Training on
NBC & Structural Analysis Software

Review of Structural Systems & Structural Analysis

22 August – 2 September, 2014 Kathmandu

Presented by: D. Shrestha, SDE

Topics Covered

A Short Review of:

1. Structural Systems
2. RCC Frame Action
3. Loads, Load Cases and Combinations
4. Load Path
5. Analysis Methods

STRUCTURE

That Part of the object (building, bridge, chair, living body, etc) which must resist the applied loads or which is responsible for maintaining the shape of the object under the influence of the environment.

- The influence of the environment on structures takes the form principally of loads & forces.
- Environment means anything in contact with the structure (e.g. vehicles, furniture, people, , wind, temperature, earthquake, etc) which affects the structure by exerting forces on it.

Some definitions…

- Force: Influence on a body, causing or attempting to cause the movement of the body or part of it, or causing a change in its movement, if it is already in motion.
- Load: A force applied to a structure by the environment or by any object (including the structure itself or other structures). It is any external force applied to a structure.

Forces Acting in Structures

- Forces induced by gravity
  - Dead Loads (permanent): self-weight of structure and attachments
  - Live Loads (transient): moving loads (e.g. occupants, vehicles)
- Forces induced by wind
- Forces induced by earthquakes
- Forces induced by rain/snow
- Fluid pressures
- Others

Types of Loads on Structures

Gravity Load: due to the effect of weight of the objects on the structure, including the weight of the structure itself.

- A) Dead Load: Load resulting from the self weight of the structure and any permanently attached components such as walls, flooring, permanent partitions, etc
- B) Live Load: Load arising from the function of the structure, including attached components whose location is not fixed, such as movable partitions.

Load types…

- **Live loads** are result of the weight of the loading objects (vehicles, furniture, goods, people, etc) and are mostly vertical. In some cases, however, loads may be applied in non-vertical directions, for instance loads due to braking of vehicles, loads transmitted through pulleys, earth or hydrostatic pressure)

Load types…

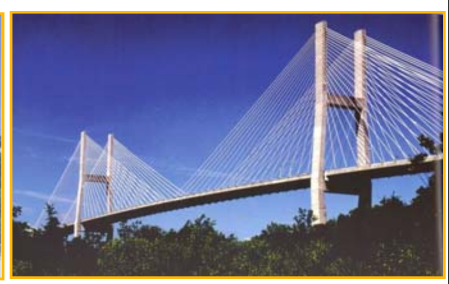
- **Environmental Loads:** These are not a direct result of the weight of objects, but of movement in the structures' environment. The most common environmental loads are wind loads and earthquake load. Wind load is a result of moving air hitting the structure. Earthquake load is a result of movement of the earth in which structure is founded.
- **Other environmental influences:** change of temperature, support settlement, Lack of fit, prestressing, etc.

Types of Structures

- All structures are three dimensional.
- Structures are classified as Planar or plane structure and Spatial or Space Structure for the sake of approximation in structural analysis and not with respect to its geometry.

Examples of Typical Structures



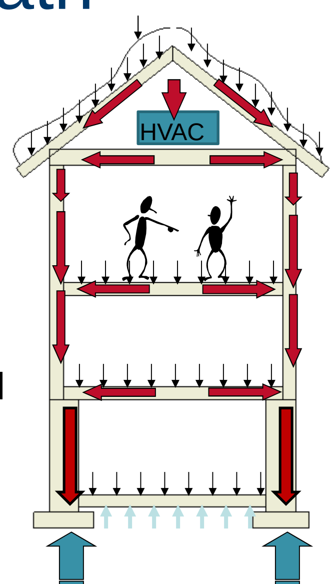



Load Path

- Load path is the path load travels from where it acts to where it is resisted.

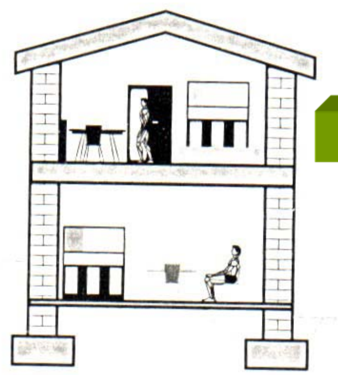
Load Path

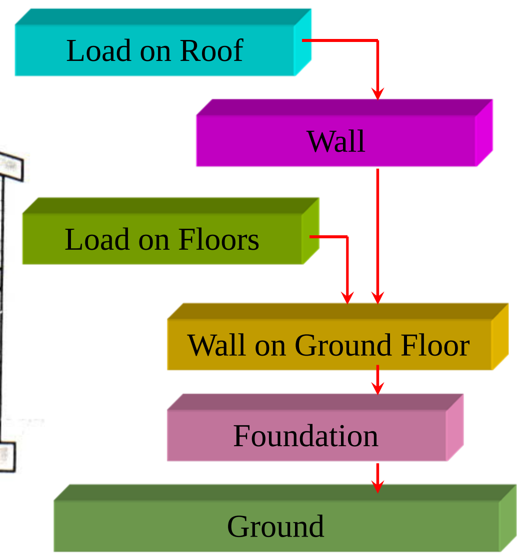
- The path that a load travels through the structural system
- "Tracing" or "chasing" the loads
- Each structural element must be designed for all loads that pass through it



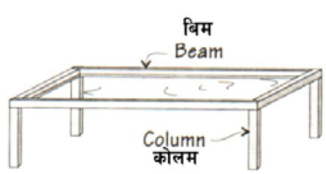
LOAD BEARING SYSTEM

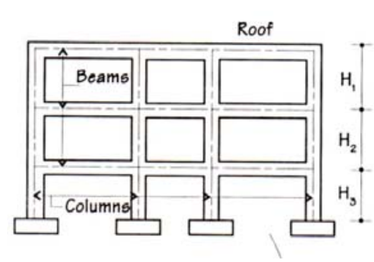
Vertical Load Path



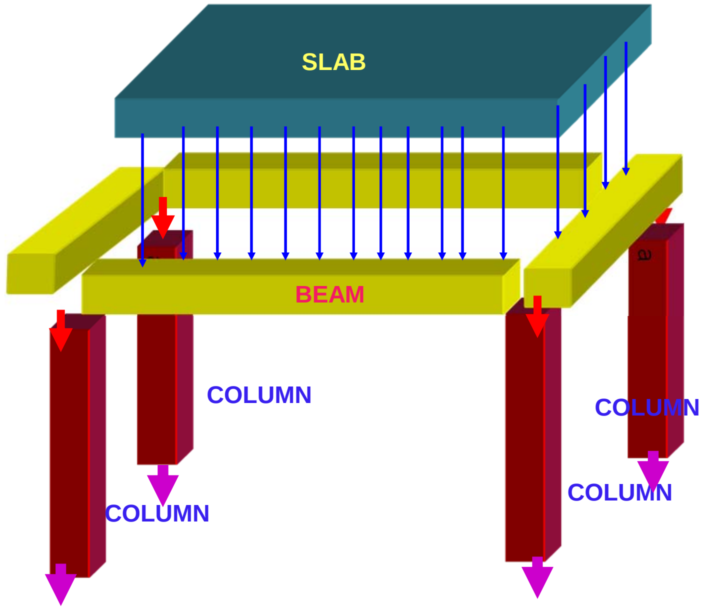


FRAME STRUCTURE

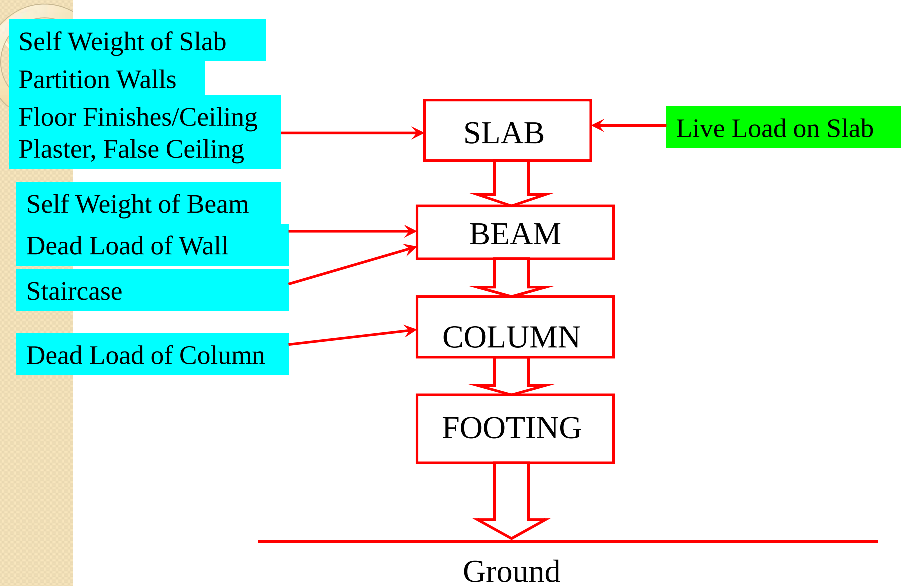




Vertical Load Path in RCC Frame



Vertical Load Path in RCC Frame



Lateral Load Path

- There are multiple components within a building that are used to transmit earthquake motion from the foundation to the uppermost parts of the building and subsequently transmit inertia forces from the uppermost parts of the building down to the foundation.
- These transmitting and resisting components define the building's lateral load-path. There are two primary load path components, the vertical components such as columns, shear walls, braced frames, moment's frames and horizontal components such as roof, floor slabs, and foundation.

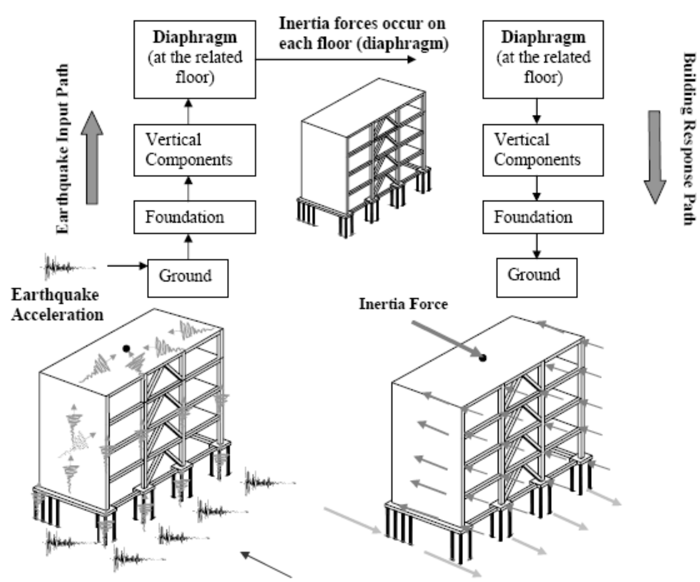
Lateral Load Path

- Roof and floor slabs are called diaphragms. Diaphragms function is to distribute inertia forces from the story above to the vertical resisting components that take the earthquake forces from the stories at and above their level and deliver them to the vertical resisting components in the story immediately below.
- The transmission of earthquake forces from the horizontal components (diaphragms) to the vertical resisting components is done through cords and collectors. Cords are structural members along the boundary of the diaphragms that resist tension and compression forces. Collectors are structural members that transmit diaphragms forces into the vertical resisting components such as columns, shear walls or frames.

Vertical Components

- Vertical components consist of columns, shear walls and braces. The functions of these components are to resist loads distributed by the horizontal diaphragm and transfer to the lowest part of the building, namely the foundation.

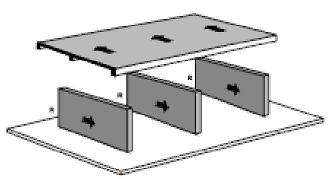
Lateral Load Path in Vertical Elements

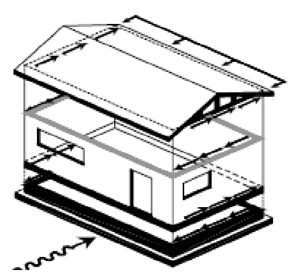


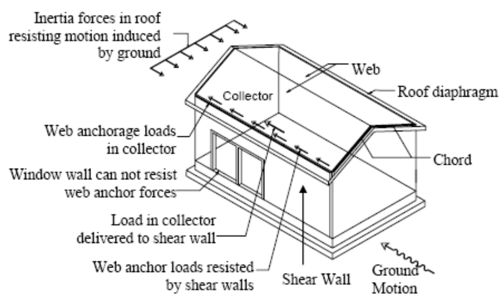
Horizontal Components

- Horizontal components consist of floor and roof slabs (usually called diaphragms). Beams act as collectors and its function is to distribute inertia forces created as a result of the building acceleration and to distribute to vertical components.

Lateral Load Path in Diaphragms



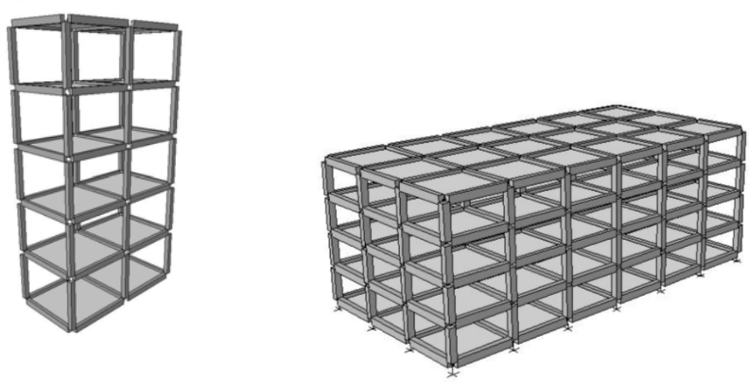




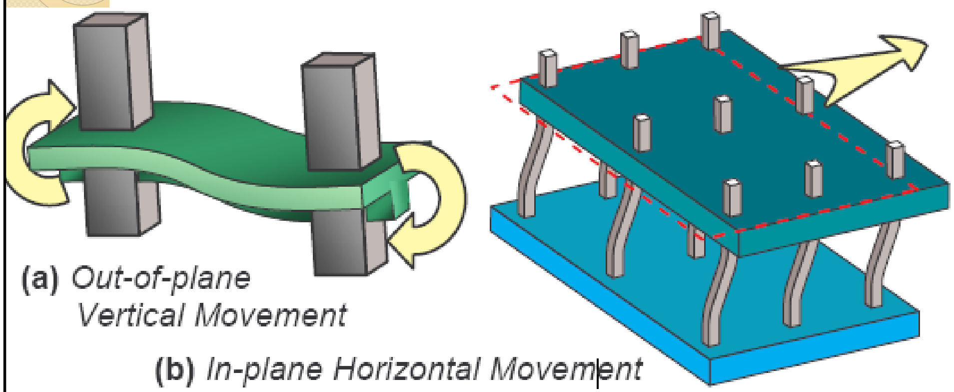
Moment Resisting Frame Systems

- This resisting system consists of columns and beams that are rigidly connected and form integral units of 2-D portals, and these units form integral 3-D portals providing a complete space frame throughout the building to carry vertical loads. Bending of the beams and columns provides the resistance to lateral load.

Moment Resisting Frame System



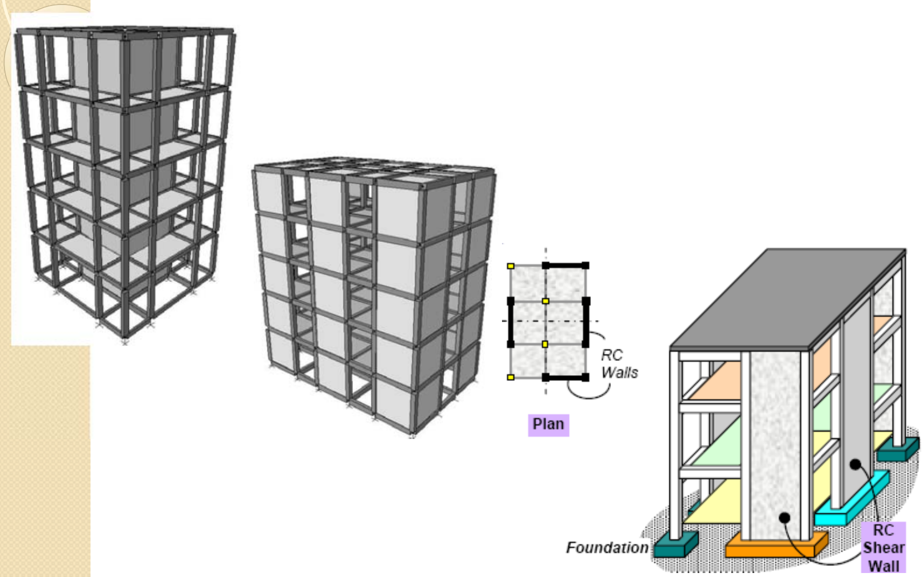
Moment Resisting Frame



Shear Wall Systems

- Shear wall systems consist of mainly vertical as well as lateral loads resisting walls located along exterior wall lines as well as interior locations. Columns are also used to provide complete load carrying space frames.
- This system has a large in plane shear capability. For out of plane lateral loads (forces working perpendicular to the wall), the system needs walls in the direction of the lateral load. Therefore this system has walls in both directions.
- In this type of resisting system, shear forces are the dominant factors, even though high-rise buildings are also subjected to bending.

Shear Wall System

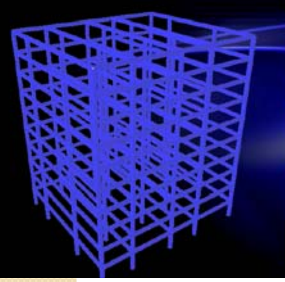


Structural System for Lateral Stiffness

- Braced: Shear Wall, Diagonal Bracing
- Unbraced: Moment Resisting Frame-SMRF(with ductile design), OMRF(h<48 m, for low seismic zone)
- Dual System: Shear Walls + Frames
- Tube System: columns placed on the periphery of building so that it acts like a box in plan.

Structural Systems

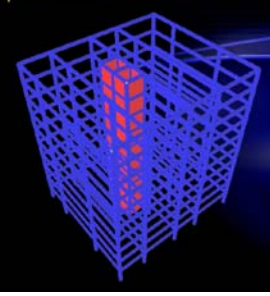
Moment Resisting Frame



- The Load is transferred by shear in columns, that produces moment in columns and in beams
- The Beam-Column connection is crucial for the system to work
- The moments and shear from later loads must be added to those from gravity loads

suitable for more than 4 storeys

Shear Wall and Frame

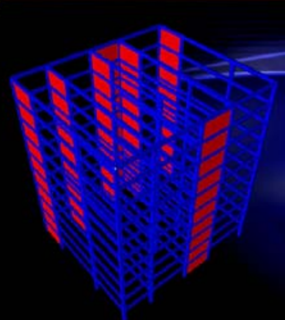


- The lateral loads is primarily resisted by the shear in the walls, in turn producing bending moment
- The openings in wall become areas of high stress concentration and need to be handled carefully
- Partial loads is resisted by the frames
- Traditionally 75/25 distribution haws been used

suitable for more than 10-12 storeys

Structural Systems

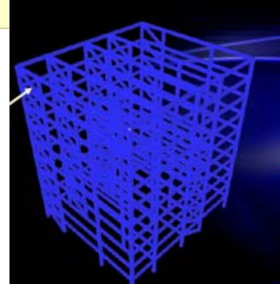
Shear Wall - Frame



- The Walls are part of the frame and act together with the frame members
- The lateral loads is primarily resisted by the shear in the walls, in turn producing bending moment.
- Partial loads is resisted by the frame members in moment and shear

suitable for more than 10-12 storeys

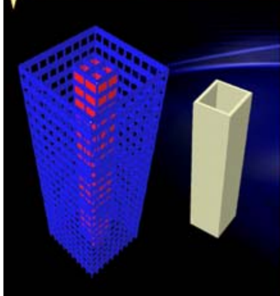
Braced Frame



- The lateral loads is primarily resisted by the Axial Force in the braces, columns and beams in the braced zone.
- The frame away from the braced zone does not have significant moments
- Bracing does not have to be provided in every bay, but should be provided in every story

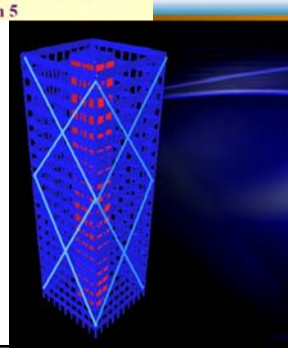
Structural Systems

Tubular Structure



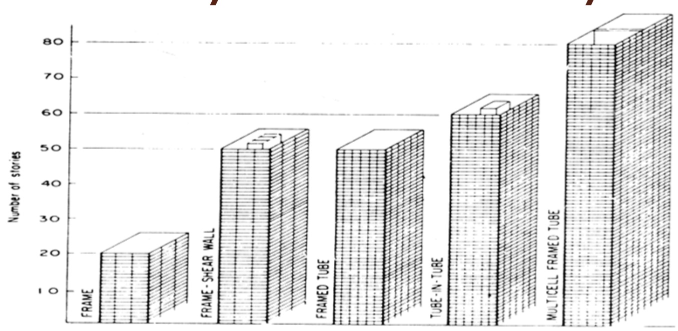
- The system is formed by using closely spaced columns and deep spandrel beams
- The lateral loads is primarily resisted by the entire building acting as a big cantilever with a tubular/ box cross-section
- There is a "shear lag" problem between opposite faces of the tub[e] due to in-efficiency of column beam connection
- The height to width ratio should be more than 5

Braced Tube Systems



- Diagonal Braces are added to the basic tubular structure
- This modification of the Tubular System reduces shear lag between opposite faces

Suitability of Structural Systems



Structural System for Various Heights of Office Buildings

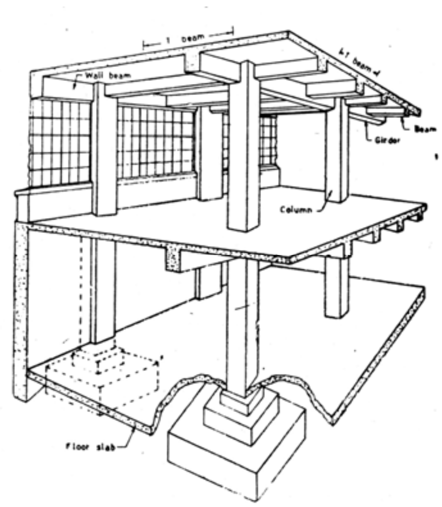
No of Storeys	Structural Systems
1 to 4	Load Bearing Brickwork
5 to 12	RC Frame
13 to 20	RC Frame with Shear Walls
21 to 30	RC Core with frames & Shear Walls
31 to 40	RC Core Interior+Framed Tube in the Periphery

Concept of Ordinary Frame Structure

- RCC frame consists of Floor slabs, beams, girders & columns continuously placed to form a rigid monolithic system.

- It is a three dimensional structure or space structure.

RCC Frame



The Building Structural System

•**The Floor Diaphragm:**
the horizontal floor system that supports and connects vertical supporting unit.

•**The Gravity Load Resisting System:**
the structural system (beams, slab, girders, columns, etc) that act primarily to support the gravity or vertical load.

•**The Lateral Load Resisting System:**
the structural system (columns, shear walls, bracings, etc) that act primarily to resist lateral loads

Building Response

1. For Gravity Load:
Analysis of Gravity Load system for Dead loads, Live Load, Pattern load, temperature, shrinkage
Important Elements: Floor Slab, beams, Openings, Joists, etc.

2. For lateral Loads:
Analysis of Lateral Load resisting System for Wind loads, seismic loads, Structural Unsymmetry
Important Elements: Columns, Shear Walls, Bracing, Beams.

3. For Gravity + Lateral Load

Combined analysis or combination of analysis

Building-Foundation Interaction

Modeling of Structure

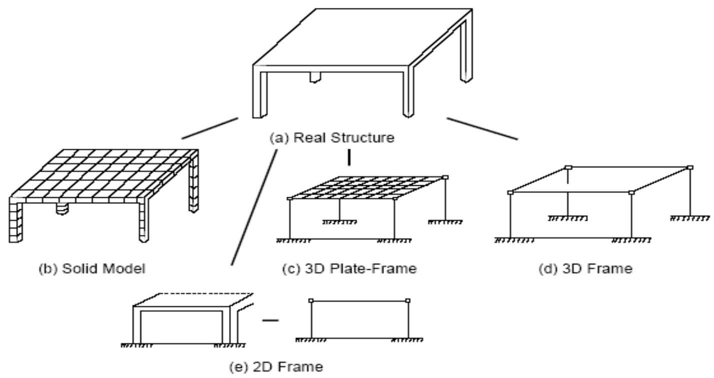


Figure 1.3 Various Ways of Modeling a Structure *(Anwar 2000)*

Modeling of Frame Structure as 2D Frames:

- It can be analyzed as a system of interconnected two-dimensional vertical frames along two mutually perpendicular horizontal axes for analysis.
- The frames are analyzed independently of each other.

2D Modeling of 3D Building

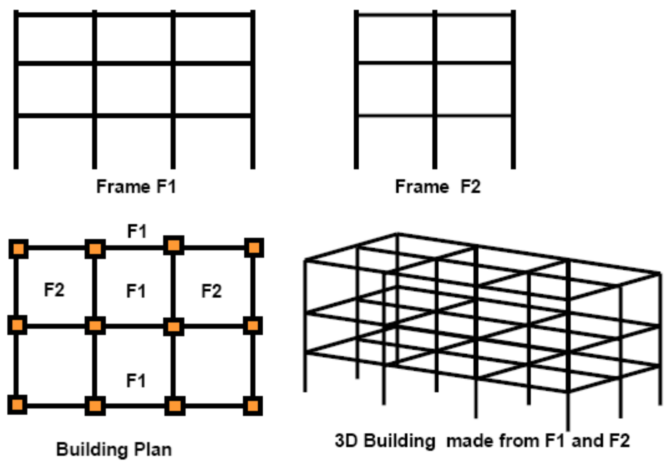


Figure 1.8 A 3D Building as a System of Two Typical 2D Frames

2D modeling

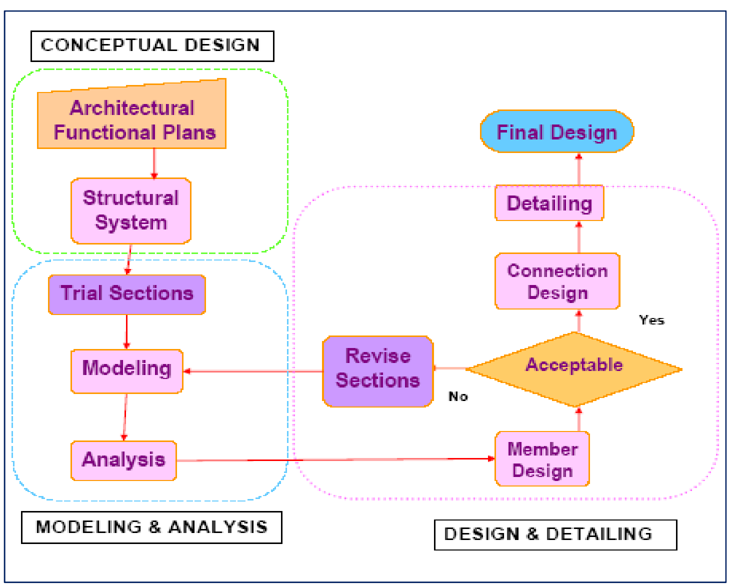
- Advantages:
- Easier to model, analyze & interpret
- Fairly accurate for gravity load analysis

2D modeling

Problems:

- Centre of stiffness and centre of forces may not coincide.
- Difficult to consider building torsional effects
- Difficult to model non-rectangular framing system
- Several frames may need to be modeled in each direction.

Structural Design Process



Member Stiffness

- It is EI/L
  - E = Young' modulus of Concrete
  - I = Moment of Inertia
  - L = Length of member
- EI should reflect degree of cracking and inelastic action.
- EI varies along the length of member and is afunction of stress level.
- Exact determination of EI is quite complex.

Code Recommendation of E_c

IS 456:2000

- Initial Tangent modulus of Concrete:
- $Ec = 5000*\sqrt{\sigma_{ck}}$ in N/mm^2
- σ_{ck} = 28-day characteristic strength of concrete in N/mm^2

BS:8110

- $Ec = 5500*\sqrt{(\sigma_{ck}/\mu_m)}$ MPa
- μ_m = partial safety factor for concrete

ACI:318

- $Ec = 4500*\sqrt{(\sigma_{ck})}$ Mpa

Moment of Inertia (I)

Can be calculated on the basis of:

- Gross concrete section: cross-sectional area ignoring reinforcement
- Gross Equivalent Section: concrete cross-section + area of reinforcement transformed on the basis of modular ratio (m=15 for all grade of concrete)
- Cracked section: area of concrete in compression + area of reinforcement transformed on the basis of modular ratio.

Practical Value of I

Practical Value:

- Beams/girder/columns: on the basis of gross section with no allowance made for renforcing steel.

Continuous T-beam:

- I greater for sagging moment with flanges in compression, I smaller for hogging moment with flanges cracked due to tension.
- I for uncracked T beam = 1.5 to 2 times Ic
- I for cracked T-beam = 0.5 to 0.75 times Ic
- I for cracked rectangular beam = 0.4 to 0.6 times Ic
- Real I is less than Ic for part of member and it exceeds Ic for the balance. Hence average I = 1.5*Ic

LOADS

- Actual Loads and Load Effects that exist in Real structure

Gravity Loads:
- Dead loads: self load+ imposed dead load +partitions
- Live Load: Occupants, Equipment, etc

Lateral Loads:
- Wind load: wind pressure converted to load on each floor
- Seismic Load: Base shear converted to load on each floor
- seismic excitation imparted at structure base for dynamic response.

Secondary Loads:
- Temperature, Creep, Shrinkage
- Settlement

Load Cases (Load Pattern in SAP2000)

- Different possibilities of occurrence of the basic Loads

Dead Loads
- Self load only
- Additional dead load

Live Load
- Full Live Load
- Pattern of Live Loads

Wind Load Effects

- Different wind direction: left-right(x,y)

Seismic Load Effects

- Different earthquake direction: left-right(x,y)

Load Combinations

- Different possibilities of occurrences of various "Load Cases"

1.Service Load Combinations

- Simple addition and subtraction of load Cases

2.Ultimate Load Combinations

- Factored combination of load cases
- Consider importance of loads
- Consider probability of variation
- Consider probability of simultaneous application

Load Cases vs Load Combinations

Analyze for Load Cases-
Design for Load Combinations

Important Load Combinations

Design Load Combinations for the Limit State Method

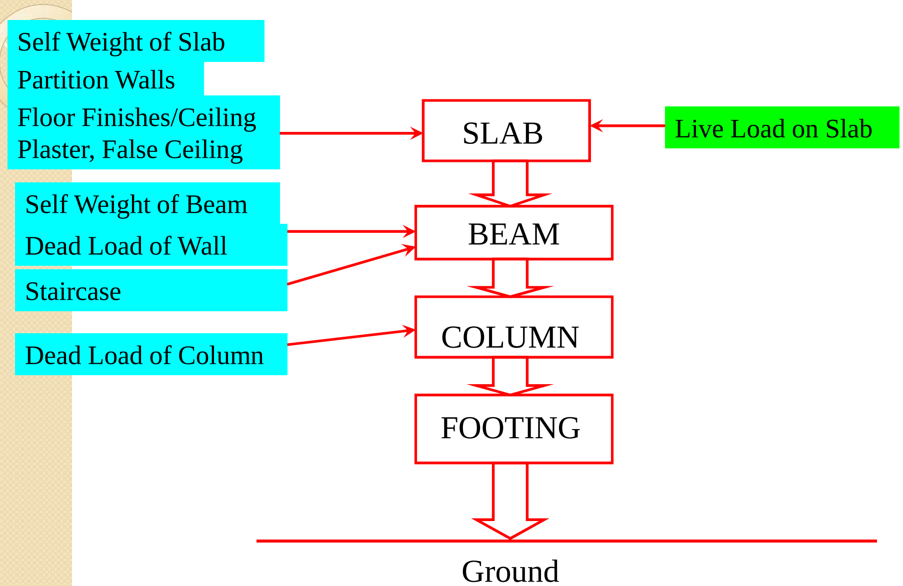
NBC 105/110:1994

- 1.5DL+1.5LL
- DL +1.3 LL ±1.25 E
- DL+1.3 SL±1.25 E
- 0.9 DL ± 1.25 E

IS 875:1984 /IS 1893:2000

- 1.5 DL+1.5 LL
- 1.2 DL +1.2 LL ±1.2 E
- 1.5 DL±1.5 E
- 0.9 DL ± 1.5 E

Vertical Load Path in RCC Frame



Load Transfer from Slab to Beam

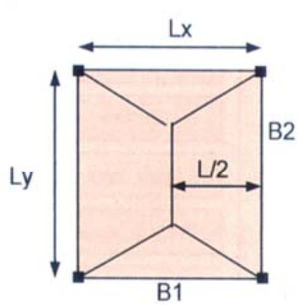
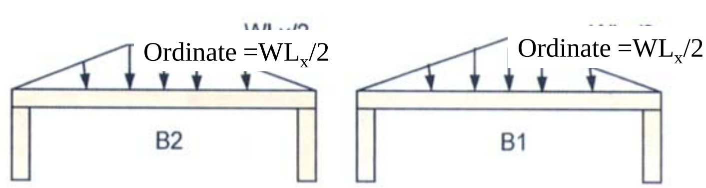


Figure 1: Conventional assumption of Transfer for Beam-Slab System



Calculation of Load from Slab to Beam

- Equivalent UDL:

<u>with respect to mid-span BM</u>

- short span: $w_{eq} = q*(L_x/3)$
- long span: $w_{eq} = q*(L_x/2)*(1-1/3\beta^2)$

(beam shear is increased)

<u>with respect to Equal Shear at Support</u>

- short span: $w_{eq} = q*(L_x/4)$
- long span: $w_{eq} = q*(L_x/4)*(2-1/\beta^2)$

Calculation of Load from Slab to Beam

Approximate method for triangular load

- Assume the load to be uniformly distributed.
- Magnify the end moment by 5/4
- Magnify the mid-span moment by 3/2

Steps in Analysis and Design

- **Preliminary design**
  - Define section sizes
  - Estimate design loads (dead, imposed)
  - Estimate time period of the building
  - Estimate earthquake load, eccentricity if any in structure
  - Distribute it to the structural members (taking consideration of torsion, if any)
  - Analyze building for defined material, structural system, loading etc. (assess bending moment, shear force, axial load)
  - Design the section
  - Check the codal requirements
  - Check if the design meets the codal requirement or not

Steps (Contd…)

- **Final design**
  - Revise the materials, structural system, sectional properties if required
  - Revise the steps discussed in Preliminary design
  - Check if detailing can be made and it meets codal requirement (steel placement in beam column joint, splicing locations etc in RC frame construction)
  - Finalize the section and detailing
  - Construct structural drawings

Analysis for Vertical Loads

<u>Preliminary Analysis:</u>

- Continuous Beam
- Substitute Frame

<u>Final Analysis:</u>

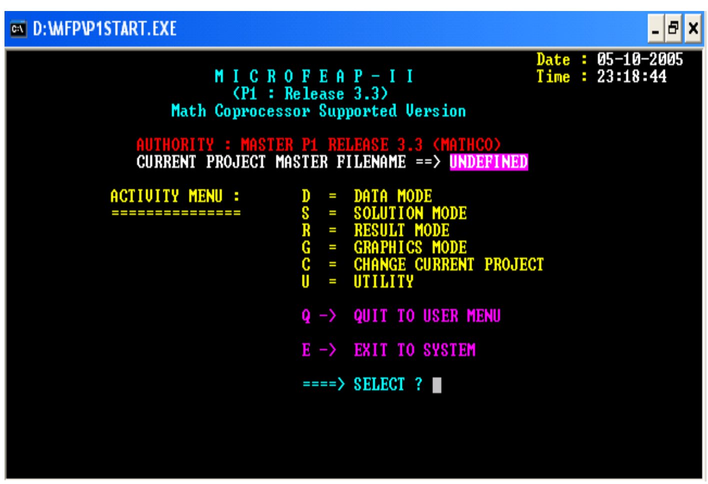
- Manual Methods: Moment distibution/ Kani's Method
- Computer Methods: Stiffness Matrix/FEA methods

Softwares:

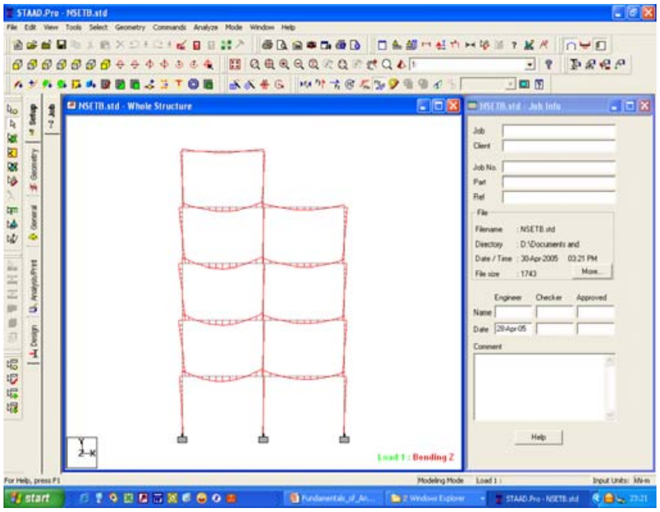
2D -MICROFEAP, GRASP,

3D -RISA, Staad.Pro, SAP2000, ETABS

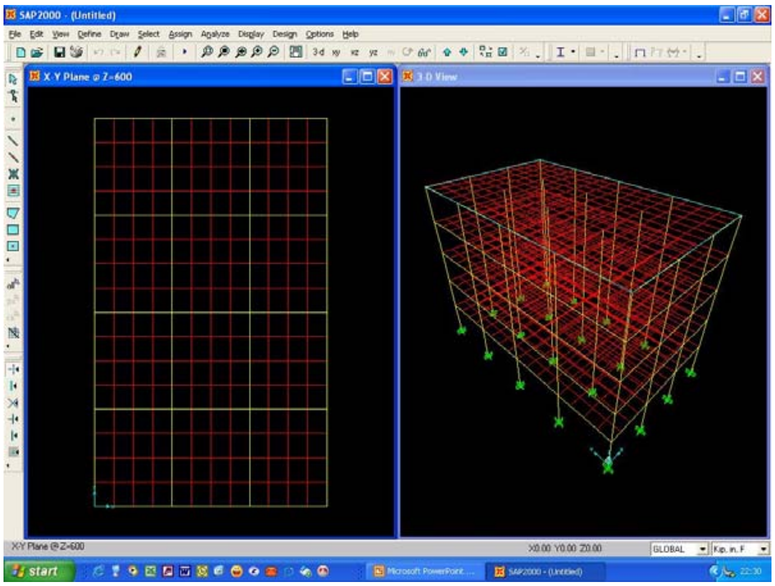
MICROFEAP- P1 for Analysis



Staad.Pro for Structural Analysis



SAP2000 for Analysis



Analysis for Lateral Loads

Preliminary Analysis:

- Portal Method
- Cantilever Method

Final Analysis:

- same as those for vertical load analysis

Frame Analysis

- Frame Analysis gives:
  - Reactions and displacements
  - Frame element forces and stresses
    - Moments
    - Shears
    - Direct forces

Design of Elements

- Design of columns
  - For direct loads and biaxial moments
  - For shears
- Design of Beams
  - For moments and shears
- Design for ductile detailing
  - Strong column – weak beams
  - Joint detailing
  - Confining reinforcements

Other Elements

- Design of slabs
  - Local moments and shears
- Design of staircase
- Non-structural elements
  - Parapets
  - Partition walls

THANK YOU!