partial Factor of Safety for Material, γ_m

	Persistent & transient		Accidental	
Limit State	**Concrete**	**Reinforcing Steel**	**Concrete**	**Reinforcing Steel**
Ultimate (ULS)				
Flexure	1.5	1.15	1.2	1.0
Shear	1.5	1.15	1.2	1.0
Bond	1.5	1.15	1.2	1.0
Serviceability (SLS)	1.0	1.0		

Partial Factor of Safety for Action, γ_f

Design value action = Characteristic action x Partial factor of safety

- To cater for **errors/inaccuracies** due to:
  - Design assumptions and inaccuracy of calculation
  - Possible unusual load increment
  - Unforeseen stress redistributions
  - Constructional errors

Partial Factor of Safety at the Ultimate Limit State

Persistent or transient design situation	Permanent actions (G_k)		Leading variable action ($Q_{k,1}$)		Accompanying variable actions ($Q_{k,i}$)	
	Unfavourable	Favourable	Unfavourable	Favourable	Unfavourable	Favourable
(a) For checking static equilibrium of a structure	1.1	0.9	1.5	0	1.5	0
(b) For the design of structural members	1.35	1.0	1.5	0	1.5	0
(c) As an alternative to (a) and (b) above to design for both situations with one set of calculations	1.35	1.15	1.5	0	1.5	0

Source: MALAYSIA NATIONAL ANNEX TO EUROCODE 2: DESIGN OF CONCRETE STRUCTURES – PART 1-1: GENERAL RULES AND RULES FOR BUILDING

Partial Factor of Safety at the Ultimate Limit State

Load combinations and patterns for the ultimate limit state:

- For the design at ultimate limit state, the load combination that will be used is (wind load is excluded):

Design load = 1.35Gk + 1.5Qk

Design situation	Permanent actions	Variable actions
All	1.0	1.0

Summary and Short Quiz