Design of Steel Structures

- **References:**
- 1. Subramanian N., *Design of Steel Structures*, Oxford University Press, 2008.
- 2. Arya A.S. and J. L. Ajmani, *Design of Steel Structures*, Nemchand & Bros, 1996.
- 3. Dayaratnam P., *Design of Steel Structures*, Wheeler Publishers, 2007.
- 4. Ramachandra, *Design of Steel Structures*, Standard books, 2011.
- 5. Duggal S.K., *Design of Steel Structures*, Tata McGraw Hill, 2000
- 6. Bhavikatti

- IS. Codes: IS:800-2007, IS:883, Steel table

- **References:**

- 1. Subramanian N., *Design of Steel Structures*, Oxford University Press, 2008.
- 2. Arya A.S. and J. L. Ajmani, *Design of Steel Structures*, Nemchand & Bros, 1996.
- 3. Dayaratnam P., *Design of Steel Structures*, Wheeler Publishers, 2007.
- 4. Ramachandra, *Design of Steel Structures*, Standard books, 2011.
- 5. Duggal S.K., *Design of Steel Structures*, Tata McGraw Hill, 2000.
- 6. IS. Codes: IS:800-2007, IS:811-1987, IS:801- 1975.

- **Internal Continuous Assessment** *(Maximum Marks-50)*
- *50% - Tests (minimum 2)*
- *30% - Assignments (minimum 2) such as home work, problem solving, quiz, literature survey, seminar, term-project, drawings, etc.*
- *20% - Regularity in the class*
- **University Examination Pattern:**
- *Examination duration: 3 hours Maximum Total Marks: 100*
- *The question paper shall consist of 2 parts.*
- *Part A (20 marks) - Five Short answer questions of 4 marks each. All questions are compulsory. There should be at least one question from each module and not more than two questions from any module.*
- *Part B (80 Marks) - Candidates have to answer one full question out of the two from each module. Each question carries 20 marks.*
- *Note: Use of* IS. Codes (IS:800-2007, IS:811-1987, IS:801- 1975) *and Structural Steel Tables are permitted in examination halls.*

- **IS 800- 2007 -GENERAL CONSTRUCTION IN STEEL — CODE OF PRACTICE (Third Revision)**

- **IS 801- 1995 - CODE OF PRACTICE FOR USE OF COLD-FORMED LIGHT GAUGE STEEL STRUCTURAL MEMBERS IN GENERAL BUILDING CONSTRUCTION**

- **IS 811- 1995 – SPECIFICATION FOR COLDFORMED LIGHTGAUGE STRUCTURAL STEEL SECTIONS**

- **STEEL TABLE**

Steel Structures

- Strength approximately **ten** times that of concrete,
- Large strength to weight ratio, more economical than concrete structures.
- Constructed very fast
- Ductile and can withstand earthquakes.
- Can be easily repaired and retrofitted to carry higher loads.
- Eco-friendly material and can be easily dismantled and sold as scrap.
- **Lifecycle cost of steel structures**, ie, the cost of construction, maintenance, repair and dismantling- less than that for concrete structures.
- Produced in the factory under better quality control, hence higher reliability and safety.

- **Designed and protected to resist corrosion and fire**. **Detailed for easy fabrication and erection**.
- **Good quality control** is essential to ensure proper fitting of the various structural elements. The effects of temperature to be considered in design.

- To prevent development of cracks under fatigue and earthquake loads, connections and in particular welds should be designed and detailed properly.

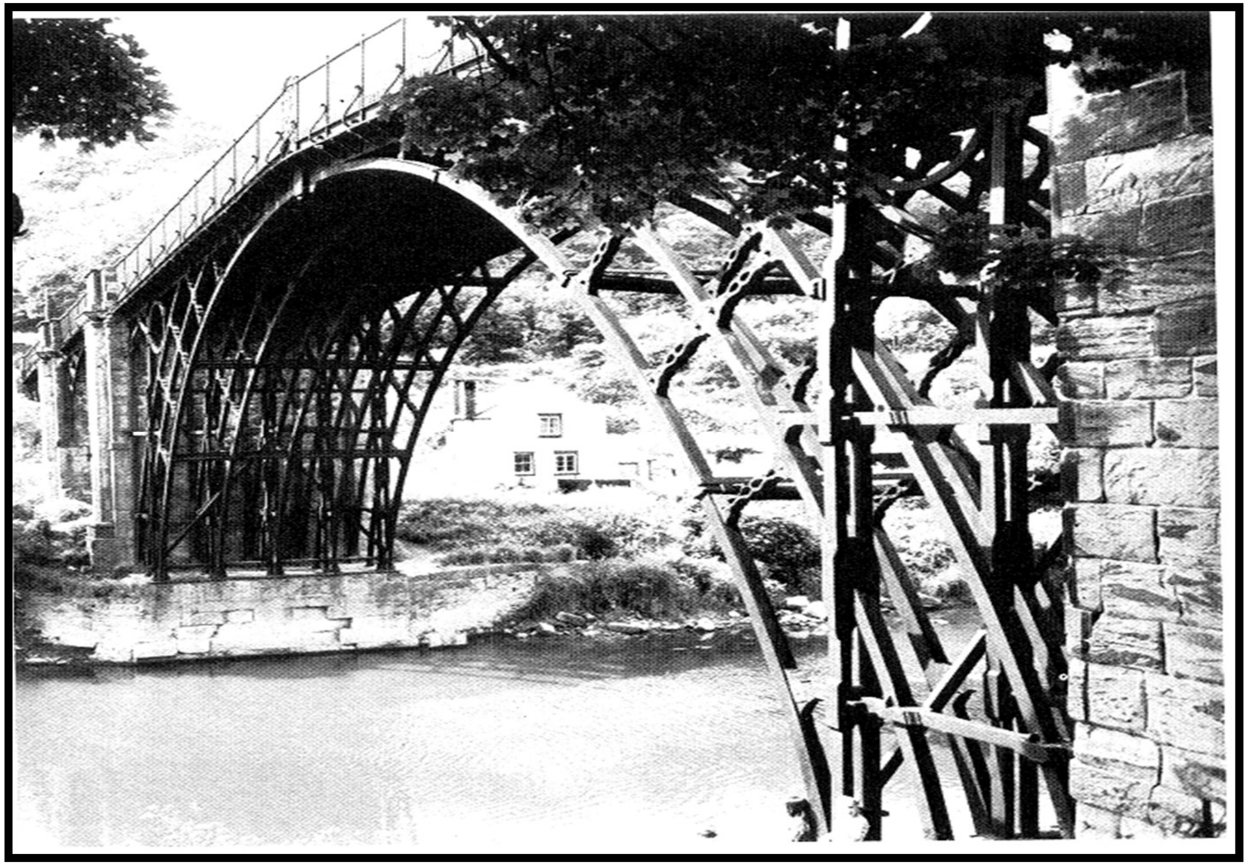
- In steel buildings, dividing walls are of masonry or other materials, and often a concrete foundation is provided.
- Steel is also used with concrete in composite constructions and in combined frame and shear wall constructions.

- Fabrication of steel members is done in workshop and transported to site and assembled.
- Tolerances specified for steel fabrication and erections are **small** compared to those for RC structures.
- Welding, tightening of high-strength friction grip bolts require proper training.
- To be handled by trained persons and assembled with proper care, resulting in structures with better quality.
- Steel offers much better compressive and tensile strength than concrete and enables lighter constructions.

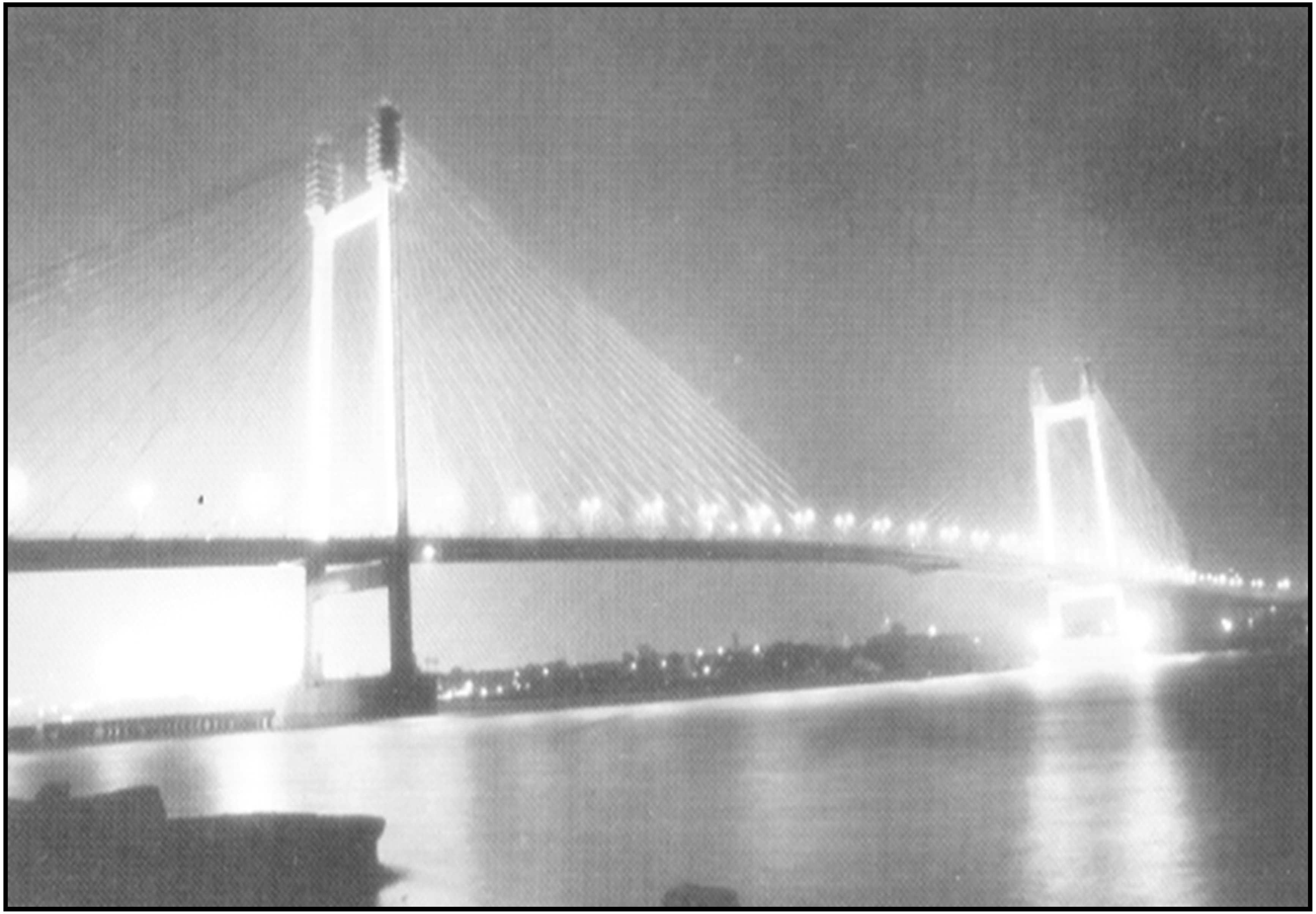
Advantages

- **Large strength to weight ratio**
- **High ductility –** during earthquakes, large deflections give visible evidence of impending failure.
- Ductile nature of steels enables to yield locally, thus preventing premature failures.
- **Uniformity-** Quality of steel construction is superior, when compared with that of construction involving other materials.
- **Environment-friendly** Structural steel is recyclable and environment-friendly. Over 400 million tonnes of steel are recycled annually worldwide, which represents 50% of all steel produced.
- Can readily be disassembled at the end of its useful life.

- **Versatility- can** fasten different members together by simple connection techniques such as welding, bolting, and riveting
- **Prefabrication-** manufactured at the factory (produced using strict supervision and quality control), transported to site, and erected using bolting and a minimum amount of welding.
- **Additions to existing structures** repair and retrofit of steel members simpler than in concrete members.
- **Least disturbance to the community**
- **Fracture toughness**
- **Maintenance costs** Most steels are susceptible to corrosion when freely exposed lo air and water, and must therefore be periodically painted
- **Speed of erection and demountability**



World's first cast iron bridge - Coalbrookadale bridge at Shropshire, U.K
(Source: John H. Stephens, The Guinness book of Structures (Bridges, towers, tunnels, dams), 1981)



The second Hooghly cable stayed bridge
1992

Beijing National Stadium

costs $423 million is famous for its largest steel structure in the world.2008

Eiffel Tower

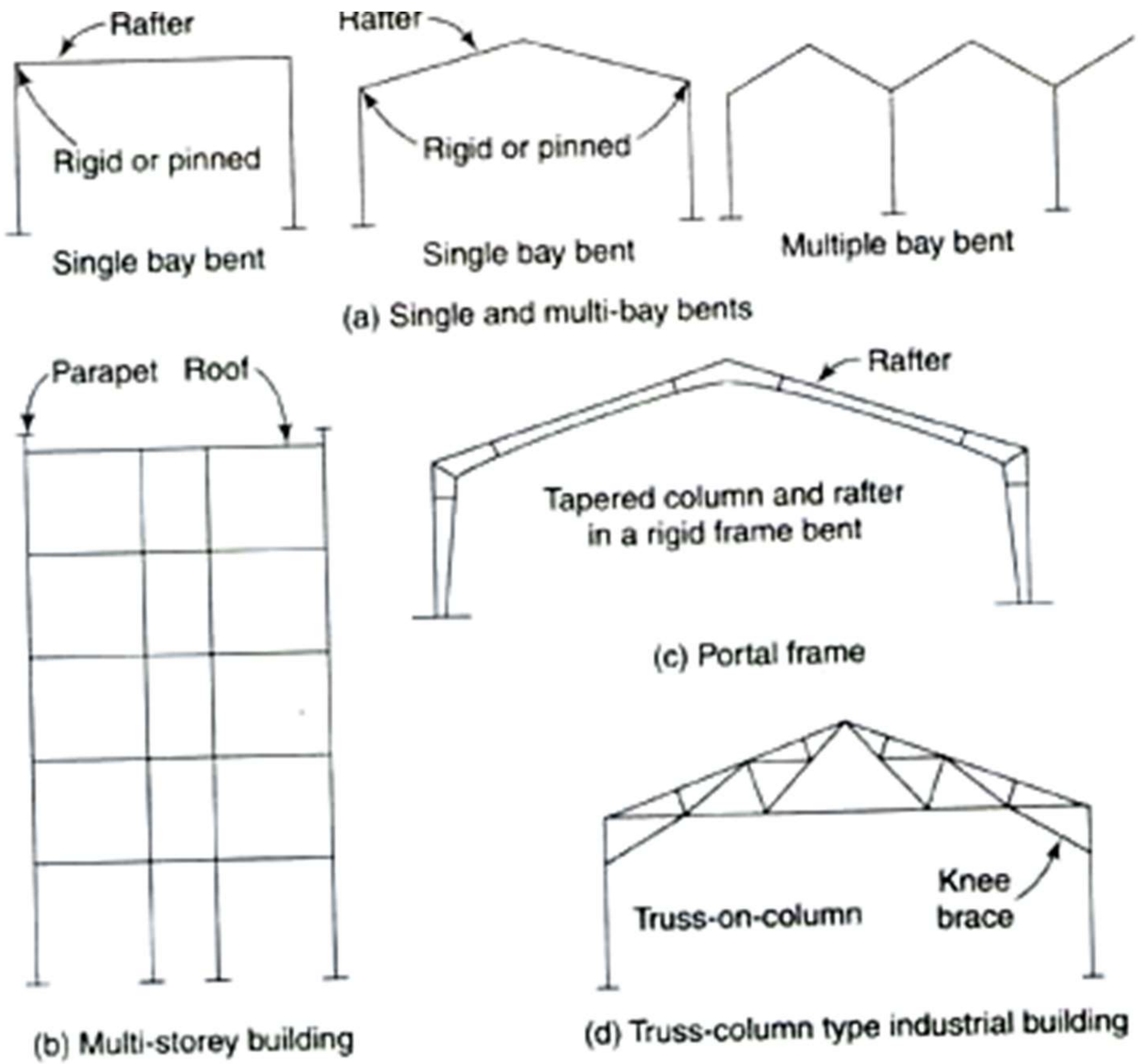
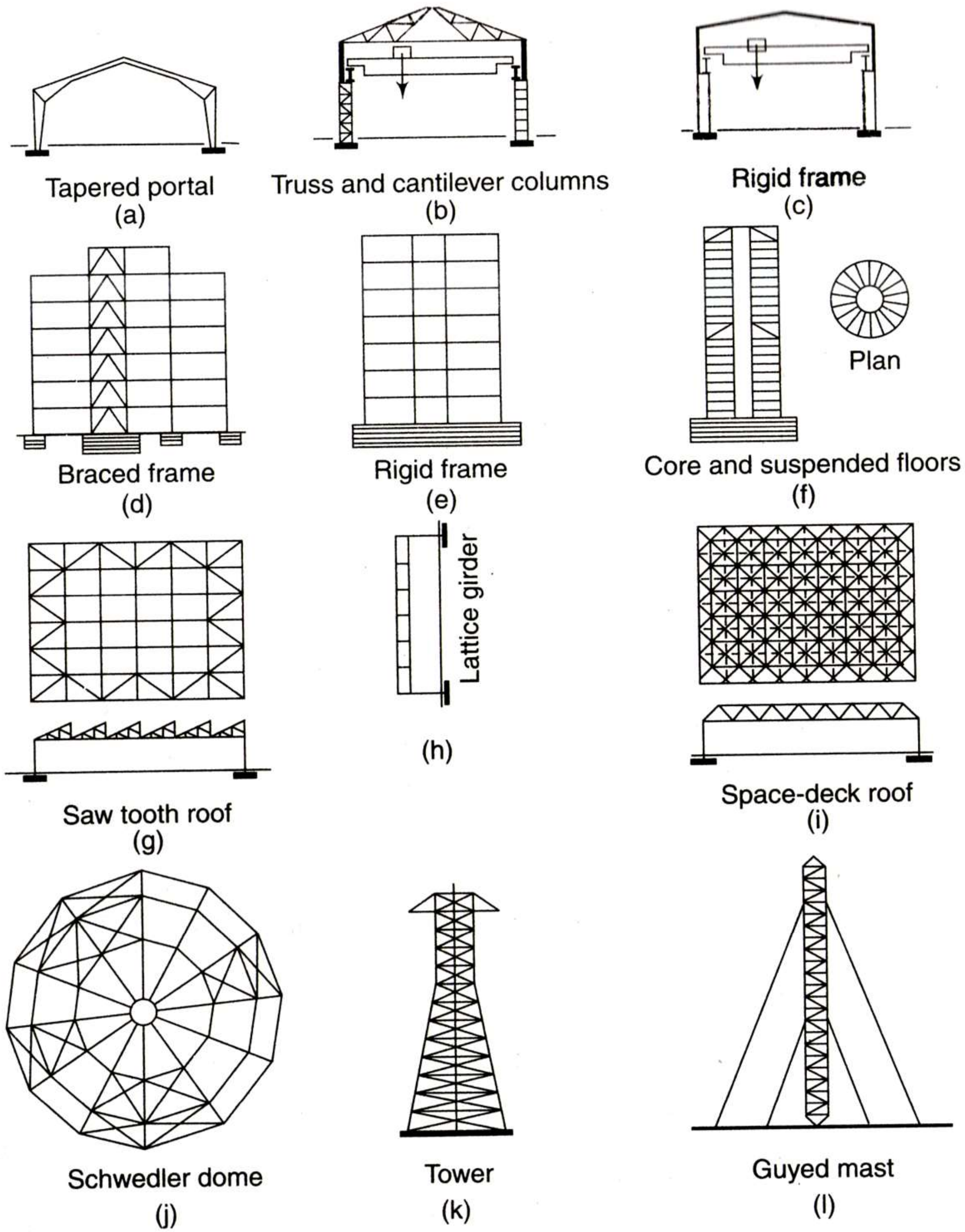


Fig. 1.41 Types of steel structures

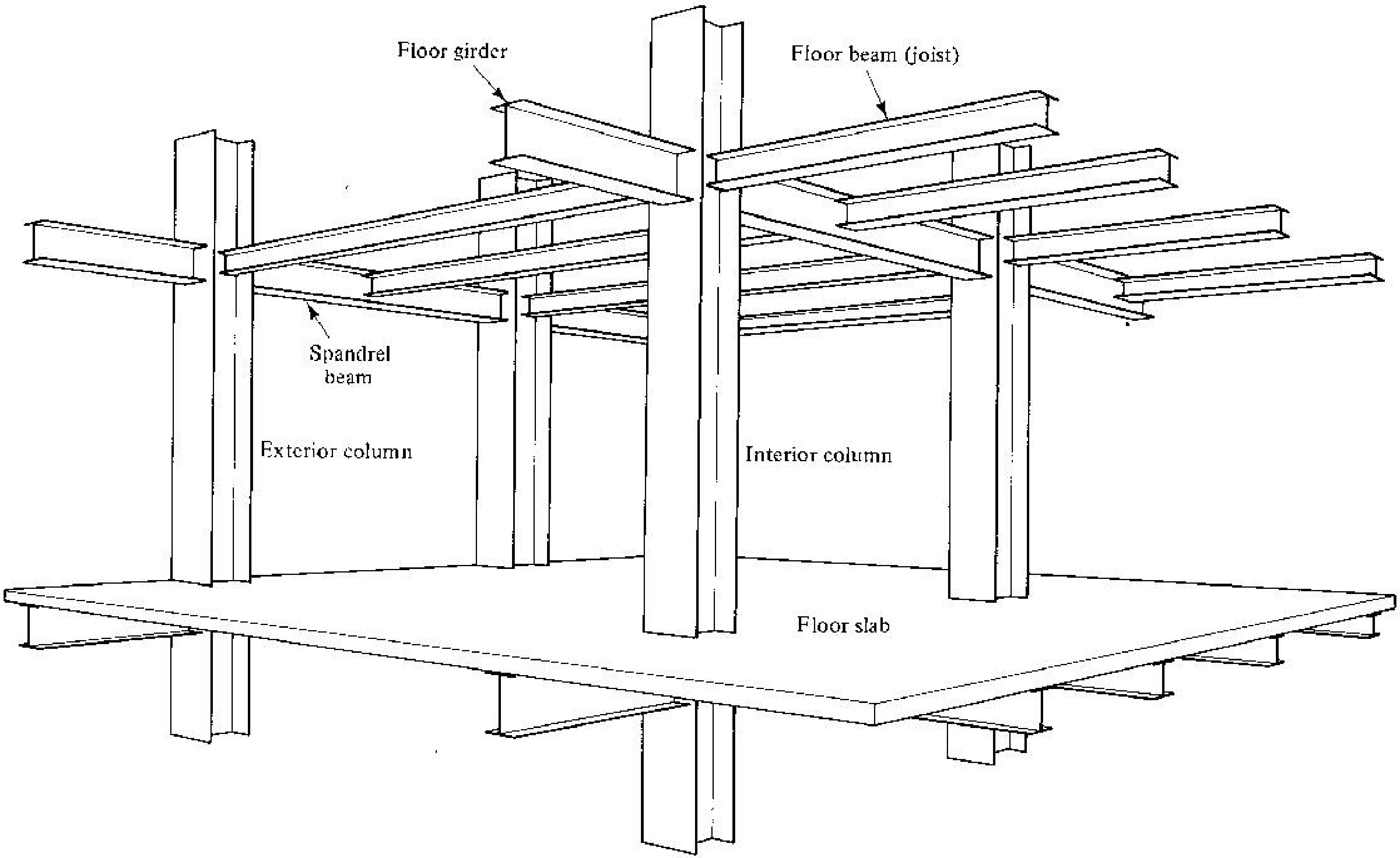


Examples of steel-frame structures (MacGinley 1997)

MAJOR BUILDING STRUCTURAL SYSTEMS

- Wall-bearing construction
- Beam and column construction
- Trusses
- Rigid frames
- Arches
- Suspension cables and cable-stayed systems
- Steel lamella roof
- Dome

Beam and column construction



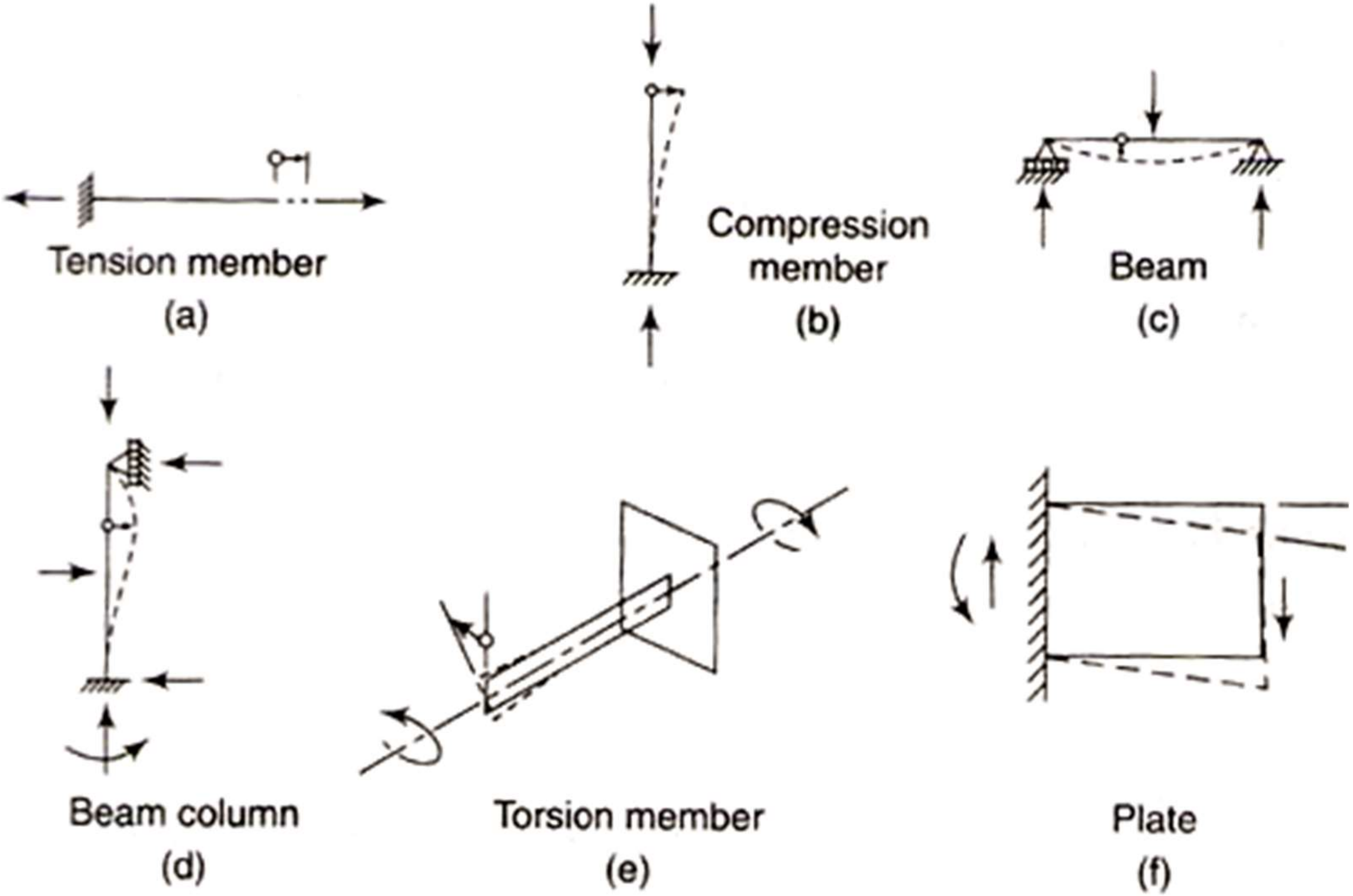
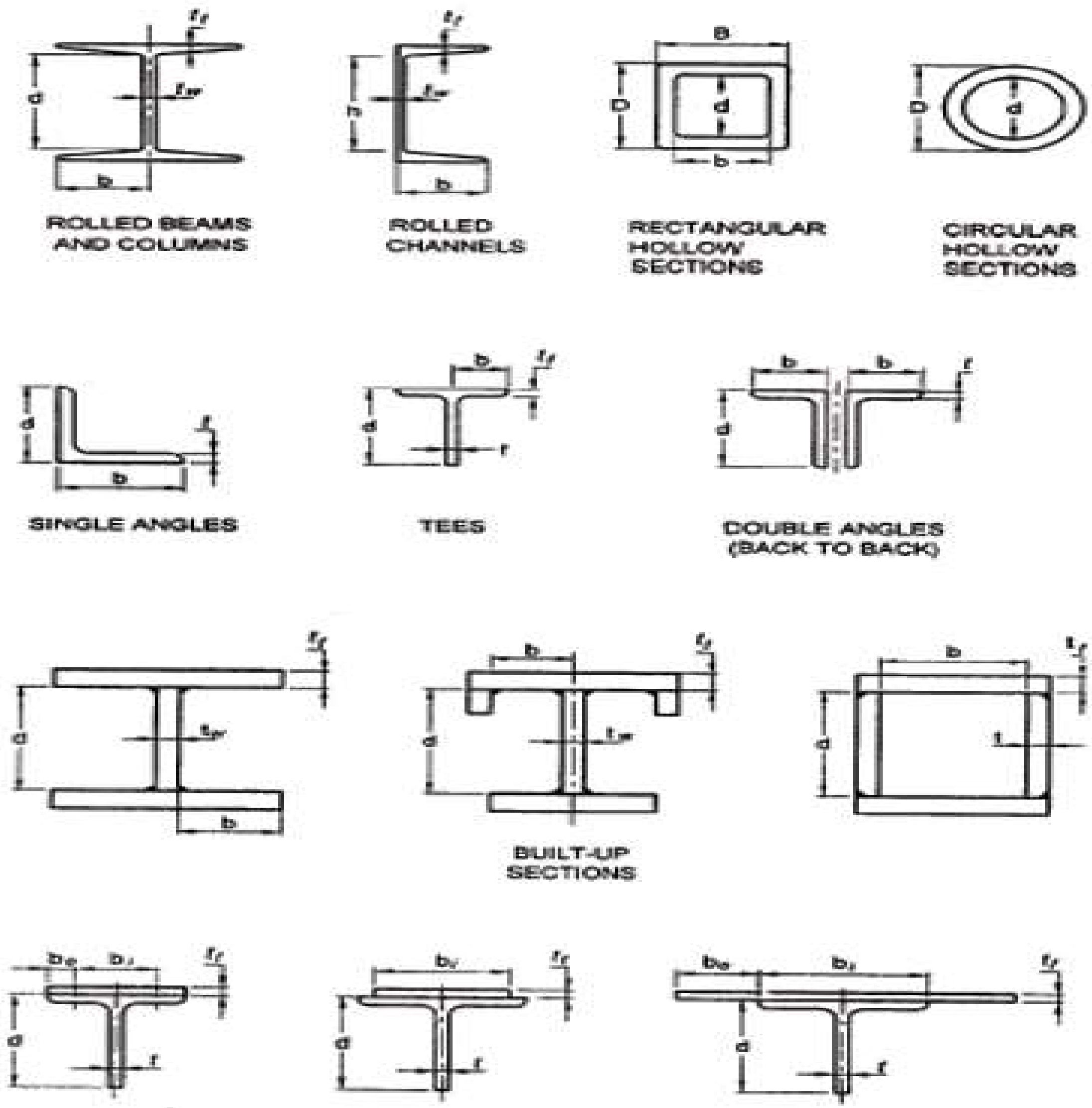


Fig. 1.44 Various types of structural members



COMPOUND ELEMENTS

b_i — Internal Element Width

b_e — External Element Width

FIG. 2 DIMENSIONS OF SECTIONS

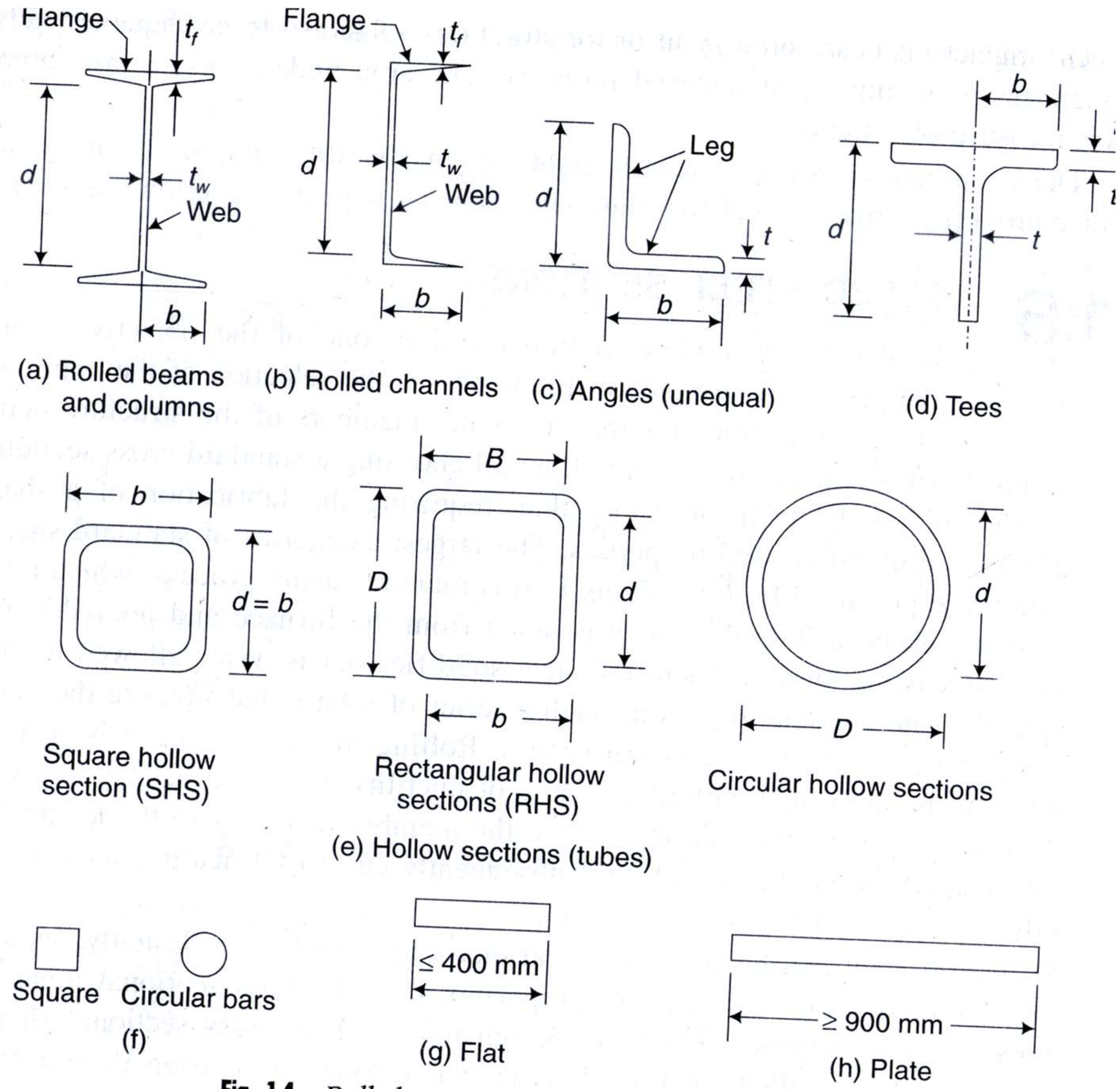
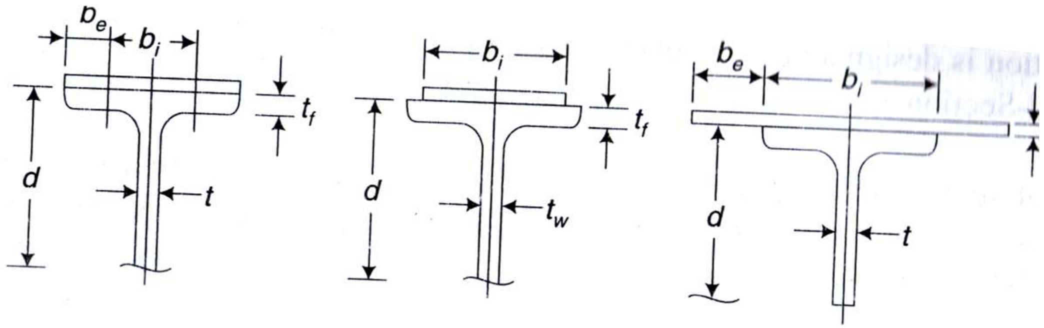
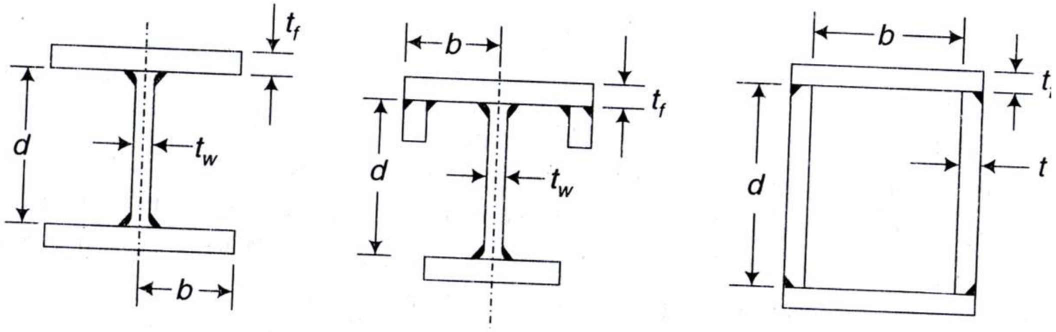


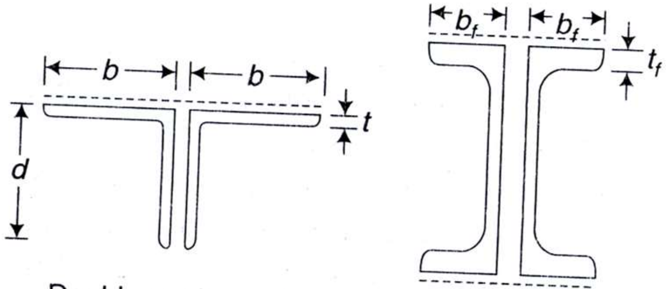
Fig. 1.4 *Rolled structural shapes and dimensions*



(a) Compound sections (I-sections with cover plates)



(b) Fabricated sections (welded girders)

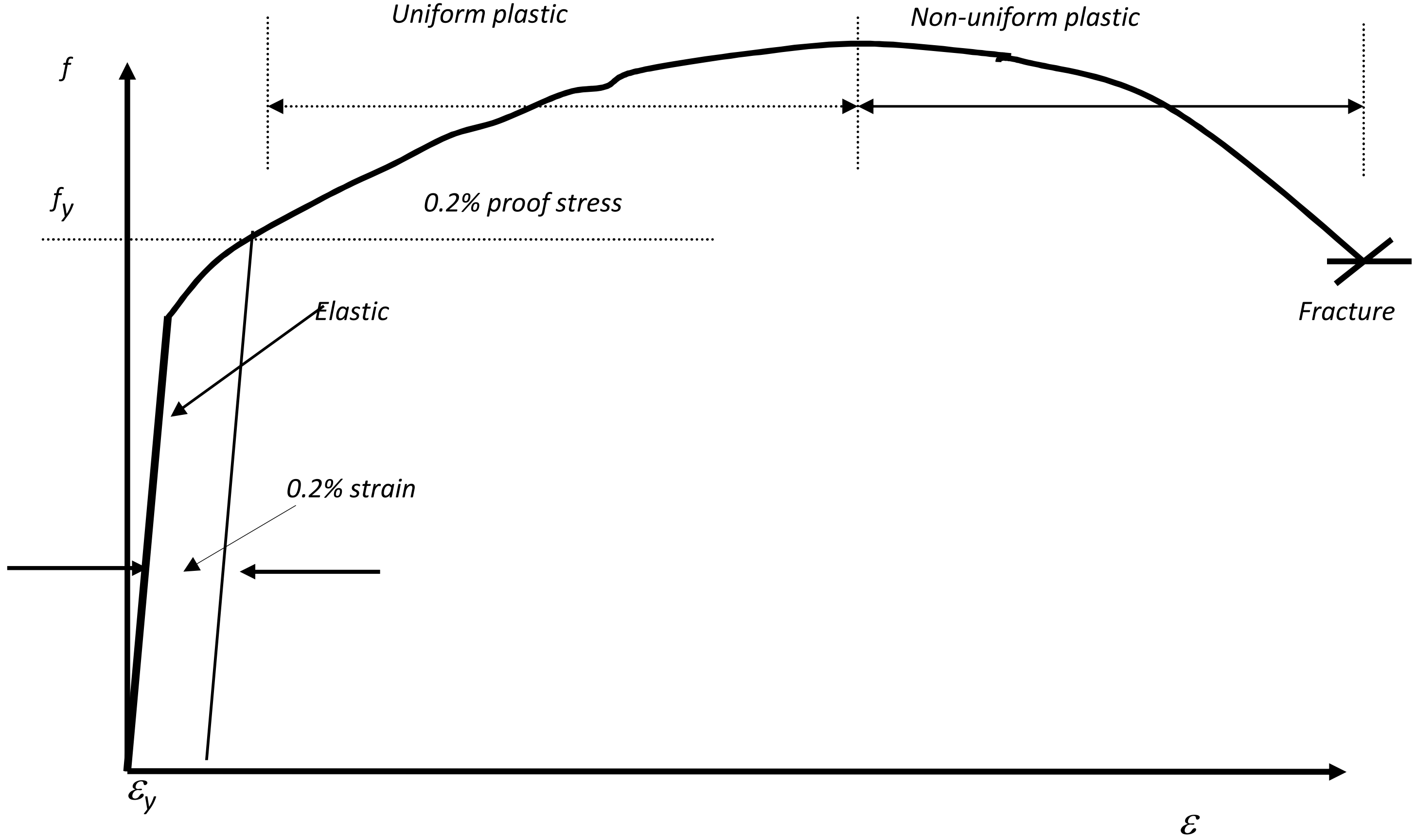


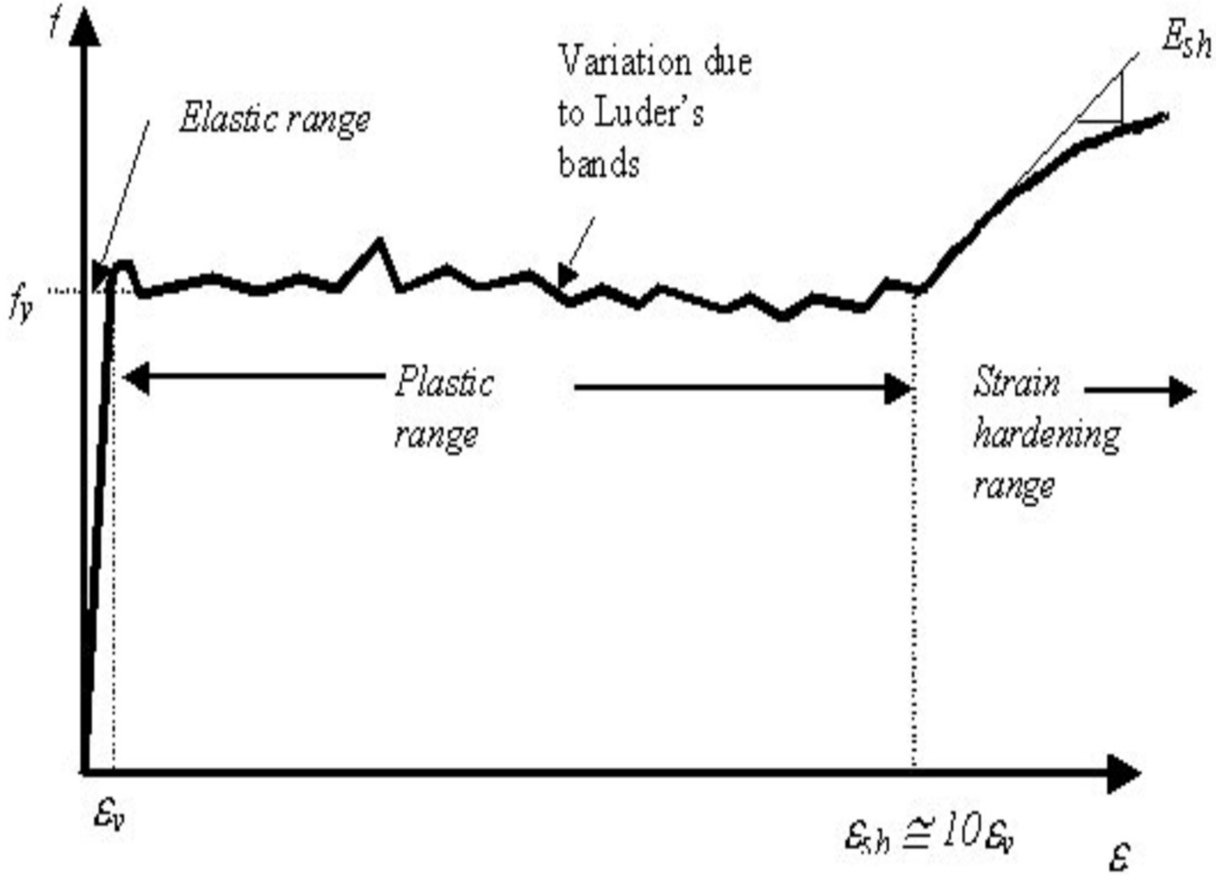
Double angle section   Double channel section

(c) Built-up sections

Fig. 1.5 *Sections for heavy loads*

Stress strain curve for continuously yielding structural steels





f
Elastic range
Variation due
to Luder's
bands
E_{sh}
f_y
Plastic
range
Strain
hardening
range
ε_y
$\varepsilon_{sh} \cong 10\,\varepsilon_y$
ε

- *Ductility* — It is the property of the material or a structure indicating the extent to which it can deform beyond the limit of yield deformation before failure or fracture.
- The ratio of ultimate to yield deformation is usually termed as ductility.

Physical properties of major structural materials

Item	Mild steel	Concrete M20 grade	Wood
Unit mass (kg/m^3)	7850	2400	290-900
Maximum stress (MPa)			
Compression	250	20	5.2-23
Tension	250	3.13	2.5-13.8
Shear	144	2.8	0.6-2.6
Young's modulus (MPa)	2×10^5	22,360	4600-18000
Coefficient of linear expansion(°C x 10^{-6})	**12**	**10-14**	4.5
Poisson's ratio	0.3	0.2	0.2

Mechanical properties of some typical structural steels

Type of steel	Design-ation	UTS (MPa)	Yield strength (MPa)			Elongation Gauge	Charpy V - notch values Joules (min)
			Thickness (mm)				
			<20	**20-40**	**>40**		
Standard structural steel	Fe 410A	410	250	240	230	23	27
	Fe 410B	410	250	240	230	23	27
	Fe 410C	410	250	240	230	23	27
			<16	**16-40**	**41-63**		
Micro alloyed high strength steel	Fe 440	440	300	290	280	22	-
	Fe 540	540	410	390	380	20	-
	Fe 590	590	450	430	420	20	-

- Physical properties of structural steel irrespective of its grade may be taken as: Page: 12

- Unit mass of steel, p = 7850 kg/m^3
- Modulus of elasticity, E = 2.0 x 10^5 N/mm^2 (MPa)
- Poisson ratio, ν. = 0.3
- Modulus of rigidity, G = 0.769 x 10^5 N/mm^2 (MPa)
- Co-efficient of thermal expansion a = 12 x 10^{-6} /°C

- Tensile Properties of steel – Table-1 , Pg-13

Design (section 3,pg 15)

- Objective of design is the achievement of an acceptable probability that structures will perform satisfactorily for the intended purpose during the design life.
- With an appropriate degree of safety, they should sustain all the loads and deformations, during construction and use and have adequate resistance to certain expected accidental loads and fire.
- Structure should be stable and have alternate load paths to prevent disproportionate overall collapse under accidental loading.

- Design for strength R>W

  – Specifies that the design resistance of a structural component is greater than the required strength to transmit the loads safely

- Design for serviceability

  – In the serviceability design criteria for structures, the designer seeks to make the structure sufficiently stiff so that its deflections under the most adverse working loads will not affect its serviceability

FACTORS CONSIDERED IN THE DESIGN

- Materials to be used
- Arrangement and structural system and flooring system to be adopted
- Fabrication and type of jointing
- Method of erection of the framework to be used
- Type of construction for floor, walls, cladding and finishes
- Installation of ventilating/ heating plant, lifts, water supply, power etc.
- Corrosion protection required
- Fire protection required
- Operating and maintenance costs

Designer has to ensure the structures:

- Fit for their purpose
- Safe
- Economical and durable
- **Uncertainties affecting safety of a structure**
    - ➢uncertainty about loading
        - ➢Variability of the loads
        - ➢Variability of the load distribution through the structure
    - ➢uncertainty about material strength and
    - ➢uncertainty about structural dimensions and behaviour

DESIGN PHILOSOPHIES

Working stress method
Ultimate load design method
Limit state method

Design Philosophies

- A general statement assuming safety in engineering design is:
- **Resistance ≥ Effect of applied loads ---(1)**
- In eq (1) it is essential that both sides are evaluated for same conditions and units e.g. compressive stress on soil should be compared with bearing capacity of soil

Design Philosophies…

- Resistance of structures is composed of its members which comes from **materials & X-section**
- Resistance, Capacity, and Strength are somewhat synonym terms.
- Terms like Demand, Stresses, and Loads are used to express Effect of applied loads.

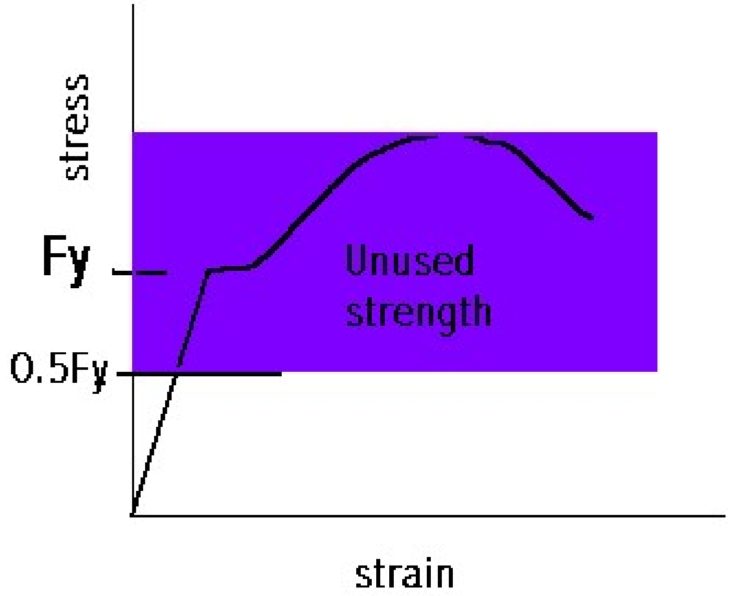
Allowable Stress Design (ASD)

- A type of WSM-
- Safety in the design is obtained by specifying, that the effect of the loads should produce stresses that is a fraction of the yield stress f_y, say one half.
- This is equivalent to:

FOS = Resistance, R/ E

= fy/0.5fy

= 2



Allowable Stress Design (ASD)…

- Since the specifications set limit on the stresses, it became allowable stress design (ASD).

- It is mostly reasonable where stresses are uniformly distributed over X-section (such on determinate trusses, arches, cables etc.)

Allowable Stress Design (ASD)…

- Mathematical Description of A S D

$$\frac{\phi R_n}{\gamma} \geq \sum Q_i$$

- R_n = Resistance or Strength of the component being designed
- Φ = Resistance Factor or Strength Reduction Factor
- Q_i = Effect of applied loads
- γ / φ = Factor of Safety FS

Working Stress Method (WSM)

- Traditional method of design
- Safety is ensured by limiting stress in the material
- Material is assumed to behave in linear elastic manner
- Stress strain behavior is assumed to be linear
- Permissible stress < $\frac{yield\ stress}{factor\ of\ safety}$
- Axial(tension/compression), shear, permissible=0.6f_y
- bending (tension/compression)=0.66 f_y
- Average shear stress τ_{aver}=0.4f_y
- Bearing stress= $\sigma_{p=0.75f_y}$
- Load factor is not considered, only service load
- Very conservative, only up to yield stress
- But member can take some load, even though some deformation
- Not economical

Working Stress Method (WSM)

- Adequate safety can be ensured by suitably restricting the stresses material due to the expected *working loads* (service loads) on the structure.
- The limitations due to non-linearity (geometric as well as material) and buckling are neglected.

- Refer pages-1-5 Terminology
- *Elastic Design* — Design, which assumes elastic behaviour of materials throughout the service load range.
- *Elastic Limit* — It is the stress below which the material regains its original size and shape when the load is removed. In steel design, it is taken as the yield stress.

- Stresses caused by the characteristic loads must be less than an "*allowable stress*", which is a fraction of the yield stress

- Allowable stress may be defined in terms of a "*factor of safety*" which represents a margin for overload and other unknown factors which could be tolerated by the structure

Allowable stress = (Yield stress) / (Factor of safety)

Limitations

- Material non-linearity

- Non-linear behaviour in the post buckled state and the property of steel to tolerate high stresses by yielding locally and redistributing the loads not accounted for.

- No allowance for redistribution of loads in statically indeterminate members

ASD Drawbacks

- Implied in the ASD method is the assumption that the stress in the member is zero before any loads are applied, i.e., no residual stresses exist from forming the members.
- ASD does not give reasonable measure of strength, which is more fundamental measure of resistance than is allowable stress.
- Another drawback in ASD is that safety is applied only to stress level. Loads are considered to be deterministic (without variation).

ULTIMATE LOAD DESIGN METHOD

- Load factor method/ Plastic Design Method
- Plastic design method is a special case of limit states design, wherein the limit state is attained when the members reach plastic moment strength *Mp* and the structure is transformed into a mechanism
- Plastic moment strength is the moment strength when all the fibres of the cross section of a member are at the yield stress *fy*
- Introduced **Load factor- Ratio of Ultimate load to working load**
- The satisfactory 'strength' performance at ultimate loads does not guarantee satisfactory 'serviceability' performance at normal service loads.
- Plastic design does not using other limit states such as instability, fatigue, or brittle fracture.

- However, the safety provided in these methods lacked scientific basis. The science of reliability-design was developed with the objective of providing a rational solution to problem of 'adequate safety'

Limit States Method (LSM)

- advancement over traditional design philosophies. Unlike WSM, which bases calculations on service load conditions alone, and unlike ULM, which bases calculations on ultimate load conditions alone,
- LSM aims for a comprehensive and rational solution to the design problem, by considering *safety* at ultimate loads and *serviceability* at working loads.
- LSM philosophy uses a multiple safety factor format that attempts to provide adequate safety at ultimate loads as well as adequate serviceability at service loads, by considering all possible 'limit states'.

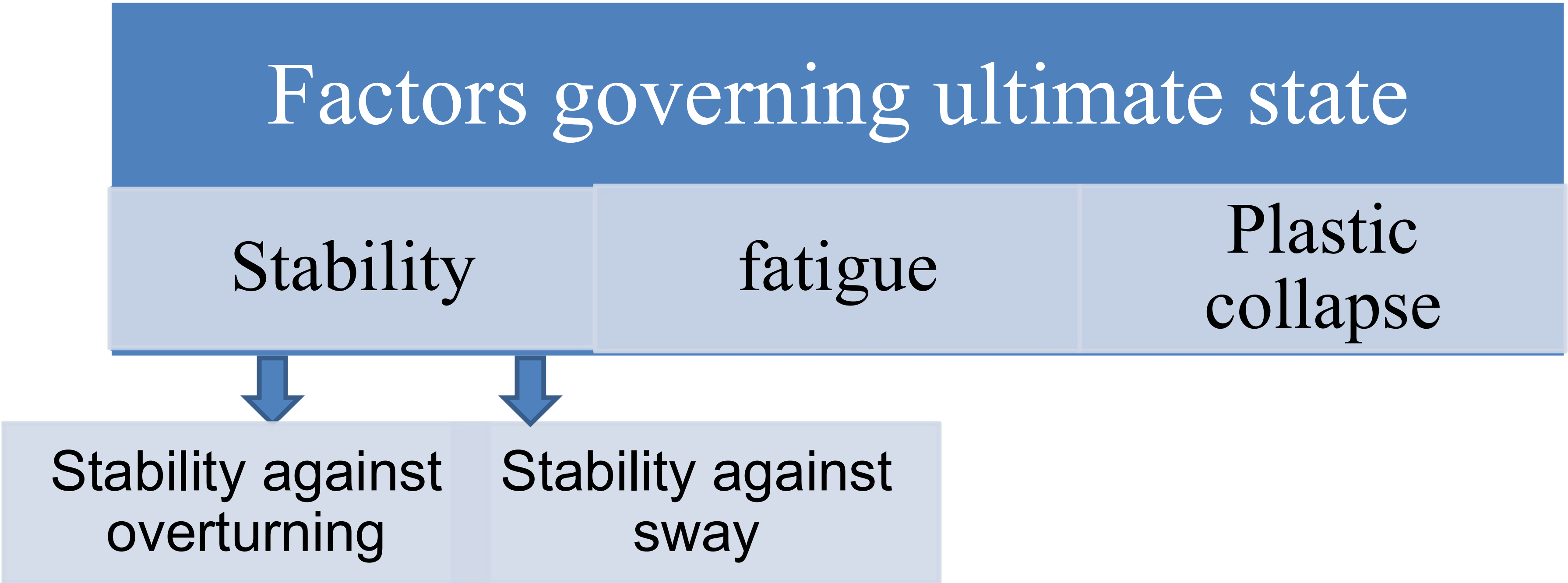
Limit States Method (LSM)

Limit States

Ultimate Limit State	Serviceability Limit State
Strength (yield, buckling)	Deflection
Stability against overturning and sway	Vibration
Fracture due to fatigue	Repairable damage due to fatigue
Brittle Fracture	Corrosion

Selection of the various multiple safety factors is supposed to have a sound probabilistic basis, involving the separate consideration of different kinds of failure, types of materials, and types of loads.

Limit States Method (LSM)



cl.5.2.2.1

Limit state of strength -associated with failure of structure under the action of worst possible combination of loads along with proper partial safety factor that may lead to loss of life and property

a) Loss of equilibrium of the structure as a whole or any of its parts

b) Loss of stability of the structure (including effect of sway and overturning)

c) Failure by excessive deformation or rupture

d) Fracture due to fatigue,

e) Brittle fracture.

IS CODAL RECOMMENDATIONS (Section -5, Pg- 27)

- In the limit state design method, the structure shall be designed to withstand safely all loads likely to act on it throughout its life. It shall not suffer total collapse under accidental loads such as from explosions or impact or due to consequences of human error to an extent beyond the local damages.
- The objective of the design is to achieve a structure that will remain fit for use during its life with acceptable target reliability. In other words, the probability of a limit state being reached during its lifetime should be very low. The acceptable limit for the safety and serviceability requirements before failure occurs is called a limit state. In general, the structure shall be designed on the basis of the most critical limit state and shall be checked for other limit states.
- Steel structures are to be designed and constructed to satisfy the design requirements with regard to stability, strength, serviceability, brittle fracture, fatigue, fire, and durability such that they meet the following:
- Remain fit with adequate reliability and be able to sustain all actions (loads) and other influences experienced during construction and use;
- Have adequate durability under normal maintenance;
- Do not suffer overall damage or collapse disproportionately under accidental events like explosions, vehicle impact or due to consequences of human error to an extent beyond local damage.

Design Philosophies…

- Acceptable limit for the safety and serviceability requirements before failure occurs is called a Limit state
- "A limit state is a condition beyond which a structural system or a structural component ceases to fulfill the function for which it is designed."

- Design Approach used must ensure that the probability of a Limit State being reached in the Design/Service Life of a structure is within acceptable limits;
- However, complete elimination of probability of a Limit State being achieved in the service life of a structure is impractical as it would result in uneconomical designs.

- Structure and Structural Members should have adequate strength, stiffness and toughness to ensure proper functioning during service life
- Reserve Strength should be available to cater for:
  - Occasional overloads and underestimation of loads
  - Variability of strength of materials from those specified
  - Variation in strength arising from quality of workmanship and construction practices

- Structural Design must provide adequate margin of safety irrespective of Design Method

- Design Approach should take into account the probability of occurrence of failure in the design process
- An important goal in design is to prevent limit state from being reached.

- It is not economical to design a structure so that none of its members or components could ever fail. Thus, it is necessary to establish an acceptable level of risk or probability of failure.

LIMIT STATE DESIGN

Limit States are various conditions in which a structure would be considered to have failed to fulfil the purpose for which it was built.

- “Ultimate Limit States” are those catastrophic states, which require a larger reliability in order to reduce the probability of its occurrence to a very low level.

- “Serviceability Limit State" refers to the limits on acceptable performance of the structure.

Ultimate Limit State	Serviceability Limit State
Strength (yield, buckling)	Deflection
Stability against overturning and sway	Vibration
Fracture due to fatigue	Repairable damage due to fatigue
Brittle Fracture	Corrosion

Limit States

LIMIT STATES FOR DESIGN PURPOSES

- Ultimate Limit State is related to the maximum design load capacity under extreme conditions. The partial load factors are chosen to reflect the probability of extreme conditions, when loads act alone or in combination.

- Serviceability Limit State is related to the criteria governing normal use. Unfactored loads are used to check the adequacy of the structure.

- Fatigue Limit State is important where distress to the structure by repeated loading is a possibility

Highlights

IS : 800 - 1984

Working stress method

- Factor of safely for yield stress, allowable stresses are less than 'f_y'.
- Pure elastic approach for analysis of structures under working loads.
- Yielding or buckling never occurs at working loads
- Deformations are evaluated at working loads.

IS : 800 – 2007

Limit State Method

- Partial safety factor for material (γ_m) for yield and ultimate stress.
- Working loads are factored (increased) as per partial safely factor (γ_f) causing Limit State of strength.
- Post buckling and post yielding plays important role in estimating capacity of structural elements at Limit State.
- Deformations are evaluated at working loads.

General Principles of Limit State Design

- Structure to be designed for the Limit States at which they would become unfit for their intended purpose by choosing, appropriate partial safety factors, based on probabilistic methods.

- Two partial safety factors, one applied to loading (γ_f) and another to the material strength (γ_m) shall be employed.

Table 4 Partial Safety Factors for Loads, γ_f, for Limit States

(*Clauses* 3.5.1 *and* 5.3.3)

Combination	Limit State of Strength					Limit State of Serviceability			
	DL	LL[1]		WL/EL	AL	DL	LL[1]		WL/EL
		Leading	Accompanying				Leading	Accompanying	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DL+LL+CL	1.5	1.5	1.05	—	—	1.0	1.0	1.0	—
DL+LL+CL+	1.2	1.2	1.05	0.6	—	1.0	0.8	0.8	0.8
WL/EL	1.2	1.2	0.53	1.2					
DL+WL/EL	1.5 (0.9)[2]	—	—	1.5	—	1.0	—	—	1.0
DL+ER	1.2 (0.9)[2]	1.2	—	—	—	—	—	—	—
DL+LL+AL	1.0	0.35	0.35	—	1.0	—	—	—	—

[1] When action of different live loads is simultaneously considered, the leading live load shall be considered to be the one causing the higher load effects in the member/section.

[2] This value is to be considered when the dead load contributes to stability against overturning is critical or the dead load causes reduction in stress due to other loads.

Abbreviations:

DL = Dead load, LL = Imposed load (Live loads), WL = Wind load, CL = Crane load (Vertical/Horizontal), AL = Accidental load, ER = Erection load, EL = Earthquake load.

NOTE — The effects of actions (loads) in terms of stresses or stress resultants may be obtained from an appropriate method of analysis as in **4**.

Table 5 Partial Safety Factor for Materials, γ_m

(*Clause* 5.4.1)

Sl No.	Definition	Partial Safety Factor	
i)	Resistance, governed by yielding, γ_{m0}	1.10	
ii)	Resistance of member to buckling, γ_{m0}	1.10	
iii)	Resistance, governed by ultimate stress, γ_{m1}	1.25	
iv)	Resistance of connection:	*Shop Fabrications*	*Field Fabrications*
	a) Bolts-Friction Type, γ_{mf}	1.25	1.25
	b) Bolts-Bearing Type, γ_{mb}	1.25	1.25
	c) Rivets, γ_{mr}	1.25	1.25
	d) Welds, γ_{mw}	1.25	1.50

Table 6 Deflection Limits

Type of Building	Deflection	Design Load	Member	Supporting	Maximum Deflection
(1)	(2)	(3)	(4)	(5)	(6)
Industrial Buildings	Vertical	Live load/ Wind load	Purlins and Girts	Elastic cladding	Span/150
Industrial Buildings	Vertical	Live load/ Wind load	Purlins and Girts	Brittle cladding	Span/180
Industrial Buildings	Vertical	Live load	Simple span	Elastic cladding	Span/240
Industrial Buildings	Vertical	Live load	Simple span	Brittle cladding	Span/300
Industrial Buildings	Vertical	Live load	Cantilever span	Elastic cladding	Span/120
Industrial Buildings	Vertical	Live load	Cantilever span	Brittle cladding	Span/150
Industrial Buildings	Vertical	Live load/ Wind load	Rafter supporting	Profiled Metal Sheeting	Span/180
Industrial Buildings	Vertical	Live load/ Wind load	Rafter supporting	Plastered Sheeting	Span/240
Industrial Buildings	Vertical	Crane load (Manual operation)	Gantry	Crane	Span/500
Industrial Buildings	Vertical	Crane load (Electric operation up to 50 t)	Gantry	Crane	Span/750
Industrial Buildings	Vertical	Crane load (Electric operation over 50 t)	Gantry	Crane	Span/1 000
Industrial Buildings	Lateral	No cranes	Column	Elastic cladding	Height/150
Industrial Buildings	Lateral	No cranes	Column	Masonry/Brittle cladding	Height/240
Industrial Buildings	Lateral	Crane + wind	Gantry (lateral)	Crane (absolute)	Span/400
Industrial Buildings	Lateral	Crane + wind	Gantry (lateral)	Relative displacement between rails supporting crane	10 mm
Industrial Buildings	Lateral	Crane+ wind	Column/frame	Gantry (Elastic cladding; pendent operated)	Height/200
Industrial Buildings	Lateral	Crane+ wind	Column/frame	Gantry (Brittle cladding; cab operated)	Height/400
Other Buildings	Vertical	Live load	Floor and Roof	Elements not susceptible to cracking	Span/300
Other Buildings	Vertical	Live load	Floor and Roof	Elements susceptible to cracking	Span/360
Other Buildings	Vertical	Live load	Cantilever	Elements not susceptible to cracking	Span/150
Other Buildings	Vertical	Live load	Cantilever	Elements susceptible to cracking	Span/180
Other Buildings	Lateral	Wind	Building	Elastic cladding	Height/300
Other Buildings	Lateral	Wind	Building	Brittle cladding	Height/500
Other Buildings	Lateral	Wind	Inter storey drift	—	Storey height/300

- γ_f allows for;

  - Possible deviation of the actual behaviour of the structure from the analysis model
  - Deviation of loads from specified values and
  - Reduced probability that the various loads acting together will simultaneously reach the characteristic value.

- γ_m takes account;

  - Possible deviation of the material in the structure from that assumed in design
  - Possible reduction in the strength of the material from its characteristic value and
  - Manufacturing tolerances.
  - Mode of failure (ductile or brittle).

- *Characteristic Load (Action)* — The value of specified load (action), above which not more than a specified percentage (usually 5 percent) of samples of corresponding load are expected to be encountered.
- Value of the load, which has an accepted probability of not being exceeded during the life span of the structure.
- Characteristic load is therefore that load which will not be exceeded 95% of the time.

- *Characteristic Yield/Ultimate Stress* — The minimum value of stress, below which not more than a specified percentage (usually 5 percent) of corresponding stresses of samples tested are expected to occur.
- **Characteristic strength is expected to be exceeded by 95% of the cases.**
- Value of resistance below which not more than a prescribed percentage of test results may be expected to fall.

Actions are classified by their variation with time :

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- a) *Permanent actions* (Q_p): Actions due to self-weight of structural and non-structural components, fittings, and fixed equipment, etc.
- *Variable actions* (Q_v): Actions due to construction and service stage loads such as imposed (live) loads (crane loads, snow loads, etc.), wind loads, and earthquake loads, etc.
- *Accidental actions* (Q_a)*:* Actions expected due to explosions, and impact of vehicles, etc.

Limit State Design

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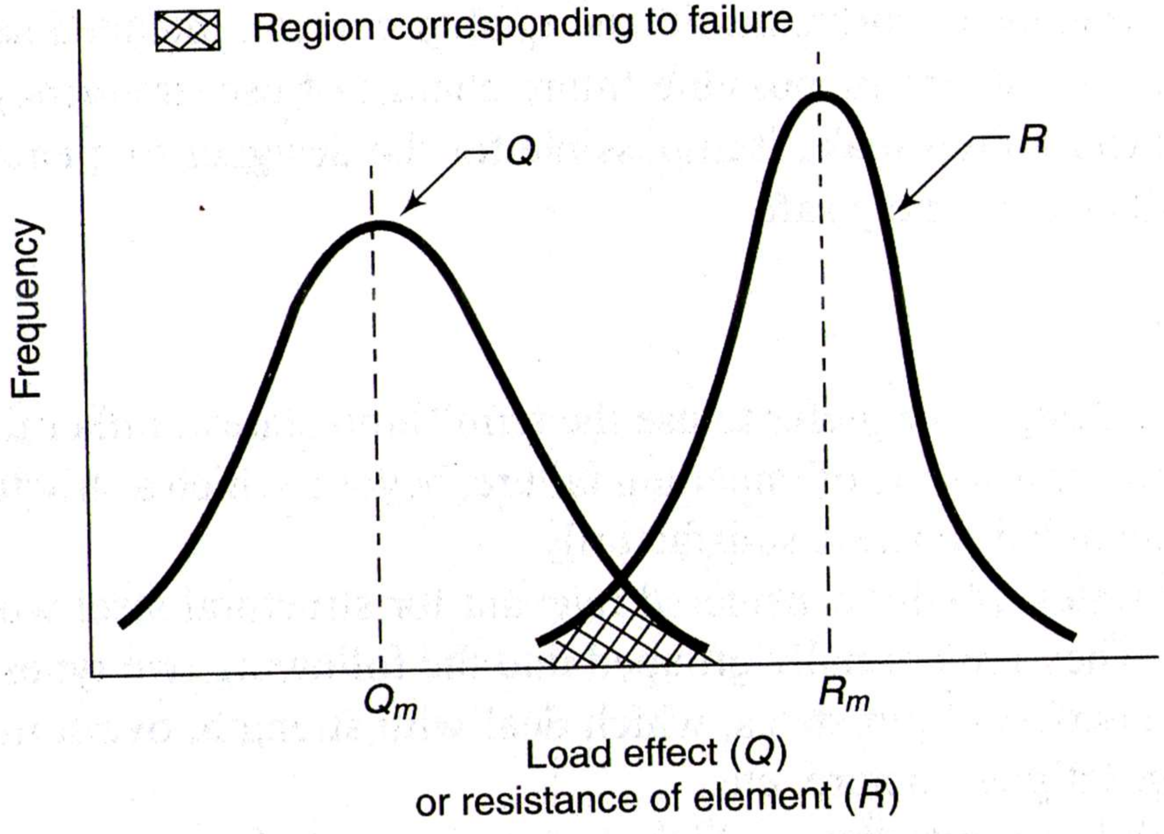
The reliability of design is ensured by satisfying the requirement:

Design action < Design strength

Design Actions $Q_d = \Sigma\gamma_{fk}Q_{ck}$

Design Strength $S_d = S_u/\gamma_m$



Frequency distribution curves

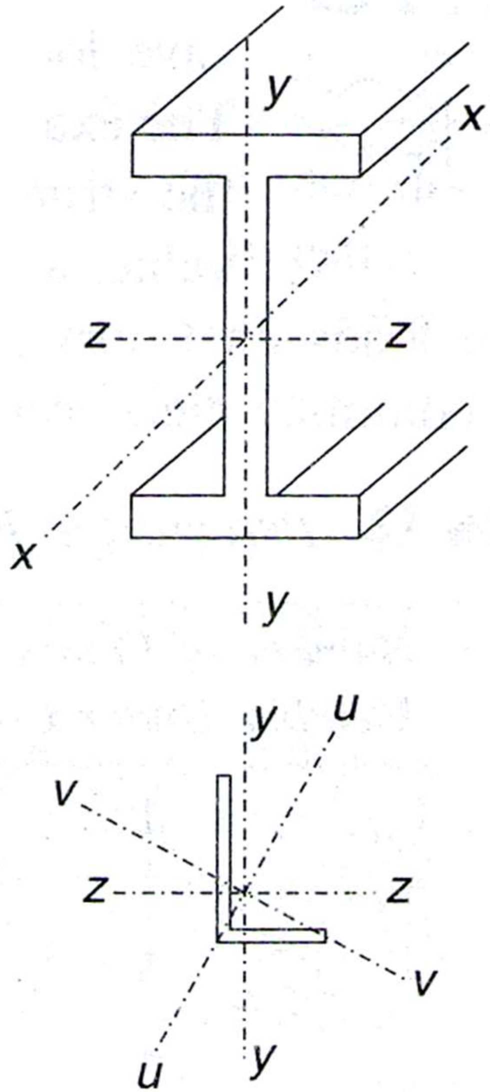


Fig. 1.6 *Notations of member axes*