Buckling Resistance of Frames and Requirements for elastic and advanced structural analysis

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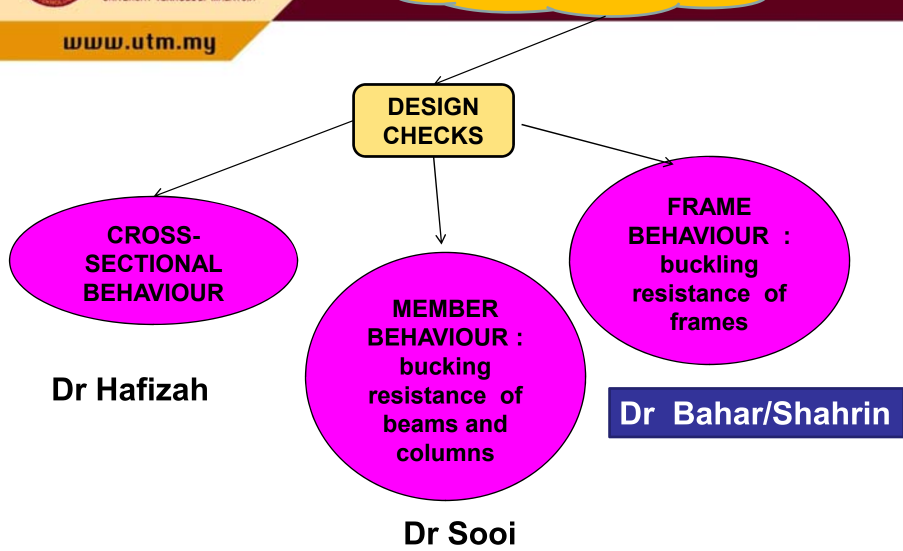
Eurocode 3



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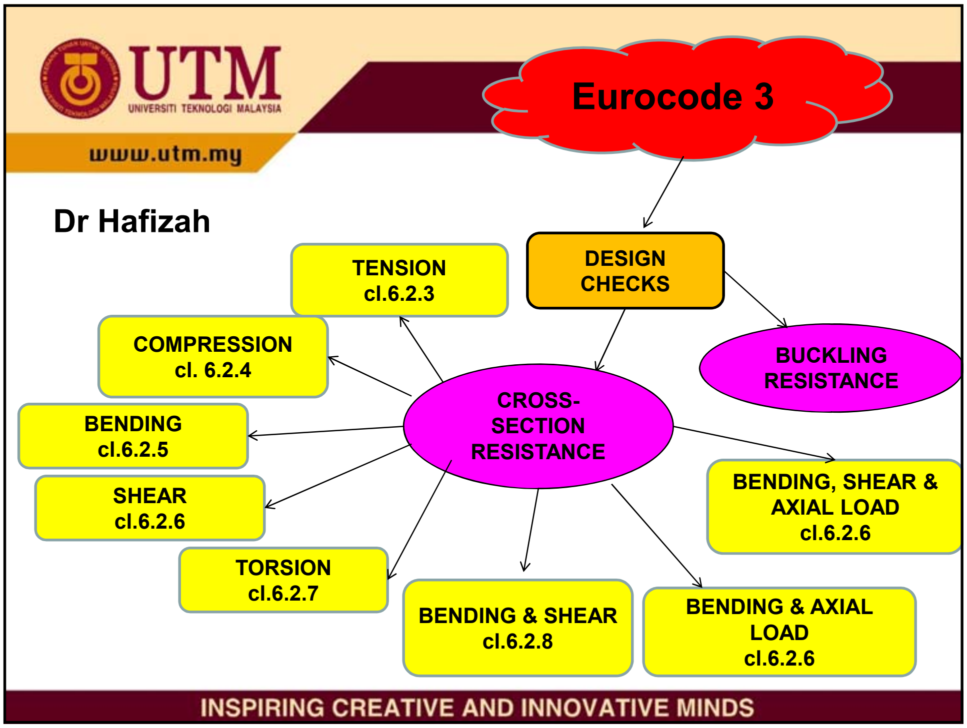
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Eurocode 3
Dr Hafizah
DESIGN CHECKS
BUCKLING RESISTANCE
CROSS-SECTION RESISTANCE
TENSION cl.6.2.3
COMPRESSION cl. 6.2.4
BENDING cl.6.2.5
SHEAR cl.6.2.6
TORSION cl.6.2.7
BENDING & SHEAR cl.6.2.8
BENDING & AXIAL LOAD cl.6.2.6
BENDING, SHEAR & AXIAL LOAD cl.6.2.6
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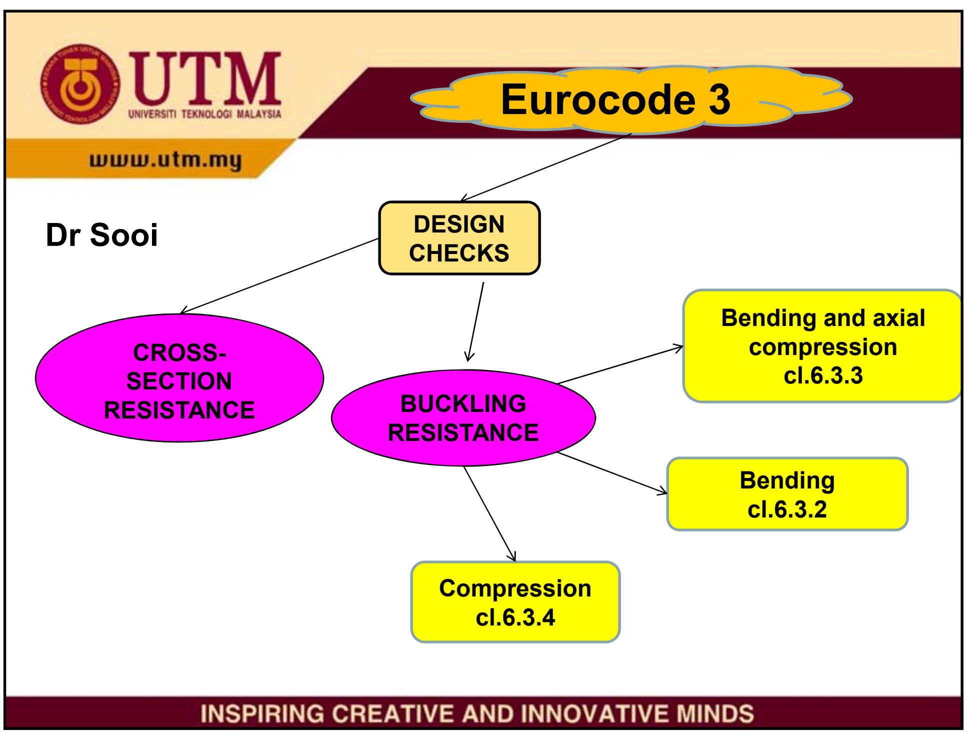
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Eurocode 3
Dr Sooi
DESIGN CHECKS
CROSS-SECTION RESISTANCE
BUCKLING RESISTANCE
Bending and axial compression cl.6.3.3
Bending cl.6.3.2
Compression cl.6.3.4
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Eurocode- 0

Distinction between Principles and Application Rules

(1) Depending on the character of the individual clauses, distinction is made in EN 1990 between Principles and Application Rules.

(2) The Principles comprise :

- general statements and definitions for which there is no alternative
- requirements and analytical models for which no alternative is permitted unless specifically stated.

(3) The Principles are identified by the letter P following the paragraph number.

(4) The Application Rules are generally recognised rules which comply with the Principles and satisfy their requirements.

(5) It is permissible to use alternative design rules different from the Application Rules given in EN 1990 for works, provided that it is shown that the alternative rules accord with the relevant Principles and are at least equivalent with regard to the structural safety, serviceability and durability which would be expected when using the Eurocodes.

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Section 5 Structural analysis and design assisted by testing

- Structural analysis
  - Modeling appropriate to limit states
  - Established engineering theory and to be verified if necessary
- Static actions, dynamic actions, fire design
- Design assisted by testing

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Eurocode 3 : Design of steel structures – Part 1-1: General rules and rules for Buildings BS EN 1993-1-1:2005

Introduction to Eurocode 3

- the principles of design, concept and formulation are generally similar to BS5950
- the main differences of the two design rules are only in the symbols, terms, safety factors and limits adopted
- distinction is made between
  - principles which must be obeyed
  - application rules which follow the principles but alternative methods are allowed
- design capacities in EC3 are categorised under cross-section resistance and member buckling resistance (based on structural behaviour and not based on element/member)

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Introduction to Eurocode 3

- based on limit state design principles which require that specific 'failure' conditions must be checked for both ultimate and serviceability conditions
- variability, principally of actions and materials, is accounted for by partial safety factors which also incorporate a global margin of safety
- EC3 incorporates theories in the first-order and second order which consider the effects of deformations
- EC3 allows us to choose the degree of accuracy of the structural analysis
- allows for the “advanced analysis approach” in analysis and design as an alternative to simplified design method

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Introduction to Eurocode 3

- frame imperfection(P-D and P-d effect) to be included in the structural modeling of frames
- a comprehensive information on the elastic-perfectly plastic and elasto-plastic methods for continuous and semi-continuous steel framing
- providing classification of the connections based on strength and rigidity
- the information on frame stability is presented in detailed whilst the terms sway and non-sway frames are well defined

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Eurocode 3 : Content

- 5. Structural analysis
  - *5.1 Structural modelling for analysis*
    - 5.1.1 Structural modelling and basic assumptions
    - 5.1.2 Joint modelling
    - 5.1.3 Ground-structure interaction
  - *5.2 Global analysis*
    - 5.2.1 Effects of deformed geometry of the structure
    - 5.2.2 Structural stability of frames
  - *5.3 Imperfections*
    - 5.3.1 Basis
    - 5.3.2 Imperfections for global analysis of frames
    - 5.3.3 Imperfection for analysis of bracing systems
    - 5.3.4 Member imperfections
  - *5.4 Methods of analysis considering material non-linearities*
    - 5.4.1 General
    - 5.4.2 Elastic global analysis
    - 5.4.3 Plastic global analysis
  - *5.5 Classification of cross sections*
    - 5.5.1 Basis
    - 5.5.2 Classification
  - *5.6 Cross-section requirements for plastic global analysis*

Whole of Chapter 5 is dedicated to Structural Analysis and Frame Behaviour

Eurocode 3 : Content

- 6. Ultimate limit states
  - *6.1 General*
  - *6.2 Resistance of cross-sections*
    - 6.2.1 General
    - 6.2.2 Section properties
    - 6.2.3 Tension
    - 6.2.4 Compression
    - 6.2.5 Bending moment
    - 6.2.6 Shear
    - 6.2.7 Torsion
    - 6.2.8 Bending and shear
    - 6.2.9 Bending and axial force
    - 6.2.10 Bending, shear and axial force
  - *6.3 Buckling resistance of members*
    - 6.3.1 Uniform members in compression
    - 6.3.2 Uniform members in bending
    - 6.3.3 Uniform members in bending and axial compression
    - 6.3.4 General method for lateral and lateral torsional buckling of structural components.
    - 6.3.5 Lateral torsional buckling of members with plastic hinges
  - *6.4 Uniform built-up compression members*
    - 6.4.1 General
    - 6.4.2 Laced compression members
    - 6.4.3 Battened compression members
    - 6.4.4 Closely spaced built-up members

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Eurocode 3 – Design Checks

- Design checks are required and it depends on the type of structure
- Frames are checked for
  - Static equilibrium
  - Frame stability
  - Resistance of cross-sections
  - Resistance of members
  - Resistance of joints
- Tension members need only checked for resistance of cross-sections

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Eurocode 3 : Design of Steel Structures

Frame Idealisation, Classification and Analysis

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General approach in analysing and designing steel frames

- Classification of the frames
- Assessment of imperfections
- Choice of the method of analysis
- Computation of internal member and moments
- Ultimate limit states check
  - resistance of cross-sections
  - Buckling resistance of members
- Serviceability limit states check
  - Deflections
  - Dynamic effects

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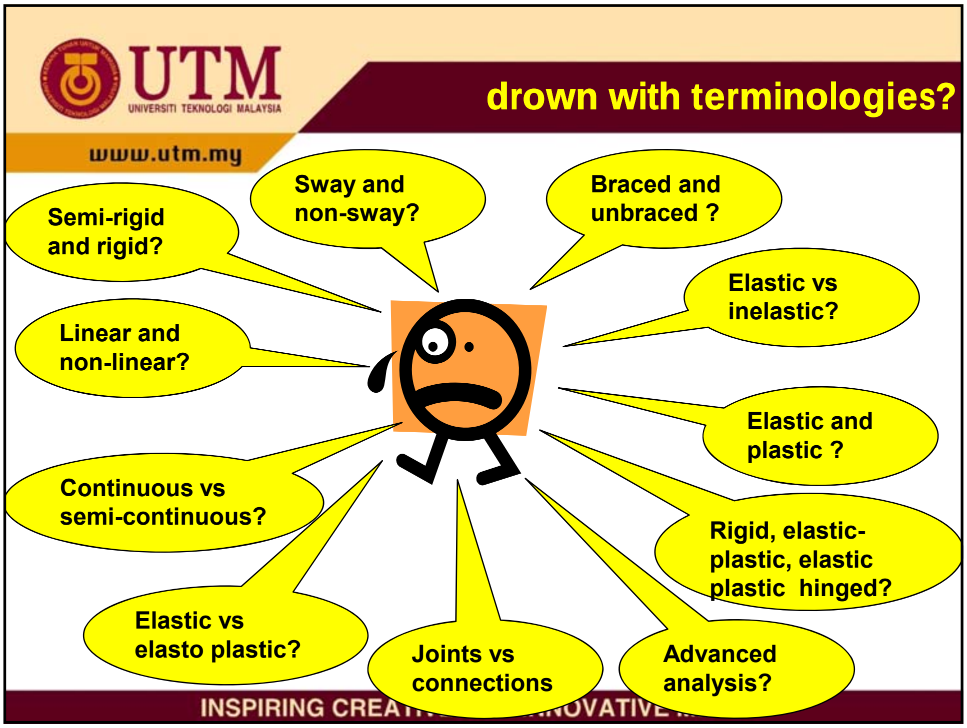
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drown with terminologies?
Semi-rigid and rigid?
Sway and non-sway?
Braced and unbraced ?
Elastic vs inelastic?
Linear and non-linear?
Elastic and plastic ?
Continuous vs semi-continuous?
Rigid, elastic-plastic, elastic plastic hinged?
Elastic vs elasto plastic?
Joints vs connections
Advanced analysis?
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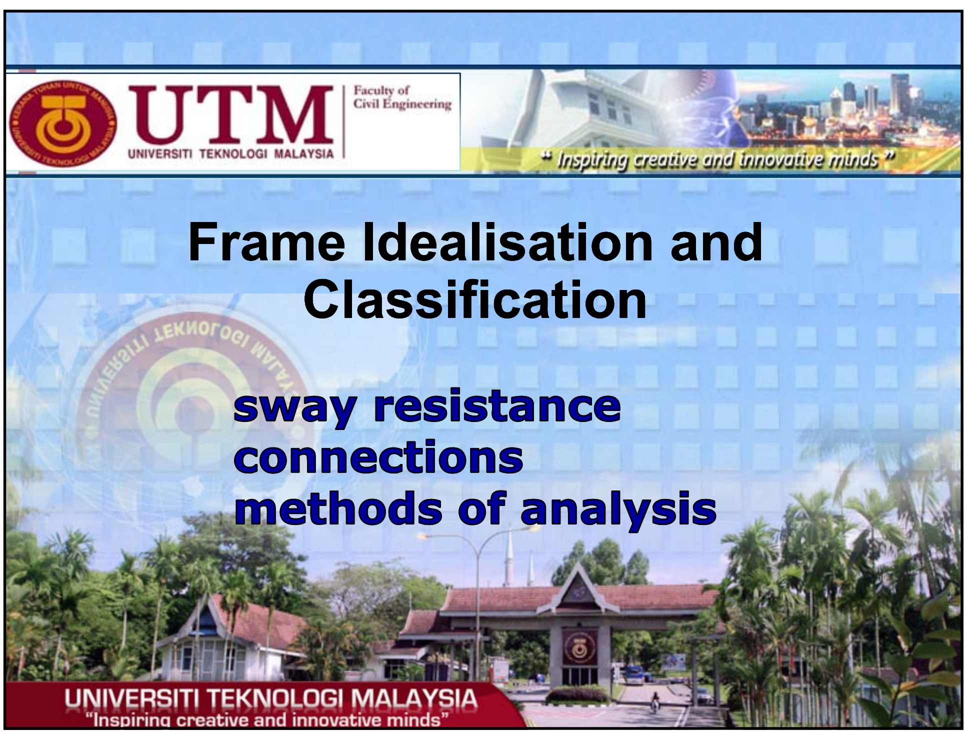
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Frame Idealisation and Classification
sway resistance
connections
methods of analysis
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Frame Idealisation

sway resistance

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Sway Stability

Consideration whether a frame is sway or non-sway case:

- Depends on frame geometry and load cases under consideration
- Determined by influenced of PΔ effect

Non-sway frame

- Horizontal loads are carried by the bracing or by horizontal support
- Change of geometry (2nd-order effect) is negligible

Sway frame

- Horizontal loads are carried by the frame
- Change of geometry (2nd-order effect) is significant

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Sway Stability

Multistorey Steel Frame

Definiton	Non-sway	Sway
	Depends on frame geometry and load cases under consideration	
	Determined by influenced of PΔ effect	
	Horizontal loads are carried by the bracing or by horizontal support	Horizontal loads are carried by the frame
	Change of geometry (2nd-order effect) is negligible	Change of geometry (2nd-order effect) significant

Sway Stability

A frame is considered to be sway case if:

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 10 \text{ for elastic analysis}$$

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 15 \text{ for plastic analysis}$$

where

α_{cr} is the factor by which the design loading would have to be increased to cause elastic instability in a global mode

F_{Ed} is the design loading on the structure

F_{cr} is the elastic critical buckling load for global instability mode based on initial elastic stiffnesses

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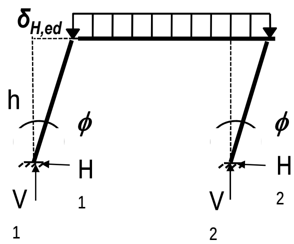
Sway Stability

α_{cr} may be calculated using the following approximate formula,

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} = \left(\frac{h}{\delta_{H,Ed}}\right)\left(\frac{H_{Ed}}{V_{Ed}}\right)$$

where:

$\delta_{H,ed}$ is the sway at the top of storey ***i***
h is the height of storey ***i***
H_{Ed} the total horizontal reactions respectively at the bottom of storey ***I***
V_{Ed} the total vertical reactions respectively at the bottom of storey ***i***



$H_{Ed} = H_1 + H_2$
$V_{Ed} = V_1 + V_2$

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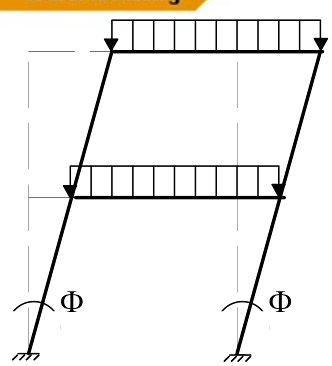
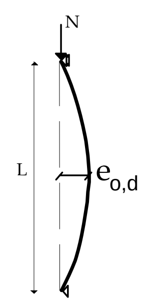
Allowing Imperfections





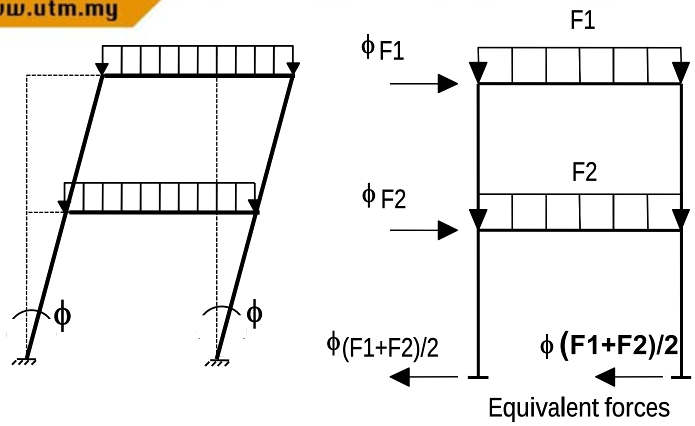
Frame imperfection

always to be allowed for

Member Imperfection

only for slender members in sway frames, otherwise it is covered in the relevant buckling curve

Allowing frame imperfection



- Frame imperfection can be replaced by an equivalent closed system of horizontal forces applied at the floor levels (including the foundation level).

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Frame imperfection

- The frame imperfection is as follows:

$$\phi = \phi_o \alpha_h \alpha_m$$

$$where \quad \phi_0 = 1/200$$

$$\alpha_h = \left(\frac{2}{\sqrt{h}}\right) \text{ but } \frac{2}{3} \le \alpha_h \le 1$$

$$\alpha_m = \sqrt{0,5\left(1 + \frac{1}{m}\right)}$$

h is the height of the structure in meters
m is is the number of columns in a row including only those columns which carry a vertical load

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Global initial sway imperfections ϕ

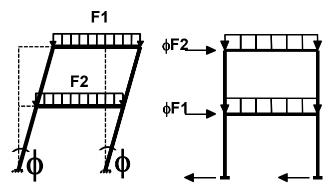
Height of the structure (h)	Number of columns (m)					
	1	2	3	4	5	6
1	0.00500	0.00433	0.00408	0.00395	0.00387	0.00382
2	0.00500	0.00433	0.00408	0.00395	0.00387	0.00382
3	0.00500	0.00433	0.00408	0.00395	0.00387	0.00382
4	0.00500	0.00433	0.00408	0.00395	0.00387	0.00382
5	0.00447	0.00387	0.00365	0.00353	0.00346	0.00341
6	0.00408	0.00354	0.00333	0.00323	0.00316	0.00312
7	0.00378	0.00327	0.00309	0.00299	0.00293	0.00289
8	0.00354	0.00306	0.00289	0.00280	0.00274	0.00270
9	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
10	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
12	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
13	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
14	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
15	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
16	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
17	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
18	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
19	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
20	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
22	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
24	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255
25	0.00333	0.00289	0.00272	0.00264	0.00258	0.00255

$$\phi = \phi_o \alpha_h \alpha_m$$

where $\phi_0 = 1/200$

$$\alpha_h = \left(\frac{2}{\sqrt{h}}\right) \text{ but } \frac{2}{3} \le \alpha_h \le 1$$

$$\alpha_m = \sqrt{0,5\left(1+\frac{1}{m}\right)}$$



Equivalent forces

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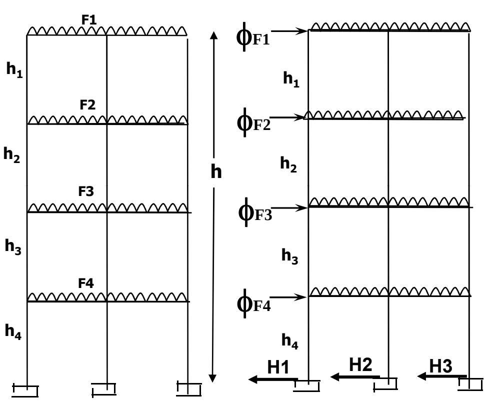

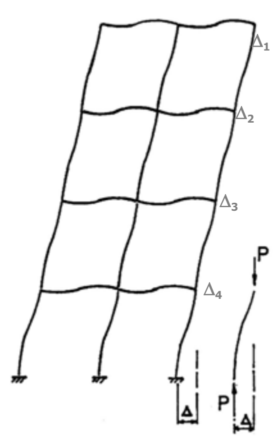

$$\delta_{1Hed} = \frac{h_1}{\Delta_1 - \Delta_2}$$

$$\delta_{2Hed} = \frac{h_2}{\Delta_2 - \Delta_3}$$

$$\delta_{3Hed} = \frac{h_3}{\Delta_3 - \Delta_4}$$

$$\delta_{4Hed} = \frac{h_4}{\Delta_4}$$

↓

$$\max\left(\frac{h}{\delta_{H,Ed}}\right)$$

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} = \max\left(\frac{h}{\delta_{H,Ed}}\right)\left(\frac{H_{Ed}}{V_{Ed}}\right)$$

Elastic Analysis	$\alpha_{cr} < 10$	**Sway Frame**
	$\alpha_{cr} \ge 10$	**Non-Sway Frame**
Plastic Analysis	$\alpha_{cr} < 15$	**Sway Frame**
	$\alpha_{cr} \ge 15$	**Non-Sway Frame**

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Example to determine whether a frame is either sway or non-sway case

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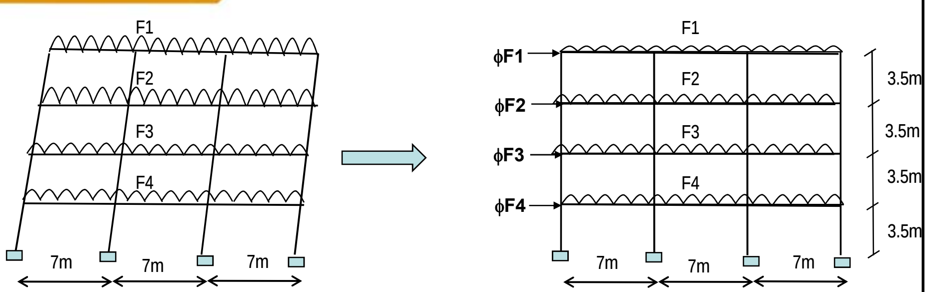
Example: Check if the frame is a sway frame



F1=850 kN
F2= F3=F4 = 3750 kN

From slide 13, m=3 and h=14m, therefore
ϕ = 0.00272

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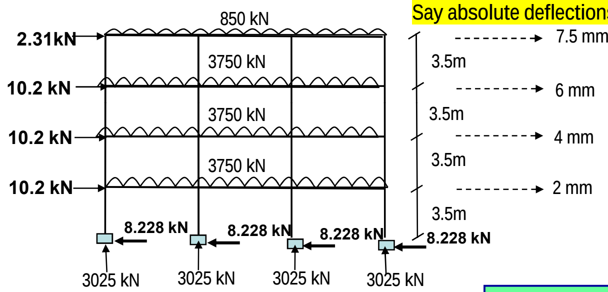
Example: Check if the frame is a sway frame

Say absolute deflections from frame analysis



$$\max\left(\frac{h}{\delta_{H,Ed}}\right) = 3500/2 = 1750mm$$

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} = \max\left(\frac{h}{\delta_{H,Ed}}\right)\left(\frac{H_{Ed}}{V_{Ed}}\right)$$

where:

- $\delta_{H,ed}$ is the sway at the top of storey *i*
- h is the height of storey *i*
- H_{Ed} the total horizontal reactions respectively at the bottom of storey *I*
- V_{Ed} the total vertical reactions respectively at the bottom of storey *i*

Elastic Analysis	$\alpha_{cr} < 10$	**Sway Frame**
	$\alpha_{cr} \geq 10$	**Non-Sway Frame**
Plastic Analysis	$\alpha_{cr} < 15$	**Sway Frame**
	$\alpha_{cr} \geq 15$	**Non-Sway Frame**

$$\alpha_{cr} = 1750\left(\frac{32.91}{12100}\right) = 4.8$$

Therefore it is a sway frame

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Sway Stability

Multistorey Steel Frame

Definiton	Non-sway	Sway
	Depends on frame geometry and load cases under consideration	
	Determined by influenced of PΔ effect	
	Horizontal loads are carried by the bracing or by horizontal support	Horizontal loads are carried by the frame
	Change of geometry (2nd-order effect) is negligible	Change of geometry (2nd-order effect) significant

Analysis and design ?

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Frame classification

connections

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Joints in frame

The effects of the behaviour of the joints in analysing frame structure, may generally be neglected, however if such effects are significant. they should be taken into account.

To know whether the joint behaviour is significant or not, joint are classified into:

- Simple
  - joint may be assumed not to transmit bending moments;
- Continuous
  - the behaviour of the joint may be assumed to have no effect on the analysis;
- Semi-continuous
  - the behaviour of the joint needs to be taken into account in the analysis

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Types of construction

Simple	Semi-continuous	Continuous
- connections between members are assumed not to develop moments	- some degree of connection stiffness is assumed	- connections between members capable to develop full strength/stiffness
- joint pin connected	- joint semi-rigidly connected	- joint rigidly connected
- necessary to maintain stability against sway	- Limitation in the design specifications	- elastic analysis or plastic analysis
- elastic analysis	- elastic or plastic analysis - elastic-plastic analysis - elasto-plastic analysis	

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FIN PLATE
(10mm thk.)
COLUMN SPLICE
12. 3. 1999
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DOUBLE ANGLE
WEB CLEATS
12. 3. 1999

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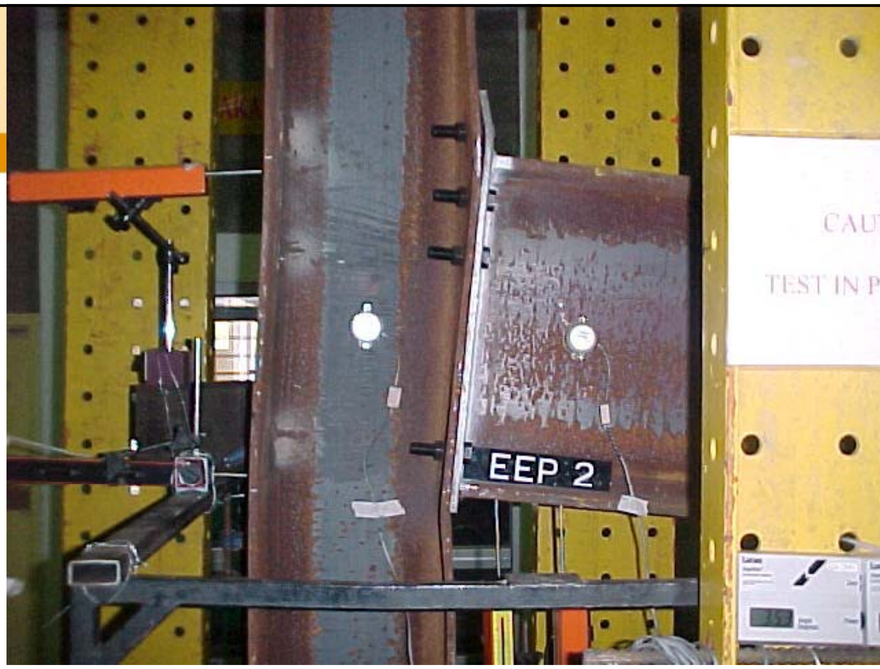
TEEP 1


FEP 3



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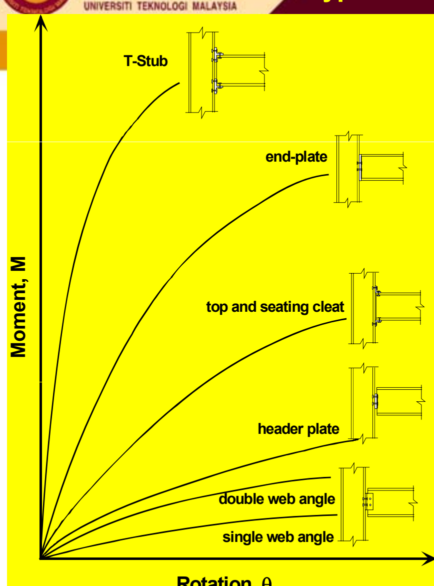
Typical Joints Expressed In Term of M-ϕ Curves



- Simple construction
  - Double angle web cleats
  - Flexible end plates
  - Fin plates
- Semi-continuous construction
  - Flushed end plates
  - Extended end plates
- Continuous Construction
  - Welded
  - Mini-haunch

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Joints in frame – EC3

Connections can be classified according to:

1) Moment Resistance
- full strength (continuous design)
- partial strength (semi-continuous design)
- nominally pinned (simple construction design).

2) Rotational Stiffness
- rigid, semi-rigid, and nominally pinned

3) Rotation Capacity - ductility

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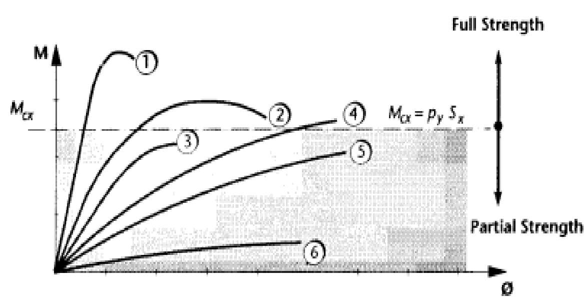
1. Moment Resistance

- Full strength - a connection with moment resistance at least equal to that of the member.
- Partial strength - a connection with moment resistance, which is less than that of the member.
- Nominally pinned - a connection, which is sufficiently flexible with moment resistance not greater than 25% of M_{cx}.



(a) CLASSIFICATION BY STRENGTH

1. Moment Resistance

- Continuous design is a design of frame where connections are considered as rigid joints for elastic analysis and full strength joints for plastic analysis.
- Semi-continuous design is a design of frame where semi-rigid connections are modelled as rotational springs and partial strength connections are modelled as plastic hinges.
- Simple construction design is a design of frame where the connections are assumed not to develop moments that affect the connected members.

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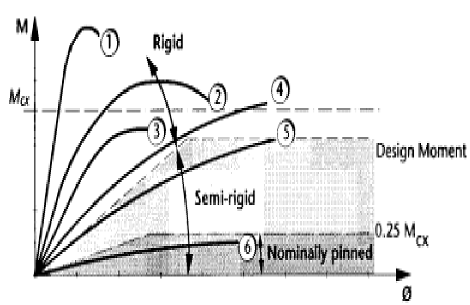
2. Rotational Stiffness



(b) CLASSIFICATION BY RIGIDITY

- Rigid - a connection which is stiff enough for the effect of its flexibility on the frame bending moment diagram to be neglected and with minimum deformation and rotation.
- Semi-rigid - a connection, which is too flexible to quantify as rigid but is not a pin.

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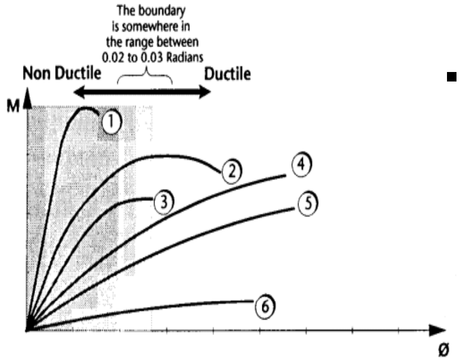
3. Rotation Capacity



(c) CLASSIFICATION BY DUCTILITY

- **Ductile connection - a connection, which has a capacity to rotate sufficiently to form a plastic hinge.**

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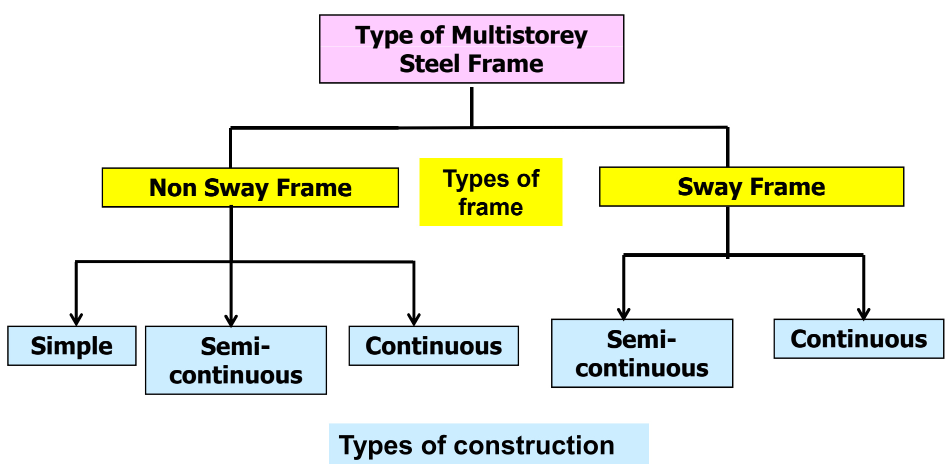
Relationship between type of frame and construction



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Summary

- The frame has first to be idealised
- Then a frame classification is carried out
  - sway-non sway
  - type of construction - connections
- then the method of analysis is will be selected … (refer next section)

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" Inspiring creative and innovative minds "

Frame classification

Methods of Analysis

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"Inspiring creative and innovative minds"

Global frame analysis

- Aims of global frame analysis
  - Determine the distribution of the internal forces
  - Determine the corresponding deformations
- Means
  - Adequate models incorporating assumptions about the behaviour of the structure and its component: members and joints

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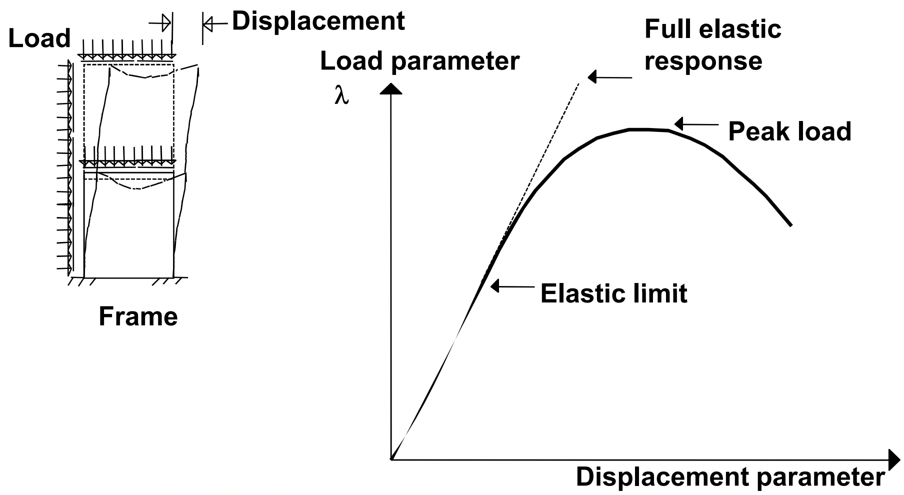
Requirements for analysis

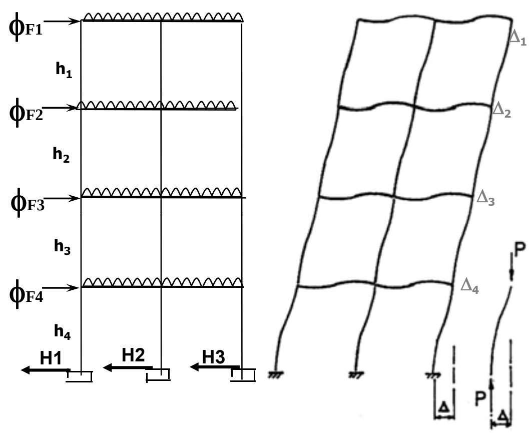
- Basic principles to be satisfied:
  - *Equilibrium* throughout the structure
  - *Compatibility* of deformation between the frame components
  - *Constitutive laws* for the frame components
- Frame model - element model
  - must satisfy the basic principles

Frame behaviour

- Actual response of the frame is non linear
  - Linear behaviour limited
  - Non-linear behaviour due to:
    - Geometrical influence of the actual deformed shape (second order effects)
    - Joint behaviour
    - Material yielding

Frame behaviour





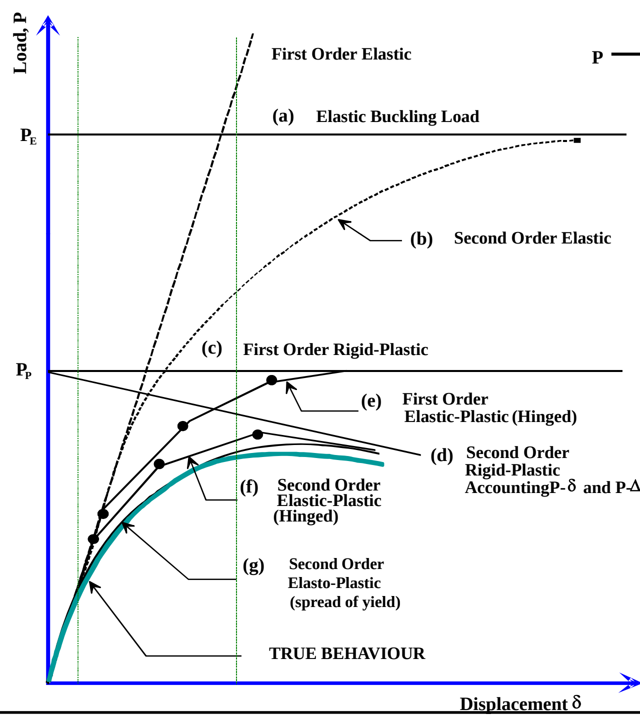
$$\delta_{1Hed} = \frac{h_1}{\Delta_1 - \Delta_2}$$

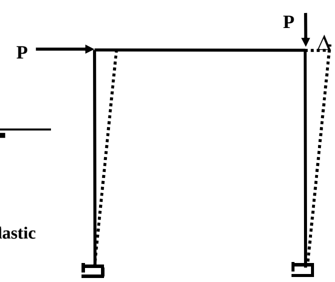
$$\delta_{2Hed} = \frac{h_2}{\Delta_2 - \Delta_3}$$

$$\delta_{3Hed} = \frac{h_3}{\Delta_3 - \Delta_4}$$

$$\delta_{4Hed} = \frac{h_4}{\Delta_4}$$

Factors affecting the deformation values;
1.Material properties
2.Geometry of the structure
3.Boundary condition
4.Loadings





Choice of analysis

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Decisions related to the analysis approach – EC3

Choice between
- an elastic and a plastic global analysis
- 1st order and 2nd order analysis
- a traditional approach and a modern approach to connection representation
- Combination of the above

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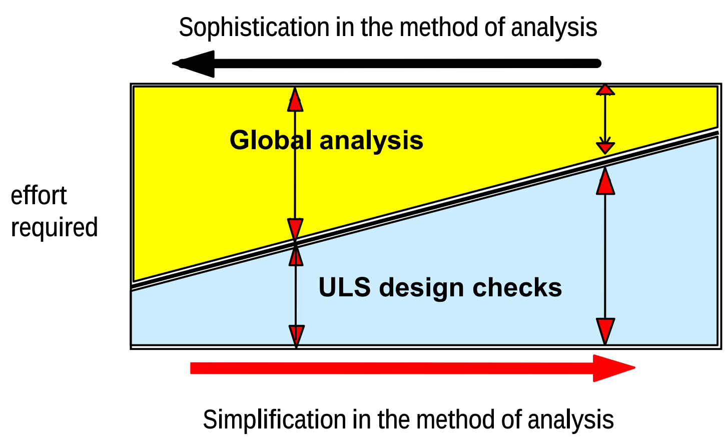
Implications for design of the choice of the global analysis



Overall Design Task= Analysis + Design Checks

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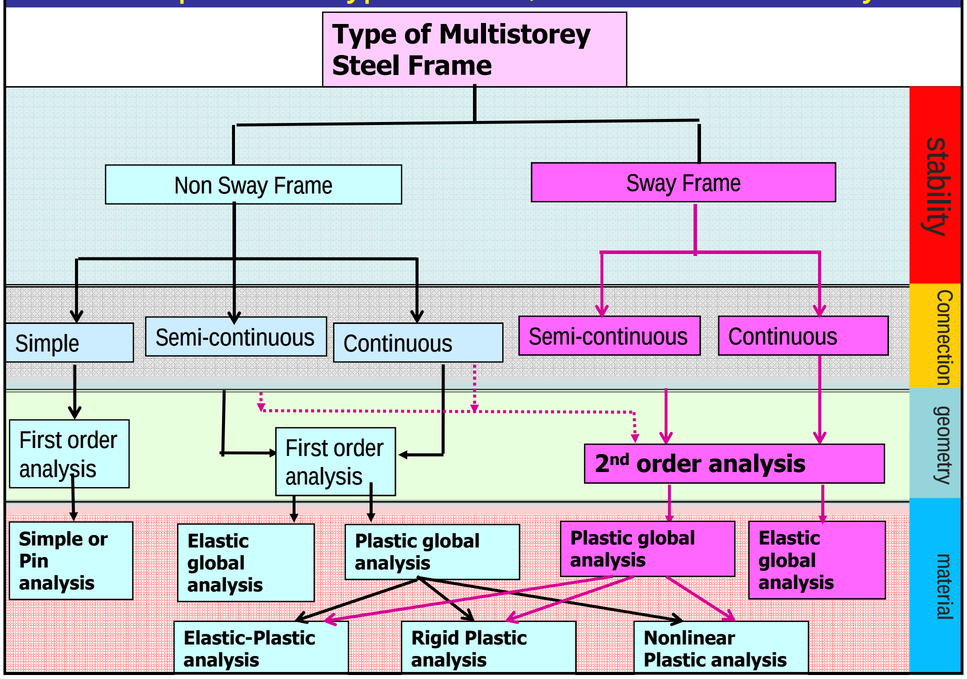
Relationship between type of frame, construction and analysis



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Sway Stability

stability
geometry

A frame is considered to be sway case if:

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 10 \text{ for elastic analysis}$$

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 15 \text{ for plastic analysis}$$

where

α_{cr} is the factor by which the design loading would have to be increased to cause elastic instability in a global mode

F_{Ed} is the design loading on the structure

F_{cr} is the elastic critical buckling load for global instability mode based on initial elastic stiffnesses

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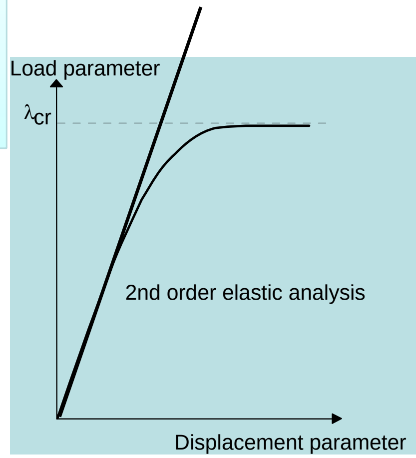
1st and 2nd order analysis

geometry

1st order analysis - Indefinite linear
- elastic response of member sections
- geometry and
- connections

- 2ND order analysis
  - Indefinite linear- elastic response of member sections and joints
  - Equilibrium established for the *deformed* structure
  - Allows for P-D effect and, if necessary, for P-d effect



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Multistorey Steel Frame

geometry
material

	Non-sway	Sway
Definiton	Depends on frame geometry and load cases under consideration	
Definiton	Determined by influenced of PΔ effect	
Definiton	Horizontal loads are carried by the bracing or by horizontal support	Horizontal loads are carried by the frame
Definiton	Change of geometry (2nd-order effect) is negligible	Change of geometry (2nd-order effect) significant
Method of analysis Geometry and material	First-order elastic analysis (stifness analysis, moment distribution)	First-order elastic analysis with indirect allowance for second order effect (P-Δ and P-δ effect)
Method of analysis Geometry and material	First-order rigid-plastic analysis	First-order rigid-plastic analysis with indirect allowance for second order effect (P-Δ and P-δ effect)
Method of analysis Geometry and material	Second-order elastic analysis	
Method of analysis Geometry and material	Second-order elastic plastic hinged analysis	
Method of analysis Geometry and material	Second-order elasto-plastic analysis	

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Connection modelling in frame analysis

Connection

- Framing and joints
  - Continuous framing: → rigid joint
  - Simple framing: → pinned joint
  - Semi-continuous framing: → semi-rigid joint

- The main approaches are:
  - the traditional approach in which the joints are considered as (nominally) pinned or rigid
  - the semi-rigid approach in which a more realistic model representing the joint behaviour is used. It is usually introduced as a spiral spring at the extremity of the member it attaches (usually the beam).

Steel Frame

		Non-sway	Sway
Definiton		Depends on frame geometry and load cases under consideration	
Definiton		Determined by influenced of PΔ effect	
Definiton		Horizontal loads are carried by the bracing or by horizontal support	Horizontal loads are carried by the frame
Definiton		Change of geometry (2nd-order effect) is negligible	Change of geometry (2nd-order effect) significant
Method of analysis	Elastic analysis	First-order elastic analysis (stifness analysis, moment distribution)	First-order elastic analysis with indirect allowance for second order effect (P-Δ and P-δ effect)
Method of analysis	Elastic analysis	Second-order elastic analysis	
Method of analysis	Plastic analysis	First-order rigid-plastic analysis	First-order rigid-plastic analysis with indirect allowance for second order effect (P-Δ and P-δ effect)
Method of analysis	Plastic analysis	Second-order elastic plastic hinged analysis	
Method of analysis	Plastic analysis	Second-order elasto-plastic analysis	

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Summary

- The frame has first to be idealised
- Then a frame classification is carried out
  ⇒ sway-non sway / braced-unbraced
- On the basis of the frame class (and the type of steel and profiles), the type of frame analysis is finally selected

- Choice of type analysis/design: depends on type of structure, available tools , EC3 requirements, etc.
- The more sophisticated the analysis tool used, the lesser the design ULS checks

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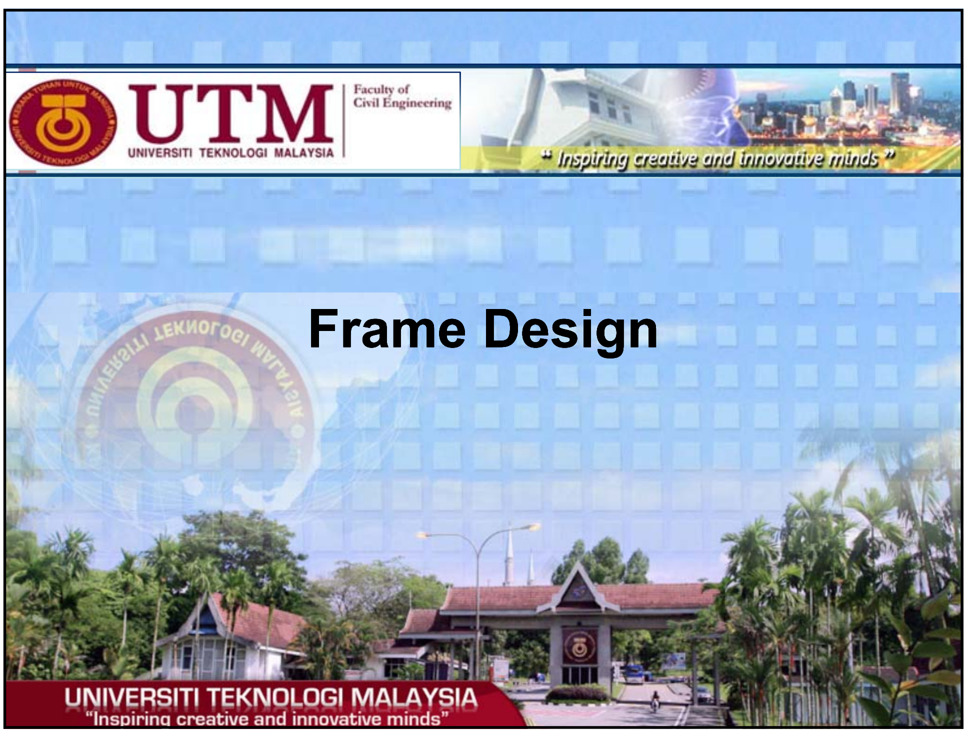

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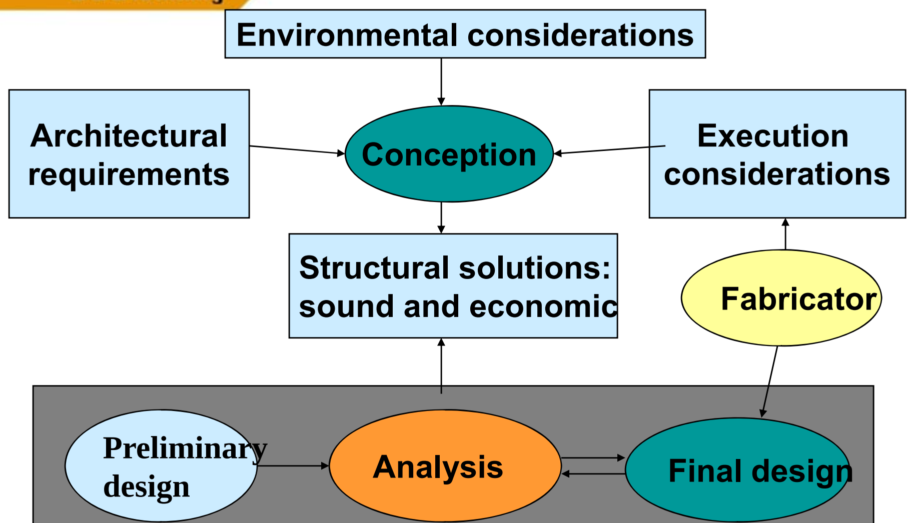
Conception to final design



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Decisions related to the analysis approach – EC3

- Choice between
  - an elastic and a plastic global analysis
  - 1st order and 2nd order analysis
  - a traditional approach and a modern approach to connection representation
  - Combination of the above

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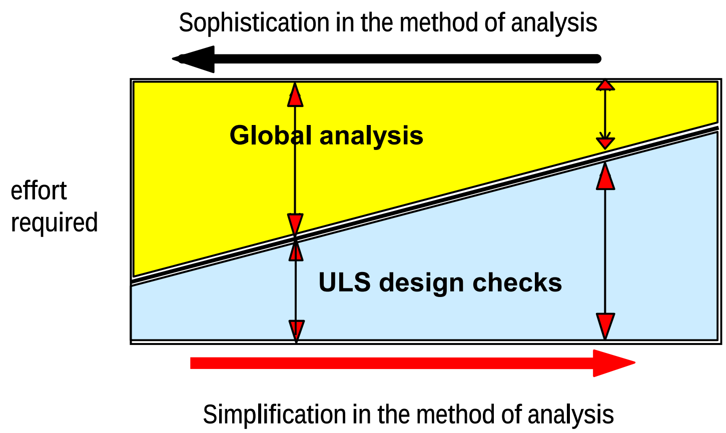
Implications for design of the choice of the global analysis



Overall Design Task= Analysis + Design Checks

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Steel Frame

		Non-sway	Sway
Definiton		Depends on frame geometry and load cases under consideration	
Definiton		Determined by influenced of PΔ effect	
Definiton		Horizontal loads are carried by the bracing or by horizontal support	Horizontal loads are carried by the frame
Definiton		Change of geometry (2nd-order effect) is negligible	Change of geometry (2nd-order effect) significant
Method of analysis	Elastic analysis	First-order elastic analysis (stifness analysis, moment distribution)	First-order elastic analysis with indirect allowance for second order effect (P-Δ and P-δ effect)
Method of analysis	Elastic analysis	Second-order elastic analysis	
Method of analysis	Plastic analysis	First-order rigid-plastic analysis	First-order rigid-plastic analysis with indirect allowance for second order effect (P-Δ and P-δ effect)
Method of analysis	Plastic analysis	Second-order elastic plastic hinged analysis	
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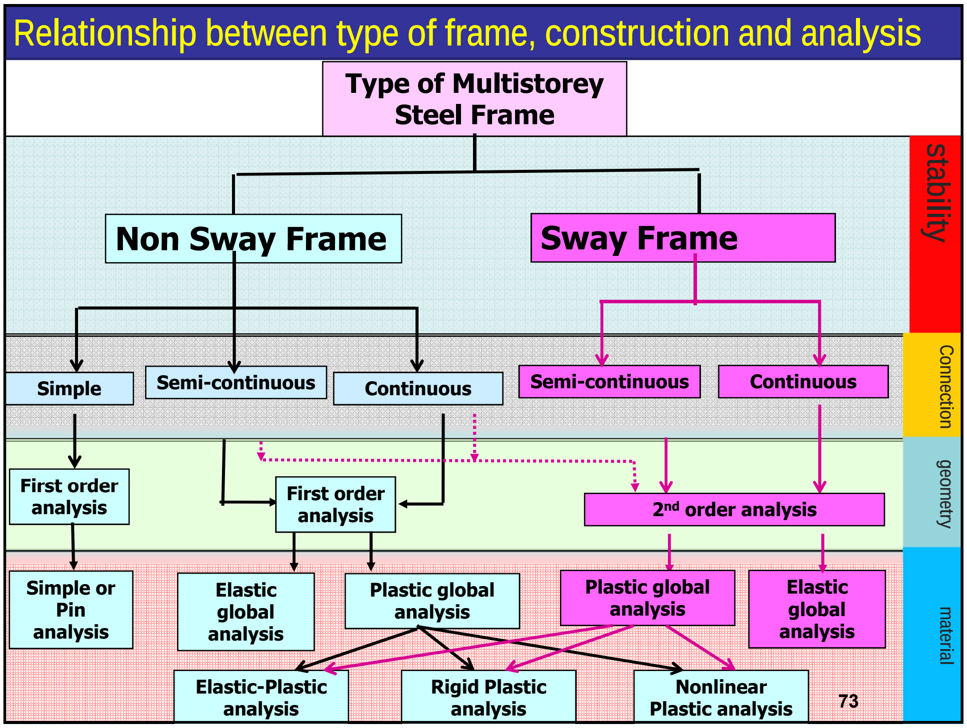
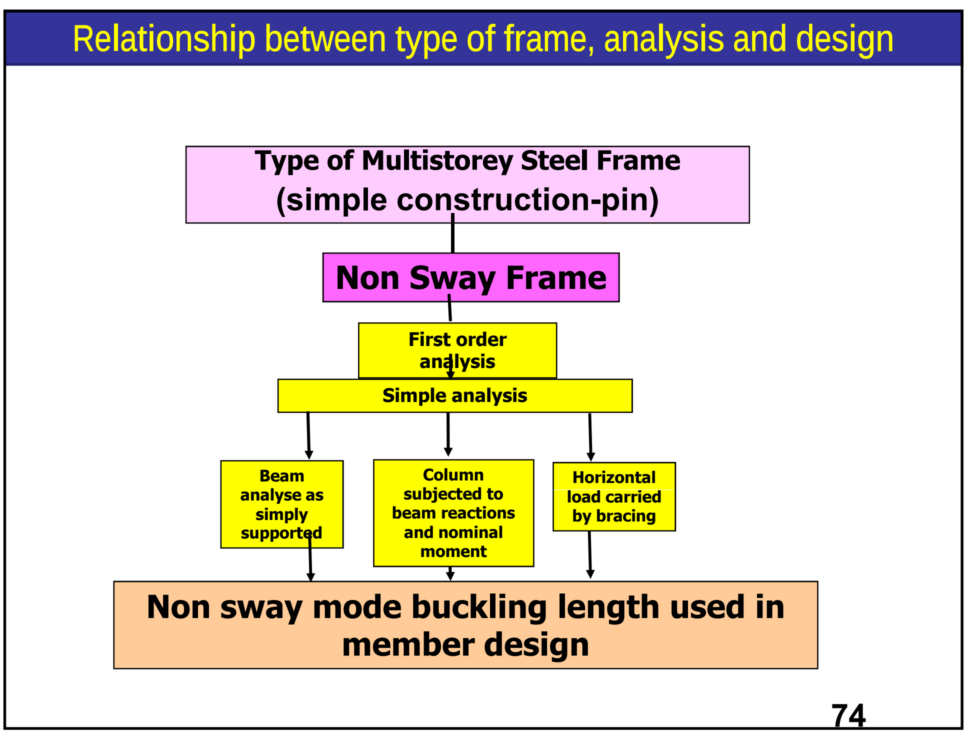
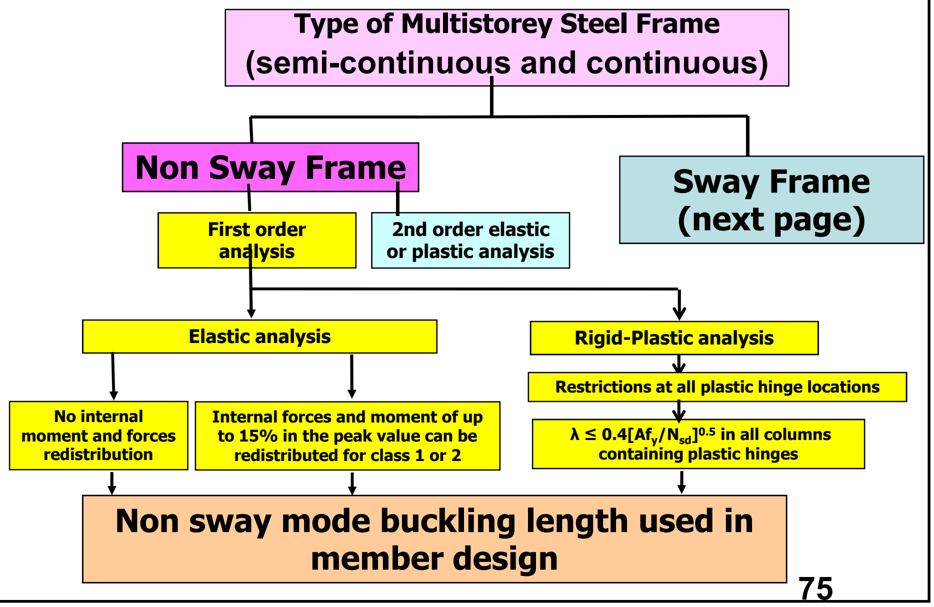

Relationship between type of frame, construction and analysis
Type of Multistorey Steel Frame
Non Sway Frame
Sway Frame
stability
Simple
Semi-continuous
Continuous
Semi-continuous
Continuous
Connection
First order analysis
First order analysis
2nd order analysis
geometry
Simple or Pin analysis
Elastic global analysis
Plastic global analysis
Plastic global analysis
Elastic global analysis
material
Elastic-Plastic analysis
Rigid Plastic analysis
Nonlinear Plastic analysis
73


Relationship between type of frame, analysis and design
Type of Multistorey Steel Frame
(simple construction-pin)
Non Sway Frame
First order analysis
Simple analysis
Beam analyse as simply supported
Column subjected to beam reactions and nominal moment
Horizontal load carried by bracing
Non sway mode buckling length used in member design
74

Relationship between type of frame, analysis and design



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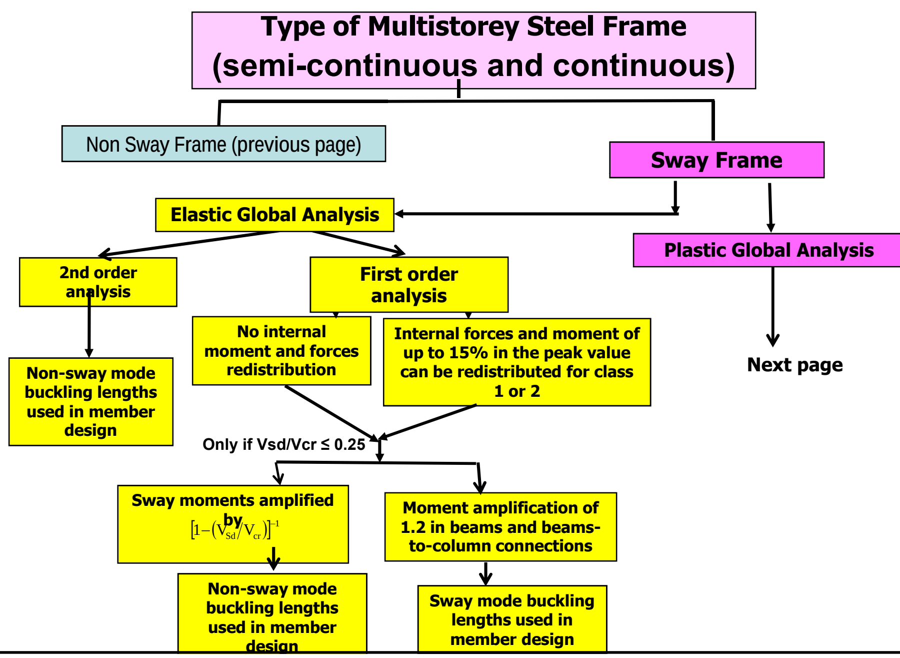
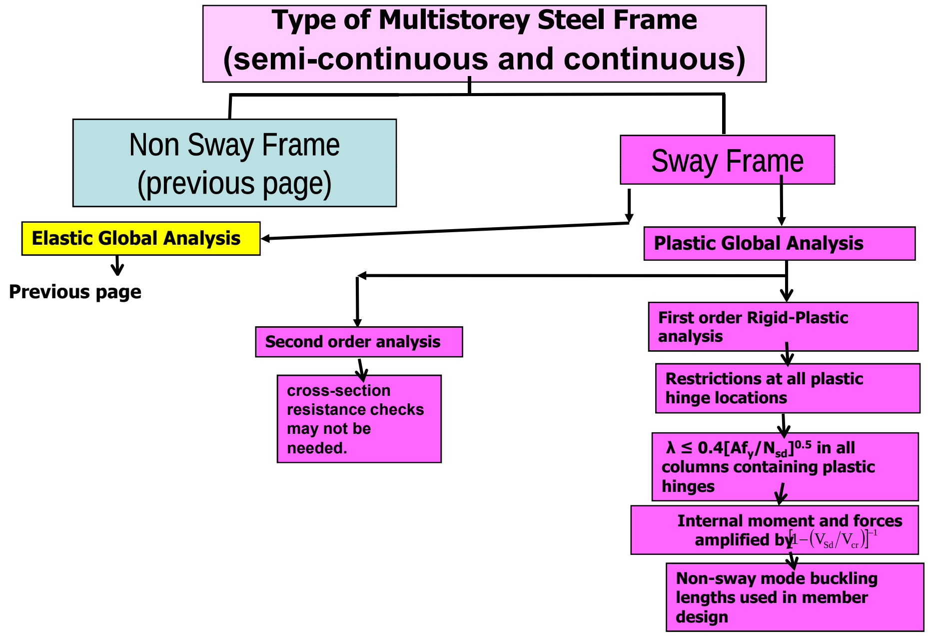
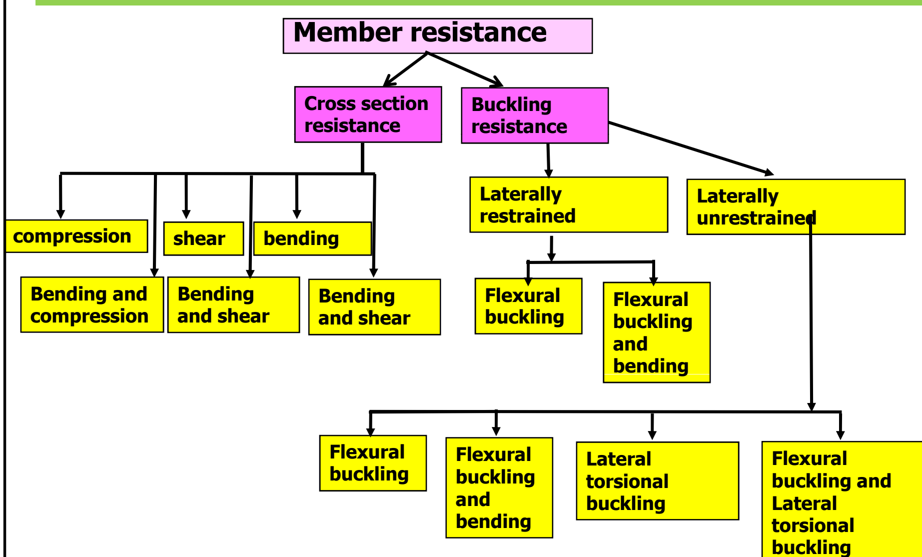
Relationship between type of frame, analysis and design



Relationship between type of frame, analysis and design



Resistance of frame members subjected to a combination of compression, shear and bending moment



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Implications of the choice of the type of analysis on design

The more sophisticated the analysis tool employed, the less are the design check tasks following analysis.

- With a "true" 2nd order elastic analysis, the in-plane stability check, for the members and for the frame, is no longer needed.
- Following a "true" 2nd order elastic-plastic analysis, in addition, cross-section resistance checks may not be needed.

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Choice between elastic analysis and plastic analysis

- Elastic analysis can always be used.
- Plastic analysis allowed only when one meets the restrictions on steel properties, cross-section classification, restraints (at or near plastic hinges) and, if needed, on joint ductility.

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Choice of method of analysis/design

Factors which orient the choice:

- type of structure : conception meeting architectural, environmental and execution considerations and needs
- availability of class 1 and 2 sections for plastic analysis/design
- other Eurocode requirements: 1st or 2nd order analysis?, seismic design needed?
- available software/designer's experience

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Frame classification

- Decision on the use of bracing or not influences sway classification
- Preliminary member sizing and estimates of column vertical loads: use to provide an *indication of the sway classification* using:

$$V_{Sd}/V_{cr} \leq 0{,}1 : \text{Non-sway : can use 1st order analysis}$$

$$V_{Sd}/V_{cr} > 0{,}1 : \text{Sway : must allow for 2nd order effects}$$

- Industrial portal frame: EC3 not suitable

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Sway frame : 2nd order effects

Alternatives to a "true" 2nd order analysis:

- 1st order analysis + "Amplified Sway Moment" method when:

$$\text{Elastic design: } V_{Sd}/V_{cr} \leq 0{,}25 \Rightarrow \text{Amplify } M_{sway} \text{ by } 1/(1 - V_{Sd}/V_{cr})$$

$$\text{Plastic design: } V_{Sd}/V_{cr} \leq 0{,}20 \Rightarrow \text{Amplify all forces by } 1/(1 - V_{Sd}/V_{cr})$$

- 1st order analysis + "Sway Mode Buckling Length" method (20% sway moment increase) - *use not advised*

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1st order elastic analysis and relevant design checks

- Member sections and joints: ultimate design resistance: redistribution possible
- In-plane and out-of plane beam-column stability check - usually with in-plane buckling lengths
- In-plane frame stability : accounted for by including 2nd order effects (when needed)
- Beams: Lateral torsional buckling
- Others:Local buckling, Fire resistance etc.

1st order plastic analysis and design

- Restrictions: (steel properties, section class etc.)
- Rigid-plastic analysis and design:

  braced non-sway frames, or unbraced of no more than 2 storeys (but see exception)
- Elastic-plastic analysis and design
- Relevant design checks usually as for 1st order elastic design

2nd order plastic analysis and design

- Elastic-plastic analysis and design
- Rigid-plastic analysis and design with amplified forces -based on Merchant-Rankine formula (use restricted)
- Merchant-Rankine approach - not explicitly mentioned in EC3
- Design checks depend on analysis tool, mostly as for 2nd order elastic analysis

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Traditional approaches to design

- Pinned-Rigid Joints + elastic analysis
- Rigid- plastic analysis/design : in some countries only: Industrial portal frames and other frames of no more than 2 storeys
- "Wind-moment" + elastic analysis

  - no moment in joints for vertical loads only

  - joints transmit moments due to wind
- Partial strength non-sway frames: plastic hinges at joints and in beam span

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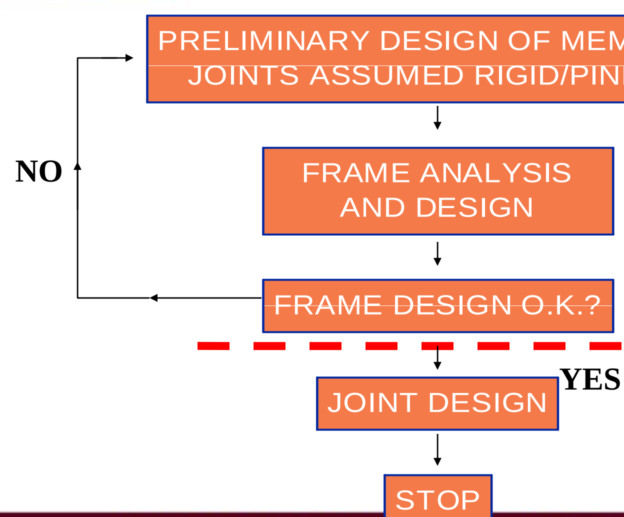
Traditional design approach



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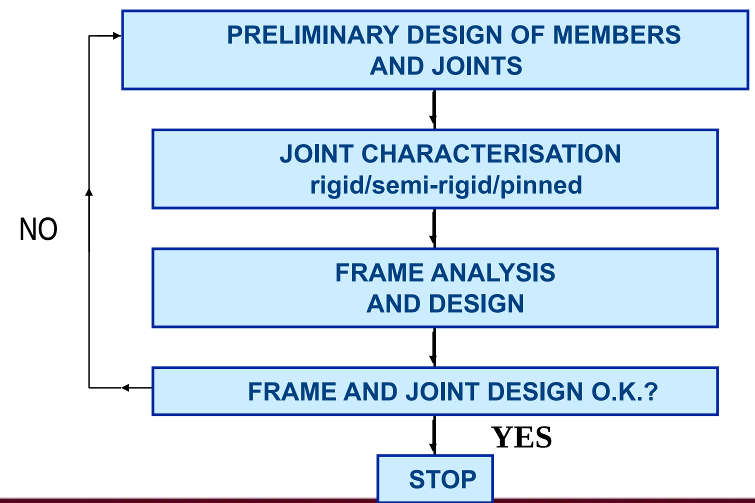
Modern design approach



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Modern approach = consistent design : include joint response

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- Joint response allowed for from the outset i.e. from the preliminary design stage
  - Member sizing allows for joint response
- Better appreciation of structural behaviour
- Can optimise overall costs, noting that
  - a significant part of fabrication and erection costs is related to joints
  - the least weight frame solution is not necessarily the cheapest

Note: If sway, advised to use "true" 2nd order analysis

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Design practice and its implications

Role	Case A	Case B1	Case B2
Member design	Engineer	Engineer	Fabricator
Joint design	Fabricator	Engineer	Fabricator
Fabrication	Fabricator	Fabricator	Fabricator

Roles of the parties in the design and fabrication processes

- Case A sometimes leads to costly joint reinforcement if rigid joints have been adopted
- Case B1 requires the designer to be aware of the implications of joint assumption on costs
- Case B2 is ideal for a consistent design approach which aims at global economy

Practical application of modern design approaches

Approaches easily integrated into current design practices:

- “Good guess stiffness” for semi-rigid joint + elastic analysis
- “Fixity factor” approach in the traditional approach using elastic analysis
- Rigid-plastic analysis of non-sway frames using partial strength joints

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Summary

- Choice of type analysis/design: depends on type of structure, available tools , EC3 requirements, etc.
- The more sophisticated the analysis tool used, the lesser the design ULS checks
- Joint representation: a consistent approach can permit optimisation of costs
- Simple aids exist for integrating the « consistent approach » into traditional practice/breakdown of design tasks

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