



GANDHI SCHOOL OF ENGINEERING

Brahmapur, Odisha

E-Notes

Basic Civil Engineering

Complete E-Notes

B.Tech 1st Year · Semester 1 · Circuit Branch

Academic Year 2026-27



How to use these notes

These notes follow the official 2026-27 syllabus for Basic Civil Engineering (2-0-0, 2 credits, 30 contact hours, 100 university marks + 50 internal). Each module has these parts:

- **Theory** in exam language, with neat labelled diagrams and comparison tables.
- **Solved numericals** (material quantities, bearing capacity, water demand, population forecasting, road geometry, duty and delta) worked step by step.
- **Practice problems with solutions** and **MCQs** with answers and reasons.

At the end: 2-mark questions with answers, a long-question bank, a model paper and a quick-revision sheet.

Module	Topic	Classes
I	Introduction to civil engineering; residential buildings (NBC classification, components, planning, site selection); foundations and bearing capacity	6
II	Properties and uses of construction materials: stone, brick, cement, aggregates, mortar, concrete, timber, steel, non-ferrous metals, paint, plastics, glass, adhesives, tiles, composites	6
III	Transportation: modes, Indian road system, road classification, components of a road, rigid and flexible pavements	6
IV	Water supply: sources, per capita demand, drinking water standards, public water supply layout, conventional water treatment	6
V	Irrigation: importance, classification of projects, irrigation systems, field water distribution, multipurpose projects, dams, canal irrigation layout	6

Reference books (from syllabus)

- S. Gopi, Basic Civil Engineering, Pearson.
- S.S. Bhavikatti, Basic Civil Engineering, New Age International.
- Also useful: IS 456 (concrete), IS 1077 (bricks), IS 10500 (drinking water), IS 1172 (water requirements), National Building Code of India 2016, IRC publications.

Common units and conversions



Quantity	Unit	Conversion
Length	m, km	1 km = 1000 m
Area	m ² , hectare (ha)	1 ha = 10,000 m ² ; 1 km ² = 100 ha
Volume	m ³ , litre (L)	1 m ³ = 1000 L
Discharge	m ³ /s (cumec), L/s	1 cumec = 1000 L/s = 86,400 m ³ /day
Stress, pressure	N/mm ² (MPa), kN/m ² (kPa)	1 N/mm ² = 1 MPa = 1000 kN/m ²
Unit weight	kN/m ³	water = 9.81 kN/m ³ ($\approx$ 10)
Density	kg/m ³	cement $\approx$ 1440 kg/m ³ (loose)



Contents

How to use these notes	2
Basic Civil Engineering	8
Module I: Introduction, Residential Buildings and Foundations	8
1.1 Introduction to civil engineering	8
1.2 Various disciplines of civil engineering	8
1.3 Importance of civil engineering in infrastructure development	8
1.4 Interdisciplinary nature of construction projects	9
1.5 Residential buildings: NBC classification of buildings	9
1.6 Basic components of a building and their requirements	10
1.7 Planning and design of buildings: fundamental requirements	11
1.8 Selection of site for a residential building	12
1.9 Introduction to building design: functional and structural	12
1.10 Foundations: purpose and classification	12
1.11 Bearing capacity of soil and related terms (definitions)	13
1.12 Illustrated overview of Module I	14
1.13 Loads acting on a building	16
1.14 Building bye-laws and regulations	16
1.15 Orientation of buildings	17
1.16 Foundations and bearing capacity (illustrated)	17
1.17 Common mistakes to avoid in Module I	18
1.18 Solved numericals: Module I	18
1.19 Practice problems with solutions: Module I	20
1.20 MCQs: Module I	20
1.21 More solved numericals: Module I	23
1.22 Short questions with answers: Module I	25
Module II: Construction Materials	26
2.1 Fundamental properties of construction materials	26
2.2 Stone	26
2.3 Bricks	27
2.4 Cement	27
2.5 Aggregates	28
2.6 Mortar	29
2.7 Concrete	29
2.8 Timber	30
2.9 Steel and non-ferrous metals	30
2.10 Paint	31
2.11 Plastics, glass, adhesives and tiles	31
2.12 Composites	32



2.13 Summary: uses of construction materials	32
2.14 Illustrated notes on bricks and brick masonry	33
2.15 Tests on cement (IS 4031)	34
2.16 Tests on bricks (IS 3495)	35
2.17 Tests on aggregates and concrete	35
2.18 Grades of concrete and the water-cement ratio	35
2.19 Mechanical behaviour of steel	36
2.20 Selection of construction materials	37
2.21 Solved numericals: Module II	38
2.22 Practice problems with solutions: Module II	39
2.23 MCQs: Module II	40
2.24 More solved numericals: Module II	43
2.25 Short questions with answers: Module II	44
Module III: Transportation Engineering	46
3.1 Importance of transportation	46
3.2 Modes of transportation	46
3.3 Indian road transport system	46
3.4 Urban roads: basic requirements and classification	47
3.5 Basic components of a road	48
3.6 Types of pavements: flexible and rigid	48
3.7 Railways, airways and waterways: basic characteristics (brief)	49
3.8 Cross-section of a road (illustrated)	49
3.9 Pavement structure (illustrated)	50
3.10 Geometric design elements of highways	51
3.11 Road development plans and IRC classification	52
3.12 Highway materials and road drainage	52
3.13 Traffic control devices and road safety	53
3.14 Railways, airways and waterways: more details	53
3.15 Common mistakes to avoid in Module III	54
3.16 Solved numericals: Module III	54
3.17 Practice problems with solutions: Module III	55
3.18 MCQs: Module III	55
3.19 More solved numericals: Module III	57
3.20 Short questions with answers: Module III	59
Module IV: Water Supply Engineering	61
4.1 Sources of water	61
4.2 Quantity of water: per capita demand	61
4.3 Drinking water standards	62
4.4 Public water supply system: necessity and basic layout	63
4.5 Conventional water treatment process (working principles only)	64



4.6 Public water supply scheme (illustrated)	65
4.7 Water treatment flow sheet (illustrated)	66
4.8 Population forecasting methods	66
4.9 Variations in demand and design capacities	68
4.10 Distribution systems: methods and layouts	68
4.11 Water quality parameters (what each test tells us)	69
4.12 Rainwater harvesting and water conservation	70
4.13 Common mistakes to avoid in Module IV	70
4.14 Solved numericals: Module IV	70
4.15 Practice problems with solutions: Module IV	72
4.16 MCQs: Module IV	72
4.17 More solved numericals: Module IV	74
4.18 Short questions with answers: Module IV	76
Module V: Irrigation Engineering	78
5.1 Importance of irrigation	78
5.2 Classification of irrigation projects	78
5.3 Irrigation systems: types	78
5.4 Field water distribution (methods of applying water)	79
5.5 Water requirement of crops: duty, delta and base period	79
5.6 Multipurpose river valley projects	79
5.7 Dams: purpose and types	80
5.8 Canal irrigation system: layout, components and definitions	80
5.9 Canal system layout (illustrated)	82
5.10 Modern methods of applying water (illustrated)	82
5.11 Dams: sections and components (illustrated)	83
5.12 Weirs and barrages	84
5.13 Ill effects of irrigation and their remedies	84
5.14 Irrigation in Odisha (case study)	84
5.15 Common mistakes to avoid in Module V	85
5.16 Solved numericals: Module V	85
5.17 Practice problems with solutions: Module V	86
5.18 MCQs: Module V	87
5.19 More solved numericals: Module V	89
5.20 Short questions with answers: Module V	90
Two-Mark Questions with Answers (University Pattern)	92
Long-Answer Questions with Model Answers	96
Model Question Papers with Answer Keys	101
Quick-Revision Formula Sheet	104



Glossary of Important Terms	106
--	------------



Basic Civil Engineering

Subject: Basic Civil Engineering · Semester 1 (Circuit branch) · 2-0-0 · 2 credits · 30 hours · University 100 + Internal 50

Module I: Introduction, Residential Buildings and Foundations

1.1 Introduction to civil engineering

Civil engineering is the branch of engineering that deals with the planning, design, construction, operation and maintenance of the physical and naturally built environment: buildings, roads, railways, bridges, dams, canals, water supply and sewerage systems, airports and harbours. It is one of the oldest engineering disciplines, originally distinguished from military engineering.

A civil engineer's work typically involves: surveying the site → investigation of soil and materials → planning and design (structural, hydraulic, transportation) → estimation and costing → construction and supervision → operation and maintenance.

1.2 Various disciplines of civil engineering

Discipline	Scope	Examples
Surveying	Measuring and mapping land; setting out works	Plotting sites, contour maps, GPS/total-station surveys
Structural engineering	Analysis and design of load-bearing structures	Buildings, bridges, towers, industrial sheds
Geotechnical engineering	Behaviour of soil and rock; design of foundations	Foundations, retaining walls, slopes, embankments
Construction technology and management	Materials, methods, planning, scheduling and cost control	Project planning (CPM/PERT), quality control
Transportation engineering	Planning and design of roads, railways, airports, ports	Highways, flyovers, traffic signals
Water resources and irrigation engineering	Development and management of water resources	Dams, canals, hydropower, flood control
Environmental engineering	Water supply, wastewater, solid waste, air pollution control	Water treatment plants, sewage treatment
Hydraulics and fluid mechanics	Behaviour of water in pipes and channels	Pipe networks, spillways
Town (urban) planning	Planning land use and infrastructure of cities	Master plans, smart cities
Earthquake engineering	Design of structures to resist earthquakes	Seismic design, retrofitting
Remote sensing and GIS	Collecting and analysing spatial data	Land use mapping, disaster management

1.3 Importance of civil engineering in infrastructure development

Infrastructure is the basic physical system that a society needs to function: transport (roads, railways, airports, ports), water (supply, sanitation, irrigation), energy (dams, power plants, transmission towers), buildings (housing, schools, hospitals), and

communication structures.

- **Economic growth:** good roads, railways and ports reduce transport cost and time, connect farms and factories to markets, and attract investment.
- **Quality of life:** safe drinking water, sanitation, housing and hospitals improve health and living standards.
- **Food security:** irrigation projects increase agricultural production (the Green Revolution depended on canals and tube wells).
- **Energy:** hydroelectric dams and the civil works of thermal and nuclear plants provide electricity.
- **Disaster management:** flood embankments, cyclone shelters, earthquake-resistant buildings save lives (Odisha's cyclone shelters are a notable example).
- **Employment:** construction is one of the largest employers in India.
- **National programmes:** Bharatmala (highways), Sagarmala (ports), Smart Cities Mission, Pradhan Mantri Awas Yojana (housing), Jal Jeevan Mission (tap water), PMGSY (rural roads).

1.4 Interdisciplinary nature of construction projects

A modern construction project involves many disciplines working together:

- **Architects** (planning and aesthetics) and **civil/structural engineers** (stability and safety).
- **Electrical engineers** (power supply, lighting, lifts, fire alarms, solar systems), **mechanical engineers** (HVAC, plumbing pumps, fire-fighting systems), **electronics and computer engineers** (building automation, CCTV, networking, sensors for structural health monitoring).
- **Environmental engineers** (waste management, rainwater harvesting), **geologists** (site investigation), **surveyors, quantity surveyors and project managers** (cost, schedule), **lawyers and planners** (approvals, land acquisition).
- For circuit-branch students: smart buildings, sensor networks, BIM (Building Information Modelling), drones for surveying and IoT-based monitoring of bridges and dams are growing areas where electrical, electronics and computer engineering meet civil engineering.

1.5 Residential buildings: NBC classification of buildings

The **National Building Code of India (NBC) 2016**, published by the Bureau of Indian Standards, classifies buildings by **occupancy** (use):

Group	Occupancy	Examples
A	Residential	Houses, flats, hostels, hotels, lodging houses, dormitories
B	Educational	Schools, colleges, training institutes
C	Institutional	Hospitals, sanatoria, orphanages, jails
D	Assembly	Theatres, cinema halls, auditoriums, stadiums, places of worship, restaurants



Group	Occupancy	Examples
E	Business	Offices, banks, IT parks, laboratories
F	Mercantile	Shops, markets, shopping malls
G	Industrial	Factories, workshops, power plants
H	Storage	Warehouses, cold storage, godowns, garages
J	Hazardous	Buildings storing or handling explosive, highly flammable or toxic materials

Residential buildings (Group A) are further divided: A-1 lodging and rooming houses, A-2 one- or two-family private dwellings, A-3 dormitories, A-4 apartment houses (flats), A-5 hotels, A-6 hotels (starred).

Classification by type of construction (fire resistance): Type 1 (most fire resistant) to Type 4 (least), according to the fire resistance rating of structural elements.

Classification by structure: load-bearing structures (walls carry the loads) and framed structures (RCC or steel columns and beams carry the loads; walls are only partitions).

1.6 Basic components of a building and their requirements

A building can be divided into the **substructure** (below ground level: foundation) and the **superstructure** (above ground: plinth, walls, columns, floors, roof, etc.).

Component	Function	Basic requirements
Foundation	Transfers all loads of the building safely to the soil; provides a level base	Strong enough; settlement within limits; safe against overturning and sliding; protected from moisture
Plinth	Portion between ground level and floor level (usually 45–60 cm high); prevents entry of surface water, insects and dampness	Damp-proof course (DPC) at plinth level; plinth beam in framed buildings; adequate height
Walls	Enclose spaces, carry loads (load-bearing walls), provide privacy, protection from weather, sound and heat insulation	Strength, stability, durability, fire resistance, thermal and sound insulation
Columns	Vertical members carrying loads from beams and slabs to the foundation (framed structures)	Adequate size and reinforcement; slenderness within limits
Beams and lintels	Horizontal members carrying loads over openings or between columns; a lintel spans a door/window opening	Strength in bending and shear; bearing on walls at least 15 cm

Component	Function	Basic requirements
Floors	Provide a level surface for occupants and furniture; divide the building into storeys	Strong, durable, smooth, non-slippery, damp-proof, easy to clean, fire and sound resistant
Roof	Topmost covering protecting the building from rain, sun, wind and snow	Strong, waterproof, well drained (slope), thermally insulated, durable
Doors and windows	Doors give access; windows give light, ventilation and view	Proper size and location; windows at least 10% of floor area (light), 1/6 recommended
Stairs, lifts, ramps	Vertical circulation between floors	Comfortable rise and tread (e.g. 150-175 mm rise, 250-300 mm tread); handrails; fire safety
Sill, parapet, chajja (sunshade)	Sill: base of window opening; parapet: low wall at roof edge for safety; chajja: projection above openings	Proper projection and drainage
Building services	Water supply, drainage, electrical wiring, lighting, fire-fighting, lifts, HVAC	As per NBC and relevant codes
Finishes	Plastering, pointing, flooring, painting	Protect and beautify surfaces

1.7 Planning and design of buildings: fundamental requirements

Principles of planning (building bye-laws apart):

- **Aspect:** arrangement of rooms to get the maximum benefit of sun and breeze (e.g. kitchen facing east for morning sun; bedrooms receiving evening breeze; in hot climates, avoid large west-facing openings).
- **Prospect:** placing doors and windows to give pleasant views outside and hide undesirable views.
- **Privacy:** internal privacy between rooms and external privacy from neighbours and the street (through proper door placement, screens, setbacks).
- **Grouping:** related rooms placed close together (kitchen next to dining; toilet near bedrooms).
- **Roominess:** efficient use of space; proper length-to-width ratio (about 1.2 to 1.5) so rooms feel spacious.
- **Furniture requirements:** rooms sized for the furniture they will contain, with space for movement.
- **Sanitation:** light, ventilation, cleanliness and sanitary facilities.
- **Flexibility:** rooms that can serve more than one purpose.
- **Circulation:** easy movement within the building (horizontal: corridors, passages; vertical: stairs, lifts); circulation space should be minimal but adequate.
- **Elegance and economy:** a pleasing appearance within the available budget.

Building bye-laws (regulations by local authorities): minimum plot size, setbacks (open space on all sides), floor area ratio (FAR/FSI = total built-up area of all floors ÷

plot area), maximum ground coverage, maximum height, minimum room sizes and heights (e.g. habitable room height about 2.75 m), parking, fire safety provisions.

1.8 Selection of site for a residential building

- **Topography and drainage:** site should be elevated, with a gentle slope for natural drainage; avoid low-lying and waterlogged areas.
- **Soil conditions:** firm soil with good bearing capacity; avoid filled-up ground, black cotton (expansive) soil and marshy land (or design special foundations).
- **Groundwater:** water table should be low; good-quality water should be available.
- **Access and facilities:** approach road, water supply, electricity, drainage and sewerage connections; nearness to schools, markets, hospitals, workplace and public transport.
- **Surroundings:** away from industrial pollution, noise, flood-prone areas, and fault zones; pleasant view (prospect).
- **Legal aspects:** clear title, permitted land use as per the master plan, approval of plans.
- **Orientation:** plot allowing proper aspect (sun and wind direction).
- **Cost:** reasonable land and construction cost; availability of materials and labour.

1.9 Introduction to building design: functional and structural

Functional design ensures that the building serves its purpose efficiently and comfortably: proper room sizes and arrangement, circulation, lighting and ventilation, acoustics, thermal comfort, services (water, electricity, drainage), accessibility for disabled persons, and fire safety (exits, staircases).

Structural design ensures that the building is safe, stable and durable under all expected loads with an adequate factor of safety, and that deflections and cracks are within limits. It involves:

- **Estimating loads:** dead load (self-weight of the structure and finishes), live (imposed) load (occupants, furniture; e.g. 2 kN/m² for residential floors as per IS 875 Part 2), wind load (IS 875 Part 3), earthquake load (IS 1893), snow load, and load combinations.
- **Analysis:** finding the forces (bending moment, shear, axial force) in beams, columns, slabs and foundations.
- **Design:** choosing sizes and reinforcement of members to resist these forces, as per IS 456 (plain and reinforced concrete), IS 800 (steel), IS 13920 (ductile detailing for earthquakes).
- **Detailing and drawings.**

Both kinds of design must go together: a building that is safe but inconvenient, or convenient but unsafe, is a failure.

1.10 Foundations: purpose and classification

The **foundation** is the lowest part of a structure that transmits its loads to the underlying soil (or rock) so that the soil is not overstressed and settlements are within permissible limits.

Purposes: distribute the load over a large area to reduce pressure on soil; provide a level surface for construction; prevent unequal (differential) settlement; give stability

against overturning, sliding and uplift; protect against scouring and undermining.

Classification.

- **Shallow foundations** (depth D less than or equal to width B , typically up to about 3 m): load is transferred to soil near the surface.
- **Spread (isolated) footing**: a separate footing under each column (square, rectangular or circular). **Simple wall footing**: a continuous strip under a wall.
- **Stepped footing**: footing widened in steps (brick or stone masonry).
- **Combined footing**: one footing supporting two or more columns (used when columns are close or near a property line). Rectangular or trapezoidal.
- **Strap (cantilever) footing**: two isolated footings connected by a strap beam.
- **Strip (continuous) footing**: a long footing under a wall or a row of columns.
- **Raft (mat) foundation**: a single thick slab covering the whole building area, used when soil bearing capacity is low or loads are heavy, to reduce differential settlement.
- **Grillage foundation**: layers of steel beams (joists) in concrete, for heavy column loads on weak soil.
- **Deep foundations** (D much greater than B): load is transferred to deeper, stronger strata.
- **Pile foundation**: long slender columns (concrete, steel or timber) driven or cast into the ground. **End-bearing piles** transfer load to a hard stratum at the tip; **friction piles** transfer load through skin friction along their length. Used for weak soils, high water table, bridges, tall buildings.
- **Well (caisson) foundation**: large hollow cylinders sunk into the ground; used for bridge piers and in river beds.
- **Pier foundation**: large-diameter cylindrical columns carrying heavy loads to a hard stratum.

Shallow foundation	Deep foundation
Depth $\leq$ width (usually < 3 m)	Depth much larger than width
Load transferred mainly by bearing at the base	Load transferred by end bearing and/or skin friction
Used where good soil exists near the surface	Used where good soil is deep or loads are very heavy
Cheaper, easier to construct	Costlier, needs special equipment
Isolated, combined, strip, raft footings	Piles, wells (caissons), piers

Causes of foundation failure: unequal settlement, shrinkage and swelling of expansive (black cotton) soils, lateral pressure, groundwater movement, weathering, overloading, and poor construction.

1.11 Bearing capacity of soil and related terms (definitions)

- **Gross pressure intensity (q):** total pressure at the base of the footing due to the weight of the superstructure, footing and backfill soil.
- **Net pressure intensity (q_n):** gross pressure minus the overburden pressure (γD_f) that existed at that level before excavation: $q_n = q - \gamma D_f$
- **Ultimate bearing capacity (q_u):** the minimum gross pressure intensity at the base of the foundation at which the soil fails in shear.

- **Net ultimate bearing capacity (q_{nu}):** the minimum net pressure intensity that causes shear failure: $q_{nu} = q_u - \gamma D_f$.
- **Net safe bearing capacity (q_{ns}):** net ultimate bearing capacity divided by a factor of safety (usually 2.5 to 3): $q_{ns} = q_{nu}/F$.
- **Safe bearing capacity (q_s):** the maximum gross pressure the soil can carry safely without shear failure: $q_s = q_{nu}/F + \gamma D_f$.
- **Allowable bearing pressure (q_a):** the maximum pressure the soil can carry without shear failure **and** without exceeding the permissible settlement. It is the smaller of the safe bearing capacity (shear criterion) and the pressure corresponding to permissible settlement.

$$q_{nu} = q_u - \gamma D_f; q_{ns} = q_{nu}/F; q_s = q_{nu}/F + \gamma D_f$$

Required area of footing $A = (\text{column load} + \text{self-weight of footing})/\text{allowable bearing pressure}$

Typical safe bearing capacities (for guidance, IS 1904 / textbooks):

Type of soil or rock	Safe bearing capacity (kN/m ²)
Hard rock (granite, trap)	3300
Soft rock	450
Coarse sand, compact and dry	450
Medium sand	250
Fine sand, loose	100 (or less)
Hard clay / hard shale	450
Medium clay	250
Soft clay	100
Black cotton soil (dry)	130-160
Very soft clay, peat, made-up ground	to be tested (often below 50)

Methods of determining bearing capacity: plate load test (field), standard penetration test (SPT), analytical methods (Terzaghi's bearing capacity equation), and presumptive values from codes (for small buildings).

Methods of improving bearing capacity: increasing the depth of foundation, compacting the soil, draining the soil, confining the soil (sheet piles), replacing poor soil with good material, grouting or chemical stabilisation, using geosynthetics.

1.12 Illustrated overview of Module I

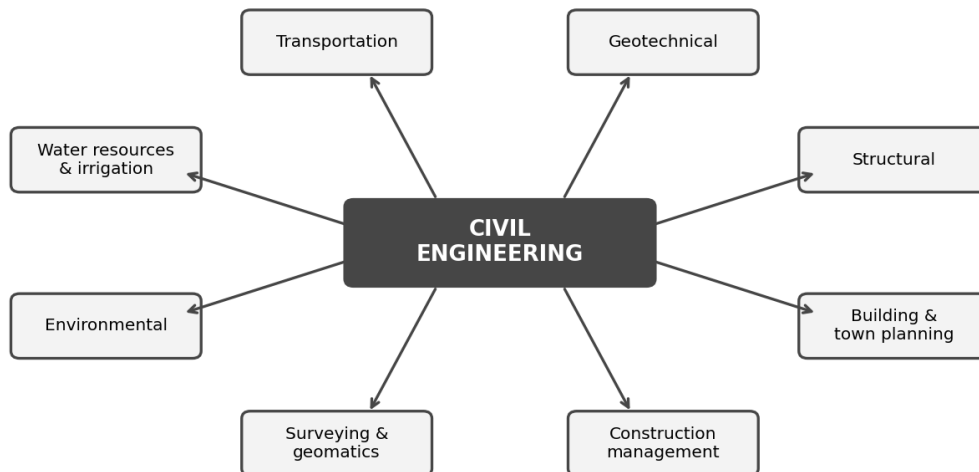


Figure 1.1: The main disciplines of civil engineering. Almost every project (a housing colony, a highway, a dam) draws on several of them together.

Civil engineering is the oldest branch of engineering after military engineering. It deals with the planning, design, construction, operation and maintenance of the **built environment**: buildings, roads, railways, bridges, dams, canals, water supply, sewerage and ports. The figure shows how the branches are related; a civil engineer must know enough of each to work in a team.

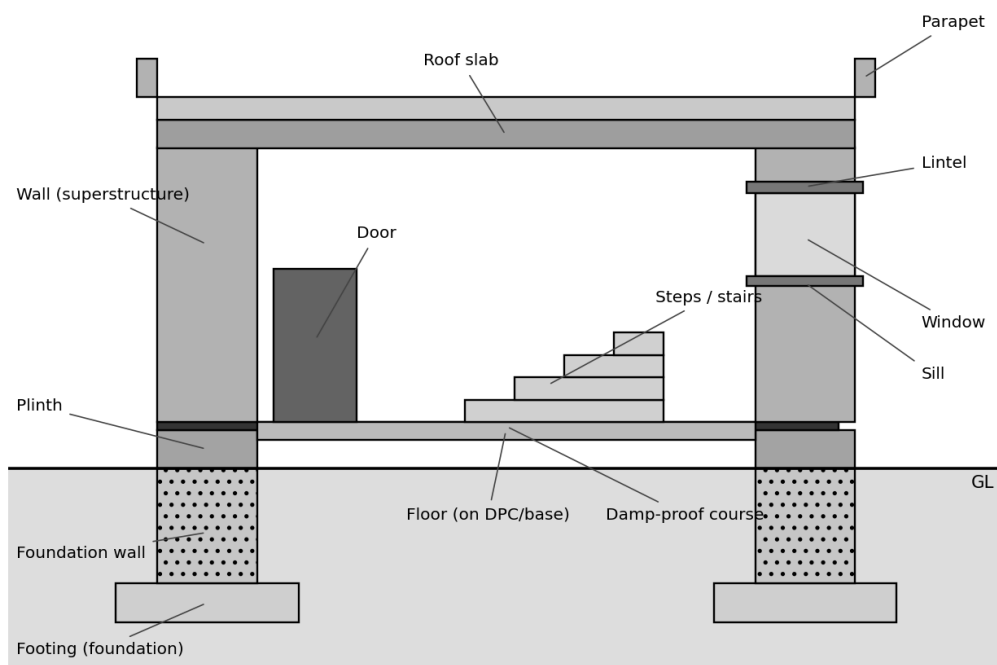


Figure 1.2: Cross-section of a load-bearing residential building showing the substructure (below plinth) and the superstructure (above plinth).

Reading the figure (from the bottom up):

- **Foundation (footing):** the lowest part, which spreads the load over a larger area of soil so that the pressure is within the safe bearing capacity.

- **Plinth:** the portion between ground level (GL) and the floor level; its height is usually 450–600 mm. It keeps surface water and dampness out of the building.
- **Damp-proof course (DPC):** a 40–50 mm layer of rich cement concrete (1:1.5:3) with waterproofing compound, or bitumen, laid at plinth level to stop moisture rising into the walls.
- **Walls:** divide space, carry loads (in load-bearing construction) and give privacy, weather protection, and sound and heat insulation.
- **Doors and windows:** give access, light and ventilation. Window area should be at least 1/10 to 1/6 of the floor area.
- **Lintel:** a beam over an opening that carries the masonry above it. **Sill:** the bottom horizontal member of a window frame, usually 0.9–1.0 m above the floor.
- **Stairs:** give access between floors; comfortable rise 150–175 mm, tread 250–300 mm.
- **Roof and parapet:** the roof protects from rain, sun and wind; a parapet (about 1 m high) gives safety on a flat roof.

1.13 Loads acting on a building

A building must be designed for all loads it may experience during its life. The Indian Standard IS 875 (Parts 1–5) gives their values.

Load	Description	Typical value / source
Dead load (DL)	Self-weight of permanent parts: walls, floors, roof, finishes	RCC 25 kN/m ³ , brick masonry 19–20 kN/m ³ (IS 875 Part 1)
Live (imposed) load (LL)	Movable loads: people, furniture, stored goods	Residential floors 2 kN/m ² ; offices 2.5–4 kN/m ² ; accessible roof 1.5 kN/m ² (IS 875 Part 2)
Wind load	Pressure of wind on walls and roof; important for tall and light structures	Depends on basic wind speed of the zone (IS 875 Part 3)
Snow load	Weight of snow on roofs in hilly areas	IS 875 Part 4
Earthquake (seismic) load	Inertia forces from ground shaking	IS 1893; India has four seismic zones (II to V)
Special loads	Temperature, shrinkage, settlement, impact, vibration	IS 875 Part 5

Load combinations: members are designed for the worst combination, for example 1.5(DL + LL) or 1.2(DL + LL + WL/EL) in limit state design.

1.14 Building bye-laws and regulations

Building bye-laws are rules framed by local bodies (municipalities, development authorities) based on the National Building Code (NBC 2016) to ensure orderly growth, safety and health.

- **Plot area and ground coverage:** the maximum percentage of the plot that may be covered by the building (e.g. 60–65% for small residential plots).
- **Floor area ratio (FAR) or floor space index (FSI):** FAR = total covered area of all floors ÷ plot area. It controls the density of development.
- **Setbacks (open spaces):** minimum distances from the building to the plot boundaries on the front, rear and sides, for light, ventilation, fire safety and future road widening.

- **Height of building:** limited by road width, FAR, airport zones and fire-fighting capability.
- **Minimum sizes of rooms:** habitable room at least 9.5 m² with a minimum width of 2.4 m; kitchen 4.5 m²; bathroom 1.8 m²; minimum ceiling height 2.75 m.
- **Lighting and ventilation:** window area at least 1/10 of floor area; no part of a room more than 7.5 m from an opening.
- **Parking, fire safety, rainwater harvesting and access for the disabled** are also required for larger buildings.

1.15 Orientation of buildings

Orientation means placing the building and its rooms on the site so as to make the best use of sun, wind and view.

- In the hot-humid climate of Odisha, the longer walls should face **north and south** to reduce direct sun on the east and west faces.
- Living rooms and bedrooms should catch the prevailing breeze (south-west monsoon wind).
- The kitchen is preferably on the east side to get morning sun; stores and staircases can be on the west as a heat buffer.
- Verandahs, sunshades (chajjas) and trees reduce heat gain.
- Good orientation reduces the need for artificial lighting and cooling, and saves energy.

1.16 Foundations and bearing capacity (illustrated)

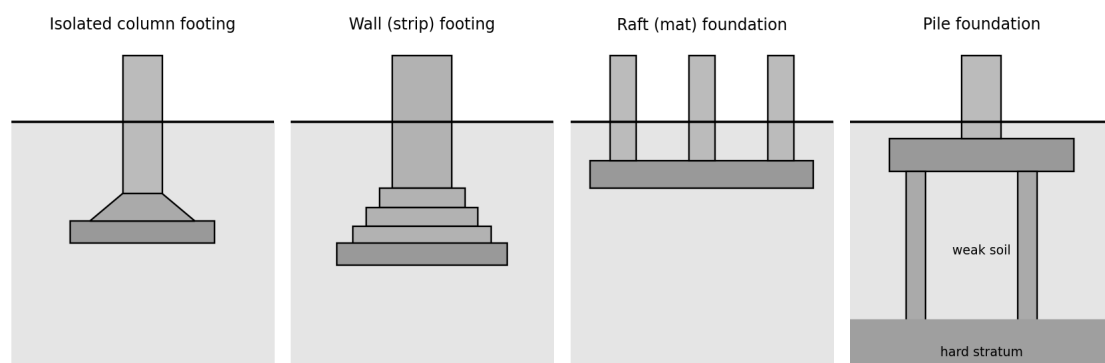


Figure 1.3: Common types of foundation. The first three are shallow foundations ($\text{depth} \leq \text{width}$); the pile foundation is a deep foundation.

How to read Figure 1.3: the isolated footing spreads one column load over a square pad; the stepped wall footing widens a wall gradually (each offset about half a brick) so that the load spreads at about 45°; the raft joins all columns on one slab so that the whole plan area carries the load; piles carry the load through weak soil down to a hard stratum (end bearing) or by friction along their surface.

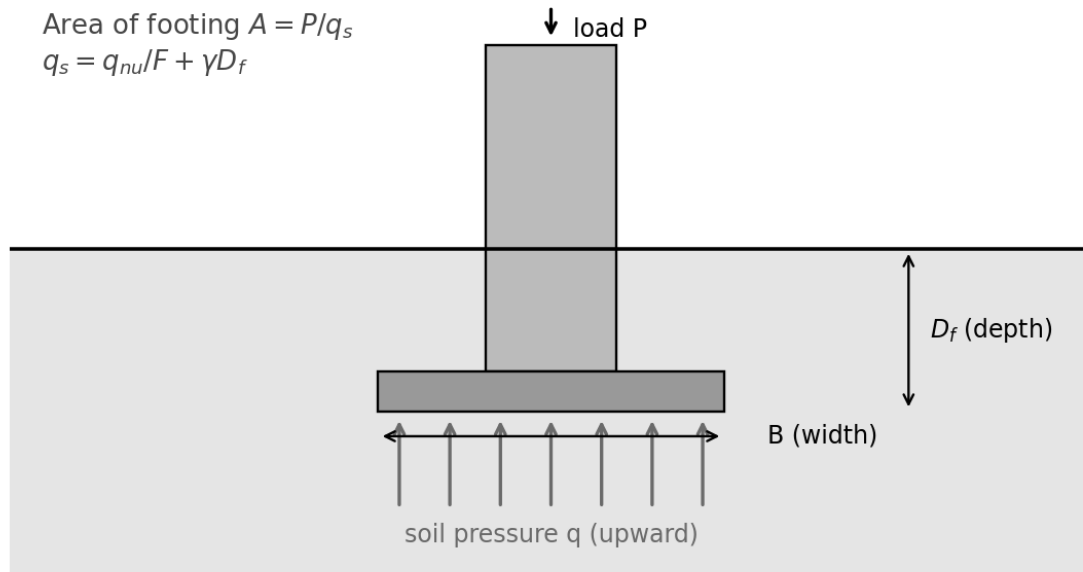


Figure 1.4: A column footing of width B at depth D_f . The soil must resist the load P with a pressure q no greater than the safe bearing capacity.

Design procedure for a simple footing:

- Find the column or wall load P and add the self-weight of the footing (about 10% of P).
- Find the safe bearing capacity q_s of the soil from tests or tables (Section 1.11).
- Required area $A = 1.1P/q_s$; choose the dimensions (square for columns, strip for walls).
- Check that the actual pressure P/A does not exceed q_s , and that settlement is within limits (25 mm for isolated footings on sand, 40–65 mm for rafts).
- Provide a minimum depth of foundation (about 0.9–1.0 m below ground) to reach firm soil, avoid seasonal moisture changes and give lateral stability. Rankine's formula gives $D_{min} = (q/\gamma)[(1 - \sin \phi)/(1 + \sin \phi)]^2$.

1.17 Common mistakes to avoid in Module I

- Confusing safe bearing capacity (adds γD_f) with net safe bearing capacity.
- Writing that a raft is a deep foundation. It is a shallow foundation.
- Listing the NBC groups incorrectly: there is no Group I; the groups are A to H and J.
- Mixing up aspect (sun and wind) and prospect (view).

1.18 Solved numericals: Module I

Problem 1. The net ultimate bearing capacity of a soil is 750 kN/m². The foundation is at a depth of 1.5 m and the unit weight of soil is 18 kN/m³. Find the net safe and safe bearing capacity with a factor of safety of 3.

$$q_{ns} = q_{nu}/F = 750/3 = 250 \text{ kN/m}^2.$$

$$q_s = q_{ns} + \gamma D_f = 250 + 18 \times 1.5 = 250 + 27 = 277 \text{ kN/m}^2.$$

Answer: Net safe bearing capacity = 250 kN/m²; safe bearing capacity = 277 kN/m².

Problem 2. The ultimate bearing capacity of a soil is 900 kN/m² for a footing at 2 m depth ($\gamma = 19 \text{ kN/m}^3$). Find the net ultimate and safe bearing capacity ($F = 2.5$).

$$q_{\text{nu}} = 900 - 19 \times 2 = 862 \text{ kN/m}^2.$$

$$q_s = 862/2.5 + 38 = 344.8 + 38 = 382.8 \text{ kN/m}^2.$$

Answer: $q_{\text{nu}} = 862 \text{ kN/m}^2$; $q_s \approx 383 \text{ kN/m}^2$.

Problem 3. A column carries a load of 800 kN. The allowable bearing pressure of the soil is 200 kN/m². Assuming the self-weight of the footing to be 10% of the column load, find the size of a square footing.

$$\text{Total load} = 800 + 80 = 880 \text{ kN. Area} = 880/200 = 4.4 \text{ m}^2.$$

$$\text{Side} = \sqrt{4.4} = 2.10 \text{ m.}$$

Answer: Provide a 2.1 m $\times$ 2.1 m square footing.

Problem 4. A 230 mm thick wall carries a load of 150 kN per metre run. If the safe bearing capacity is 120 kN/m², find the width of the strip footing (self-weight 10%).

$$\text{Load per metre} = 150 \times 1.1 = 165 \text{ kN. Width} = 165/(120 \times 1) = 1.375 \text{ m.}$$

Answer: Width $\approx$ 1.4 m.

Problem 5. Two columns carrying 500 kN and 700 kN are 3 m apart. Design (find the size of) a rectangular combined footing for a soil with allowable pressure 150 kN/m², such that the pressure is uniform. Ignore self-weight.

$$\text{Area} = 1200/150 = 8 \text{ m}^2. \text{ For uniform pressure, the centroid of the footing must coincide with the resultant of loads.}$$

$$\text{Resultant from the 500 kN column: } \bar{x} = 700 \times 3/1200 = 1.75 \text{ m.}$$

$$\text{If the footing projects equally for symmetry about the resultant with length } L = 2 \times (1.75 + 0.5) = 4.5 \text{ m (0.5 m projection beyond the lighter column), width } B = 8/4.5 = 1.78 \text{ m.}$$

Answer: Footing about 4.5 m $\times$ 1.8 m, with the resultant at its centre (projection of 0.5 m beyond the 500 kN column and 1.0 m beyond the 700 kN column).

Problem 6. A plot of 20 m $\times$ 15 m allows a floor area ratio (FAR) of 1.5 and a maximum ground coverage of 60%. Find the maximum built-up area and the minimum number of storeys needed to use the full FAR.

$$\text{Plot area} = 300 \text{ m}^2. \text{ Maximum total floor area} = 1.5 \times 300 = 450 \text{ m}^2. \text{ Maximum ground floor area} = 0.6 \times 300 = 180 \text{ m}^2.$$

$$\text{Storeys} = 450/180 = 2.5 \Rightarrow 3 \text{ storeys (ground + 2).}$$

Answer: 450 m² total; at least 3 storeys (G + 2) to use the full FAR.



Problem 7. A staircase must rise 3.0 m from floor to floor. If the rise is limited to 150 mm and the tread is 250 mm, find the number of risers, treads and the horizontal going.

Risers = $3000/150 = 20$. Treads = 19 (one less than risers in a straight flight).

Going = $19 \times 250 = 4750$ mm (usually split into two flights with a landing).

Answer: 20 risers, 19 treads, total going 4.75 m.

Problem 8. A room of 4 m × 5 m needs window area of at least 1/6 of the floor area. Find the minimum window area.

Floor area = 20 m²; window area = 20/6.

Answer: 3.33 m² (e.g. two windows of 1.2 m × 1.4 m = 3.36 m²).

1.19 Practice problems with solutions: Module I

Q1. A footing at 1 m depth in soil of $\gamma = 20$ kN/m³ has a safe bearing capacity of 220 kN/m². Find the net safe bearing capacity.

$$q_{ns} = q_s - \gamma D_f = 220 - 20.$$

Answer: 200 kN/m².

Q2. A column load of 1200 kN rests on soil with allowable pressure 300 kN/m². Find the side of a square footing (ignore self-weight).

Area = 4 m²; side = 2 m.

Answer: 2 m × 2 m.

Q3. Which foundation would you choose for (a) a multistorey building on soft clay, (b) a bridge pier in a river, (c) a single-storey house on firm soil?

(a) Raft or pile foundation; (b) well (caisson) or pile foundation; (c) strip/isolated spread footing.

Answer: As stated.

Q4. A building has 4 floors of 150 m² each on a 400 m² plot. Find the FAR.

$$\text{FAR} = 600/400.$$

Answer: 1.5.

1.20 MCQs: Module I

1. The branch dealing with foundations and soil behaviour is

- (a) environmental (b) structural (c) transportation (d) geotechnical
☐ (d) — Soil mechanics.

2. The NBC classifies a hospital under Group

- (a) C (b) E (c) A (d) D
☐ (a) — Institutional.

3. Schools and colleges belong to NBC Group

- (a) C (b) A (c) B (d) F
☐ (c) — Educational.



- 4. Shopping malls belong to NBC Group**
(a) G (b) F (c) E (d) D
☐ (b) — Mercantile.
- 5. Houses and flats belong to NBC Group**
(a) G (b) H (c) B (d) A
☐ (d) — Residential.
- 6. Warehouses are classified under NBC Group**
(a) F (b) H (c) G (d) J
☐ (b) — Storage.
- 7. The portion of a building below ground level is called**
(a) substructure (b) parapet (c) plinth (d) superstructure
☐ (a) — Foundation.
- 8. The damp-proof course is provided at**
(a) lintel level (b) plinth level (c) roof level (d) sill level
☐ (b) — Prevents rising damp.
- 9. A lintel is provided**
(a) at the roof (b) below a window (c) in the foundation (d) over a door or window opening
☐ (d) — Spans the opening.
- 10. A parapet is**
(a) a low wall at the edge of a roof (b) a floor finish (c) a window part (d) a type of foundation
☐ (a) — Safety barrier.
- 11. Arrangement of rooms to take advantage of sun and wind is**
(a) privacy (b) prospect (c) aspect (d) grouping
☐ (c) — Aspect.
- 12. Arrangement of openings to get a good view is called**
(a) prospect (b) circulation (c) aspect (d) roominess
☐ (a) — Prospect.
- 13. FAR (floor area ratio) is**
(a) plot area/built-up area (b) total floor area/plot area (c) ground coverage/plot area (d) height/width
☐ (b) — Also called FSI.
- 14. Which is a deep foundation?**
(a) isolated footing (b) strip footing (c) pile (d) raft
☐ (c) — Transfers load to depth.
- 15. A raft foundation is used when**
(a) soil bearing capacity is low and loads are heavy (b) the building is very light (c) rock is at the surface (d) soil is very strong
☐ (a) — Spreads load over whole area.
- 16. A combined footing supports**
(a) only walls (b) one column (c) a chimney only (d) two or more columns
☐ (d) — Close columns.
- 17. Piles that transfer load mainly through skin friction are**
(a) end-bearing piles (b) sheet piles (c) friction piles (d) batter piles
☐ (c) — Along the length.



- 18.** Well foundations are commonly used for
(a) houses (b) roads (c) bridge piers in rivers (d) boundary walls
☐ (c) — Deep, massive.
- 19.** The minimum pressure at which soil fails in shear is the
(a) net safe bearing capacity (b) ultimate bearing capacity (c) safe bearing capacity (d) allowable bearing pressure
☐ (b) — Definition.
- 20.** Net ultimate bearing capacity equals
(a) $q_u - \gamma D_f$ (b) q_u/F (c) $q_u + \gamma D_f$ (d) $q_u \times F$
☐ (a) — Remove overburden.
- 21.** Safe bearing capacity equals
(a) q_{nu}/F (b) $q_u \times F$ (c) $q_u - \gamma D_f$ (d) $q_{nu}/F + \gamma D_f$
☐ (d) — Gross safe pressure.
- 22.** The usual factor of safety for bearing capacity is
(a) 1 (b) 0.5 (c) 2.5–3 (d) 10
☐ (c) — Standard practice.
- 23.** Allowable bearing pressure considers
(a) shear failure and settlement (b) only settlement (c) only shear failure (d) only groundwater
☐ (a) — Both criteria.
- 24.** The field test for bearing capacity is
(a) slump test (b) plate load test (c) Vicat test (d) Los Angeles test
☐ (b) — Load on a steel plate.
- 25.** Black cotton soil is problematic because it
(a) is rocky (b) is too strong (c) is non-cohesive (d) swells and shrinks with moisture
☐ (d) — Expansive clay.
- 26.** The live load on residential floors (IS 875) is about
(a) 2 kN/m² (b) 25 kN/m² (c) 0.5 kN/m² (d) 10 kN/m²
☐ (a) — Imposed load.
- 27.** The code for plain and reinforced concrete in India is
(a) IS 800 (b) IS 1893 (c) IS 456 (d) IS 875
☐ (c) — Concrete code.
- 28.** The code for earthquake-resistant design is
(a) IS 456 (b) IS 800 (c) IS 10500 (d) IS 1893
☐ (d) — Seismic loads.
- 29.** The height of the plinth above ground is usually
(a) 45–60 cm (b) 5–10 cm (c) 2 m (d) 3 m
☐ (a) — Keeps out water.
- 30.** A good site for a house should have
(a) nearness to factories (b) filled-up ground (c) a high water table (d) firm soil and good drainage
☐ (d) — Site selection.
- 31.** Structural design mainly ensures
(a) safety and stability (b) cheapest cost only (c) aesthetics (d) colour scheme
☐ (a) — Strength and stability.



32. Functional design mainly deals with

- (a) load calculation (b) reinforcement (c) foundation depth (d) efficient use of space, circulation, lighting and ventilation

☐ (d) — Serving the purpose.

33. The self-weight of a structure is called

- (a) live load (b) snow load (c) dead load (d) wind load

☐ (c) — Permanent load.

34. In a framed structure, loads are carried by

- (a) the plinth only (b) windows (c) columns and beams (d) walls

☐ (c) — Walls are partitions.

35. Setbacks in building bye-laws refer to

- (a) depth of foundation (b) floor height (c) height of building (d) open spaces left around the building

☐ (d) — Light, air, fire safety.

1.21 More solved numericals: Module I

Problem 1. A residential floor slab 150 mm thick is made of RCC (25 kN/m^3) with a 50 mm floor finish (24 kN/m^3). The live load is 2 kN/m^2 . Find the total load per m^2 and the factored load (factor 1.5).

Slab self-weight = $0.15 \times 25 = 3.75 \text{ kN/m}^2$. Floor finish = $0.05 \times 24 = 1.2 \text{ kN/m}^2$.

Dead load = 4.95 kN/m^2 ; total with live load = $4.95 + 2 = 6.95 \text{ kN/m}^2$.

Factored load = $1.5 \times 6.95 = 10.43 \text{ kN/m}^2$.

Answer: 6.95 kN/m^2 (service); 10.4 kN/m^2 (factored).

Problem 2. A 230 mm brick wall (unit weight 20 kN/m^3) is 3 m high. Find its dead load per metre run.

Load = thickness $\times$ height $\times$ unit weight = $0.23 \times 3 \times 20$.

Answer: 13.8 kN/m .

Problem 3. A plot is $12 \text{ m} \times 18 \text{ m}$. Bye-laws require setbacks of 3 m in front, 1.5 m at the rear and 1 m on each side. Find the maximum ground coverage area and check it against a 60% limit.

Buildable length = $18 - 3 - 1.5 = 13.5 \text{ m}$; buildable width = $12 - 1 - 1 = 10 \text{ m}$.

Area within setbacks = 135 m^2 . Plot area = 216 m^2 ; $60\% = 129.6 \text{ m}^2$.

Answer: Setbacks allow 135 m^2 , but coverage is limited to 129.6 m^2 (the smaller value governs).

Problem 4. A building has a ground floor of 150 m^2 and a first floor of 140 m^2 on a 250 m^2 plot. Find the FAR and the ground coverage.

FAR = $(150 + 140)/250 = 1.16$. Ground coverage = $150/250 = 60\%$.

Answer: FAR = 1.16; ground coverage 60%.

Problem 5. A square footing $2.5 \text{ m} \times 2.5 \text{ m}$ carries a column load of 1000 kN. Find the soil pressure. Is it safe if the safe bearing capacity is 150 kN/m^2 ?

Pressure $q = P/A = 1000/6.25 = 160 \text{ kN/m}^2$.

Answer: $160 \text{ kN/m}^2 > 150 \text{ kN/m}^2$: not safe; increase the size to at least $\sqrt{(1000/150)} = 2.59 \text{ m}$, say $2.6 \text{ m} \times 2.6 \text{ m}$.

Problem 6. A strip footing 1.2 m wide carries 180 kN/m. Find the pressure on the soil and the factor of safety if the ultimate bearing capacity is 450 kN/m^2 .

$q = 180/(1.2 \times 1) = 150 \text{ kN/m}^2$. $F = 450/150$.

Answer: $q = 150 \text{ kN/m}^2$; factor of safety = 3.

Problem 7. The ultimate bearing capacity from a plate load test is 600 kN/m^2 . For a foundation at 1.2 m depth in soil of $\gamma = 18 \text{ kN/m}^3$ and $F = 3$, find the safe bearing capacity.

$q_{nu} = 600 - 18 \times 1.2 = 578.4 \text{ kN/m}^2$. $q_{ns} = 578.4/3 = 192.8 \text{ kN/m}^2$.

$q_s = 192.8 + 21.6 = 214.4 \text{ kN/m}^2$.

Answer: About 214 kN/m^2 .

Problem 8. A room $5 \text{ m} \times 4 \text{ m}$ with a ceiling height of 3 m must have windows equal to $1/8$ of the floor area. How many $1.2 \text{ m} \times 1.2 \text{ m}$ windows are needed?

Floor area = 20 m^2 ; window area = $20/8 = 2.5 \text{ m}^2$. One window = 1.44 m^2 .

Answer: $2.5/1.44 = 1.74 \Rightarrow 2$ windows.

Problem 9. A staircase rises 3.3 m. Using the rule $2R + T = 600 \text{ mm}$ with $R = 165 \text{ mm}$, find the tread and the number of steps.

Risers = $3300/165 = 20$. $T = 600 - 2 \times 165 = 270 \text{ mm}$. Treads = 19.

Answer: 20 risers of 165 mm and 19 treads of 270 mm.

Problem 10. A residential building of 4 floors each 120 m^2 is to be built. If the cost of construction is ₹ 18,000 per m^2 of floor area, estimate the cost of construction.

Total floor area = $4 \times 120 = 480 \text{ m}^2$. Cost = $480 \times 18,000$.

Answer: ₹ 86.4 lakh.

Problem 11. Soil at a site has a safe bearing capacity of 100 kN/m^2 . A load-bearing wall carries 80 kN/m . What width of strip footing is needed, including 10% self-weight? Suggest an alternative if the width is too large.

Load = 88 kN/m ; $B = 88/100 = 0.88 \text{ m}$, say 0.9 m .

Answer: 0.9 m wide strip footing (for heavier loads on this soft soil a raft or piles would be considered).

Problem 12. Four columns each carrying 600 kN are placed on a raft $8 \text{ m} \times 8 \text{ m}$. Find the average pressure on the soil.

$q = 4 \times 600/64 = 2400/64$.



Answer: 37.5 kN/m² (very low, which is why rafts suit weak soils).

1.22 Short questions with answers: Module I

Q1. What is the difference between a plinth and a DPC?

The plinth is the part of the building between ground level and floor level. The DPC is a thin waterproof layer laid at plinth level to stop rising damp.

Q2. Why is a raft foundation preferred on soft soils?

It spreads the load over the whole plan area, so the pressure is small, and it reduces differential settlement.

Q3. What is FAR?

Floor area ratio = total built-up area of all floors ÷ plot area. It controls the density of construction.

Q4. Distinguish between dead load and live load.

Dead load is the permanent self-weight of the structure (walls, slabs, finishes). Live load is the movable load of people, furniture and goods (2 kN/m² for residential floors).

Q5. Define safe bearing capacity.

The maximum pressure that the soil can carry safely without risk of shear failure and excessive settlement: $q_s = q_{nu}/F + \gamma D_f$

Q6. What is meant by prospect in building planning?

Prospect is the arrangement of doors and windows to give a pleasant view outside while hiding undesirable views.

Q7. Name two methods to find the bearing capacity of soil in the field.

Plate load test and standard penetration test.

Q8. What is a combined footing and when is it used?

A single footing supporting two or more columns; used when columns are close or an outer column is at the property line.

Module II: Construction Materials

2.1 Fundamental properties of construction materials

Physical properties.

- **Bulk density:** mass per unit volume of the material in its natural state (including pores), kg/m^3 .
- **Specific gravity:** ratio of the density of the material to that of water.
- **Porosity:** ratio of the volume of pores to the total volume, as a percentage. High porosity reduces strength and durability.
- **Water absorption:** increase in mass after immersion in water, as a percentage of dry mass. Low absorption is desirable (bricks $\leq 20\%$, good stones $\leq 5\%$).
- **Weathering resistance:** ability to withstand alternate wetting and drying, freezing and thawing.
- **Permeability:** ability to allow water to pass through.
- **Fire resistance:** ability to withstand high temperatures without losing strength or shape.
- **Thermal conductivity and thermal capacity; acoustic properties** (sound absorption).

Mechanical properties.

- **Strength:** ability to resist loads without failure: compressive, tensile, shear and flexural strength (N/mm^2).
- **Elasticity:** ability to regain the original shape after removal of load. **Plasticity:** permanent deformation without cracking.
- **Ductility:** ability to be drawn into wires or elongate significantly before failure (mild steel). **Brittleness:** failure without significant deformation (cast iron, glass, concrete in tension).
- **Hardness:** resistance to scratching and wear. **Toughness:** ability to absorb energy before fracture (impact resistance).
- **Stiffness:** resistance to deformation (measured by modulus of elasticity E).
- **Fatigue:** failure under repeated loading below the static strength. **Creep:** slow deformation under sustained load.

Durability properties. Resistance to chemical attack (sulphates, chlorides, acids), corrosion (steel), abrasion, biological attack (termites, fungi on timber), and weathering. Durable materials give a long service life with low maintenance.

Specific gravity $G = \text{density of material} / \text{density of water}$; porosity $n = \text{volume of voids} / \text{total volume} \times 100$

Water absorption (%) = $(\text{wet mass} - \text{dry mass}) / \text{dry mass} \times 100$

2.2 Stone

Classification.

- **Geological:** igneous (formed by cooling of magma: granite, basalt/trap), sedimentary (formed by deposition: sandstone, limestone, shale), metamorphic (formed by heat and pressure on existing rocks: marble from limestone, slate from shale, quartzite from sandstone, gneiss from granite).

- **Physical (structure):** stratified (layered: sandstone, slate), unstratified (massive: granite, marble), foliated (split in one direction: slate).
- **Chemical:** siliceous (silica: granite, quartzite), argillaceous (clay: slate, laterite), calcareous (lime: limestone, marble).

Qualities of good building stone: high crushing strength ($> 100 \text{ N/mm}^2$), low water absorption ($< 5\%$), durability, hardness and toughness, fine uniform texture, resistance to fire, good appearance, easy dressing, availability at low cost, specific gravity > 2.7 .

Uses: masonry for foundations, walls, retaining walls and dams; flooring and cladding (marble, granite, Kota stone); aggregate for concrete and road construction (crushed stone); railway ballast; roofing (slate); lime manufacture (limestone). Laterite blocks are common in Odisha for walls.

2.3 Bricks

Composition of good brick earth: silica (50–60%, gives shape and prevents cracking), alumina (20–30%, gives plasticity), lime (up to 5%, reduces shrinkage), iron oxide (5–6%, gives red colour and strength), magnesia ($< 1\%$). Harmful ingredients: excess lime, iron pyrites, alkalis (cause efflorescence), pebbles, organic matter.

Manufacture: preparation of clay (unsoiling, digging, weathering, blending, tempering) → moulding (hand or machine) → drying → burning (clamps or kilns, at about $900\text{--}1100^\circ\text{C}$) → sorting.

Standard (modular) size (IS 1077): $190 \times 90 \times 90 \text{ mm}$ (actual); with 10 mm mortar joints, the nominal size is $200 \times 100 \times 100 \text{ mm}$. Traditional size: $230 \times 115 \times 75 \text{ mm}$. Weight about 3–3.5 kg.

Qualities of good bricks: uniform copper-red colour, well burnt; regular shape with sharp edges; metallic ringing sound when struck; no marks when scratched with a fingernail; water absorption not more than 20% of dry weight after 24 h immersion; minimum compressive strength 3.5 N/mm^2 (common bricks), higher for first-class bricks; should not break when dropped from 1 m on hard ground; no efflorescence (white salt deposits).

Classification. First class (well burnt, uniform, table-moulded; for exposed and important work), second class (slightly irregular, for hidden work), third class (under-burnt, for temporary structures), fourth class (over-burnt, jhama bricks, used as aggregate). IS classes by compressive strength: e.g. class designations 3.5, 5, 7.5, 10, 12.5 ... 35 (N/mm^2).

Other bricks: fly-ash bricks (fly ash + lime/cement + sand; eco-friendly, uniform, now widely used), fire bricks (refractory, for furnaces and chimneys), hollow bricks and blocks (lighter, thermal insulation), concrete blocks, AAC (autoclaved aerated concrete) blocks.

Uses: walls, piers, arches, pavements; brick aggregate (brickbats) in lime concrete; surkhi (powdered brick) in mortar.

2.4 Cement

Portland cement is a fine grey powder obtained by burning a mixture of calcareous (limestone) and argillaceous (clay) materials at about 1450°C to form **clinker**, and grinding the clinker with 3–5% **gypsum** (which controls the setting time).

Main compounds (Bogue's compounds):

Compound	Formula (short form)	Approx. %	Role
Tricalcium silicate	C_3S	40-50	Early strength (first 7 days); heat of hydration
Dicalcium silicate	C_2S	20-30	Later strength (after 7 days); low heat
Tricalcium aluminate	C_3A	5-11	Flash set; highest heat; poor sulphate resistance
Tetracalcium aluminoferrite	C_4AF	8-14	Little strength; gives colour

Oxide composition: lime CaO (60-67%), silica SiO_2 (17-25%), alumina Al_2O_3 (3-8%), iron oxide Fe_2O_3 (0.5-6%), with small amounts of MgO , SO_3 and alkalis.

Hydration: when mixed with water, cement compounds react to form calcium silicate hydrate (C-S-H gel, the main binder) and calcium hydroxide, releasing heat.

Setting and hardening. Initial setting time (paste begins to lose plasticity): not less than **30 minutes** for OPC. Final setting time (paste becomes hard): not more than **600 minutes (10 h)**. Measured with the **Vicat apparatus**.

Grades of OPC: 33, 43 and 53 (the 28-day compressive strength in N/mm^2 of standard cement mortar cubes).

Types of cement: ordinary Portland cement (OPC), Portland pozzolana cement (PPC, with fly ash; lower heat, better durability), Portland slag cement (PSC), rapid-hardening cement (high early strength), low-heat cement (dams), sulphate-resisting cement (foundations in sulphate soils, marine works), white cement (decorative), quick-setting cement (underwater work), high-alumina cement.

Tests on cement: fineness (sieve or Blaine air permeability), consistency (Vicat), initial and final setting time (Vicat), soundness (Le Chatelier apparatus, expansion ≤ 10 mm for OPC), compressive strength (mortar cubes at 3, 7, 28 days), heat of hydration.

Field tests: colour uniformly greenish grey; feels smooth and cool when rubbed; a handful thrown in water should float for some time before sinking; no lumps.

Storage: in a dry, damp-proof shed on raised wooden platforms, stacked not more than 10 bags high, away from walls; use within about 3 months (strength drops with age).

Uses: mortar, concrete (plain, reinforced and prestressed), plastering, precast products (pipes, blocks, poles), grouting, foundations, dams, roads.

2.5 Aggregates

Aggregates are inert granular materials (sand, gravel, crushed stone) that form about 70-80% of the volume of concrete.

- **Fine aggregate:** particles passing the 4.75 mm IS sieve (natural river sand, manufactured/crushed sand, M-sand). Zones I to IV by grading (Zone I coarsest).
- **Coarse aggregate:** particles retained on the 4.75 mm sieve (crushed stone, gravel); common maximum sizes 10, 20, 40 mm.

Requirements: clean, hard, strong, durable, free from clay, silt, organic matter and salts; well graded (a range of sizes to reduce voids); angular aggregates give better bond, rounded ones give better workability.

Bulking of sand: moist sand occupies more volume than dry sand (bulking up to 20–40% at 4–6% moisture); allowance must be made in volume batching.

Tests: sieve analysis (fineness modulus), specific gravity and water absorption, bulk density, crushing value, impact value, abrasion value (Los Angeles), flakiness and elongation index, silt content.

2.6 Mortar

Mortar is a paste of a binding material (cement or lime), fine aggregate (sand) and water, used to bind masonry units and for plastering and pointing.

- **Functions:** bind bricks/stones together, distribute loads uniformly, fill joints and make them waterproof, provide a smooth surface (plaster).
- **Types by binder:** cement mortar, lime mortar, cement-lime (gauged) mortar, mud mortar, surkhi mortar.
- **Typical cement mortar proportions (cement : sand):** 1:3 (waterproof work, pointing), 1:4 (external plaster, important masonry), 1:5 or 1:6 (ordinary brick masonry and internal plaster).
- **Properties of good mortar:** good workability, adequate strength, water retentivity, durability, good adhesion, quick setting for construction speed, low shrinkage.

2.7 Concrete

Concrete is a mixture of cement, fine aggregate, coarse aggregate and water (and sometimes admixtures) that hardens into a stone-like mass by the hydration of cement.

- **Plain cement concrete (PCC):** strong in compression, weak in tension (tensile strength is only about 10% of compressive strength). Used for levelling courses, flooring bases, mass concrete.
- **Reinforced cement concrete (RCC):** steel bars embedded to resist tension. Steel and concrete work together because they bond well and have nearly equal coefficients of thermal expansion, and concrete protects steel from corrosion (cover). Used for beams, slabs, columns, footings.
- **Prestressed concrete (PSC):** high-strength steel tendons are tensioned to put the concrete in compression before loading; allows long spans (bridges, railway sleepers).

Grades of concrete (IS 456): M10, M15, M20, M25 ... M80, where M stands for mix and the number is the characteristic 28-day compressive strength of 150 mm cubes in N/mm². **M20 is the minimum grade for RCC** (moderate exposure). Nominal mix proportions (cement : sand : coarse aggregate): M10 1:3:6, M15 1:2:4, M20 1:1.5:3, M25 1:1:2 (approximately).

Water-cement ratio (Abrams' law): for fully compacted concrete, strength decreases as the w/c ratio increases. Typical w/c 0.4–0.55. Excess water gives weak, porous concrete; too little water gives poor workability.

Properties of fresh concrete: workability (ease of placing and compacting; measured by the **slump test**, compaction factor test, Vee-Bee test), segregation (separation of ingredients), bleeding (water rising to the surface).

Properties of hardened concrete: compressive strength (cube test at 7 and 28 days; 7-day strength $\approx$ 65–70% of 28-day), tensile strength, durability, impermeability, shrinkage, creep.

Operations in concreting: batching (by weight or volume) → mixing (hand or machine) → transporting → placing → compacting (vibrators, to remove air) → finishing → **curing** (keeping concrete moist for at least 7 days for OPC and 10 days for PPC, to allow hydration and prevent cracking).

Admixtures: plasticisers and superplasticisers (improve workability without extra water), accelerators, retarders (hot weather, long transport), air-entraining agents (freeze-thaw resistance), waterproofing compounds, mineral admixtures (fly ash, silica fume, GGBS).

Special concretes (awareness): ready-mix concrete (RMC), self-compacting concrete, high-performance concrete, fibre-reinforced concrete, lightweight concrete, precast concrete.

2.8 Timber

Timber is wood suitable for building and engineering purposes. Classification: softwood (from conifers: pine, deodar, chir; light, used for doors, windows, furniture) and hardwood (from broad-leaved trees: teak, sal, sheesham, mango; strong and durable, used for structural work and furniture).

Qualities of good timber: straight fibres, free from defects (knots, cracks, shakes, decay), uniform colour, sweet smell when freshly cut, hard, durable, resistant to fire, insects and fungi, low shrinkage, good workability.

Seasoning: removing excess moisture (to about 10–15%) to increase strength and durability and prevent warping and shrinkage. Methods: natural (air) seasoning, water seasoning, kiln (artificial) seasoning, chemical seasoning.

Defects: knots, shakes (cracks), twists, rot (dry rot, wet rot), insect attack (termites).

Preservation: coal tar, creosote, ASCU (arsenic-copper-chromium) treatment, painting and varnishing.

Industrial timber products: plywood, particle board, fibreboard (MDF), block board, veneers, laminated timber.

Uses: doors, windows, frames, formwork (shuttering), scaffolding, furniture, roof trusses, flooring, railway sleepers (earlier), piles.

2.9 Steel and non-ferrous metals

Steel is an alloy of iron and carbon (0.1–1.5% carbon) with small amounts of manganese, silicon and other elements.

- **Mild steel** (low carbon, about 0.1–0.25%): ductile, weldable; used for plain bars, structural sections, sheets.
- **High-strength deformed (HSD/HYSD) and TMT bars:** ribbed bars with higher yield strength for RCC: grades **Fe 415, Fe 500, Fe 550, Fe 600** (the number is the yield strength in N/mm²). TMT (thermo-mechanically treated) bars have a hard outer surface and a ductile core.
- **Structural steel sections:** I-sections (ISMB), channels (ISMC), angles (ISA), tees, plates, tubes — used for steel buildings, trusses, towers, bridges.

- **Stainless steel** (with chromium and nickel): corrosion resistant.

Properties: high tensile and compressive strength, ductility, weldability, uniform quality; but it corrodes if unprotected and loses strength in fire (needs protection).

Non-ferrous metals.

- **Aluminium:** light (one-third the density of steel), corrosion resistant, good conductor; used for doors, windows, partitions, cladding, roofing sheets, and electrical conductors (ACSR).
- **Copper:** excellent electrical and thermal conductor, corrosion resistant; used for electrical wiring, water pipes, earthing, damp-proof courses, roofing in heritage buildings.
- **Zinc:** used for galvanising steel (corrosion protection) and roofing sheets.
- **Lead:** used for damp-proofing and radiation shielding (limited use because of toxicity).
- **Tin:** used for tinning and in solder.

2.10 Paint

Paint is a liquid coating applied to surfaces to protect them from weather, corrosion and decay, and to improve appearance and hygiene.

Constituents:

- **Base:** the main solid ingredient forming the opaque film (white lead, zinc oxide, titanium dioxide, red lead, iron oxide).
- **Vehicle (binder):** liquid in which the base is suspended; forms the film on drying (linseed oil, synthetic resins, acrylics).
- **Pigment:** gives the desired colour.
- **Solvent (thinner):** adjusts consistency for easy application; evaporates (turpentine, naphtha, water in emulsion paints).
- **Drier:** accelerates drying (litharge, lead or cobalt compounds).
- **Extender (inert filler):** reduces cost and prevents cracking (barytes, chalk, gypsum).

Types: oil paints, enamel paints (glossy), emulsion paints (water-based, for walls), distemper (cheap, for interior walls), cement paint (exterior masonry), anti-corrosive paints (red oxide, zinc chromate primers for steel), bituminous paint, luminous and fire-retardant paints.

Painting process: surface preparation (cleaning, removing rust or old paint, filling cracks) → primer coat → putty (for smooth walls) → undercoat → finishing coats.

2.11 Plastics, glass, adhesives and tiles

Plastics are synthetic organic polymers moulded under heat and pressure.

- **Thermoplastics** (soften on heating and can be remoulded): PVC, polyethylene, polypropylene, acrylic, polystyrene. **Thermosetting plastics** (set permanently on heating): Bakelite, epoxy, melamine, polyester.
- **Advantages:** light, corrosion resistant, easy to mould, good electrical insulation, low maintenance. **Disadvantages:** low strength and stiffness, poor fire resistance, degrade in sunlight, environmental concerns.
- **Uses:** PVC and CPVC water pipes and fittings, electrical conduits and switches, water tanks, doors and windows (uPVC), flooring and wall tiles, roofing sheets, insulation (foam), geosynthetics.

Glass is a transparent amorphous solid made by melting silica sand with soda ash and lime.

- **Types:** sheet and float glass (windows), toughened (tempered) glass (4–5 times stronger; breaks into blunt pieces; doors, facades), laminated glass (plastic layer between sheets; safety and security), wired glass (fire resistance), tinted and reflective glass (reduce heat gain), glass blocks, double-glazed units (thermal and sound insulation), fibreglass.
- **Uses:** windows, doors, facades, partitions, skylights, insulation (glass wool).

Adhesives are substances that bond two surfaces together.

- **Natural:** animal glue, casein, starch. **Synthetic:** epoxy resins (strong, used for concrete repair and bonding), polyvinyl acetate (PVA, wood glue), phenol-formaldehyde and urea-formaldehyde (plywood), polyurethane, silicone sealants, tile adhesives (polymer-modified cement).
- **Uses:** plywood and laminates, tile fixing, joining pipes (solvent cement for PVC), structural repairs, sealing joints and glazing.

Tiles are thin slabs used for flooring, walls and roofs.

- **Types:** clay roofing tiles (Mangalore tiles), ceramic tiles (glazed, for walls and floors), vitrified tiles (very low water absorption, high strength, for floors), mosaic/terrazzo tiles (marble chips in cement), cement concrete tiles, paver blocks (interlocking, for pavements), stone tiles (granite, marble, Kota), vinyl tiles.
- **Requirements:** uniform size and colour, adequate strength and hardness, low water absorption, abrasion and slip resistance.

2.12 Composites

A **composite material** consists of two or more distinct materials combined to give properties better than either alone. It usually has a **matrix** (binding phase) and a **reinforcement** (strengthening phase).

- **Reinforced cement concrete:** concrete (matrix, good in compression) + steel (reinforcement, good in tension).
- **Fibre-reinforced polymers (FRP):** glass (GFRP), carbon (CFRP) or aramid fibres in a resin matrix; very high strength-to-weight ratio and corrosion resistance; used for strengthening beams and columns, bridge decks, rebars in marine structures, panels.
- **Fibre-reinforced concrete:** steel, glass, polypropylene or natural fibres in concrete to control cracking and improve toughness.
- **Ferrocement:** cement mortar reinforced with layers of closely spaced wire mesh; thin elements such as water tanks, boats, roofing shells.
- **Plywood and laminated timber, sandwich panels (foam core with metal or cement board skins).**

Advantages: tailored properties, high strength-to-weight ratio, corrosion and fatigue resistance. **Disadvantages:** higher cost, specialised manufacture, difficult recycling.

2.13 Summary: uses of construction materials

Material	Main uses
Stone	Masonry, foundations, flooring, cladding, aggregates, ballast

Material	Main uses
Brick	Walls, partitions, pavements, arches
Cement	Mortar, concrete, plaster, precast products
Sand and aggregates	Mortar and concrete, road construction, filter media
Concrete (PCC/RCC/PSC)	Foundations, beams, slabs, columns, roads, bridges, dams
Timber	Doors, windows, furniture, formwork, roof trusses
Steel	Reinforcement, structural frames, roof trusses, towers
Aluminium, copper	Doors/windows and cladding; wiring, pipes, earthing
Paint	Protection and decoration of surfaces
Plastics	Pipes, conduits, tanks, fittings, insulation
Glass	Windows, facades, partitions
Tiles	Flooring, wall and roof covering
Composites (FRP, ferrocement)	Strengthening, lightweight elements, tanks

2.14 Illustrated notes on bricks and brick masonry

Standard (modular) brick: 190 × 90 × 90 mm; nominal with mortar 200 × 100 × 100 mm

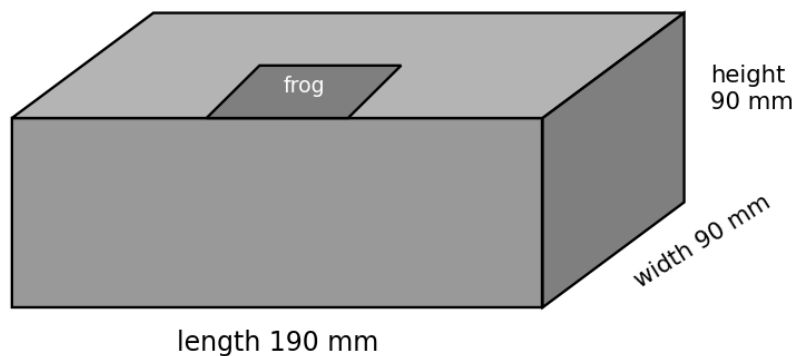


Figure 2.1: A standard modular brick. The frog (depression on the top face) gives a key for mortar and reduces weight.

Brick masonry terms:

- **Stretcher:** a brick laid with its length along the face of the wall. **Header:** a brick laid with its width along the face (length across the wall).
- **Course:** one horizontal layer of bricks. **Bed joint:** horizontal mortar joint; **perpend:** vertical joint.
- **Bond:** the arrangement of bricks so that vertical joints in successive courses do not coincide; it makes the wall act as one unit.

- **Closer:** a cut brick used to complete the bond at corners. A **queen closer** is a brick cut lengthwise in half (half width).
- **Bat:** a brick cut across its length (half bat, three-quarter bat).

English bond: alternate courses of headers and stretchers (Q = queen closer)

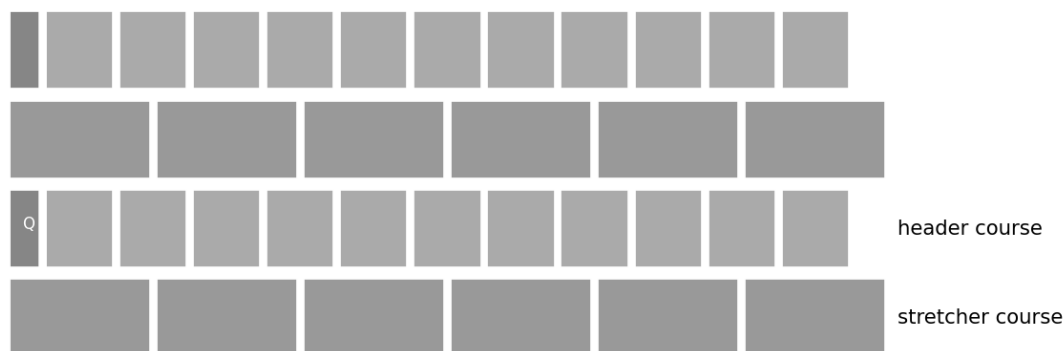


Figure 2.2: English bond, the strongest bond for walls of one brick or more.

Bond	Arrangement	Use
Stretcher bond	All stretchers; joints broken by half a brick	Half-brick partition walls
Header bond	All headers	Curved walls, footings
English bond	Alternate courses of headers and stretchers; queen closer after the first header	Load-bearing walls; strongest
Flemish bond	Headers and stretchers alternate in each course	Attractive face work; slightly weaker than English bond

Rules of good brick masonry: soak bricks before use, lay them frog upwards, keep joints 10 mm thick and fully filled, break vertical joints, raise walls uniformly (not more than 1.5 m per day), and cure for 7-10 days.

2.15 Tests on cement (IS 4031)

- **Fineness test (sieve or Blaine air permeability):** residue on the 90 μm sieve should not exceed 10% for OPC; specific surface at least 225 m^2/kg . Finer cement hydrates faster and gains early strength.
- **Standard (normal) consistency (Vicat apparatus):** the percentage of water that allows the Vicat plunger (10 mm) to penetrate to 5-7 mm from the bottom of the mould. Usually 26-33%. Used as the basis for other tests.
- **Initial and final setting time (Vicat needle):** initial setting time ≥ 30 minutes (time for mixing, transport and placing); final setting time ≤ 600 minutes (10 hours) for OPC.
- **Soundness (Le Chatelier apparatus):** expansion should not exceed 10 mm; unsound cement (excess free lime or magnesia) expands after setting and cracks.
- **Compressive strength:** 70.6 mm mortar cubes of 1:3 cement-standard sand, tested at 3, 7 and 28 days. OPC 33, 43 and 53 grades have 28-day strengths of 33, 43 and 53 N/mm^2 respectively.
- **Field tests:** cement should be free of lumps, feel smooth and cool when rubbed, and have a uniform greenish-grey colour.

2.16 Tests on bricks (IS 3495)

- **Compressive strength:** first-class bricks at least 10.5 N/mm^2 (IS classes 3.5 to 35).
- **Water absorption:** after 24 hours of immersion, not more than 20% of dry weight for first-class bricks (12–15% for good bricks).
- **Efflorescence:** white salt deposits after wetting and drying; "nil" or "slight" is acceptable.
- **Dimension tolerance:** 20 bricks laid in a row should measure $3800 \pm 80 \text{ mm}$ in length.
- **Field tests:** a clear ringing sound when two bricks are struck; no mark when scratched by a finger nail; should not break when dropped flat from 1 m height onto hard ground; uniform colour and sharp edges.

2.17 Tests on aggregates and concrete

Aggregate tests (IS 2386):

- **Sieve analysis (grading):** finds particle size distribution; fineness modulus of sand 2.2–3.2.
- **Aggregate crushing value:** resistance to crushing; not more than 45% for general concrete and 30% for wearing surfaces.
- **Impact value:** toughness under impact; not more than 45% (30% for wearing surfaces).
- **Abrasion value (Los Angeles):** resistance to wear; important for road aggregates.
- **Specific gravity and water absorption; flakiness and elongation indices** (flaky aggregates reduce strength).
- **Bulking of sand:** damp sand occupies more volume than dry sand (up to 20–40% at 4–6% moisture), so volume batching must be corrected.

Tests on fresh concrete — workability:

- **Slump test:** a frustum cone (top 100 mm, bottom 200 mm, height 300 mm) is filled in 4 layers with 25 tamps each and lifted; the drop of the concrete is the slump. Typical slump: 25–75 mm for beams and slabs, 100–150 mm for pumped concrete.
- **Compaction factor test** (for low-workability concrete) and **Vee-Bee test**.

Tests on hardened concrete: cube compression test (150 mm cubes at 7 and 28 days), split tensile test, flexure test, and non-destructive tests such as the rebound hammer and ultrasonic pulse velocity.

2.18 Grades of concrete and the water-cement ratio

Group	Grades (IS 456)	Characteristic strength f_{ck} (N/mm^2)	Typical use
Ordinary concrete	M10, M15, M20	10–20	PCC, levelling, simple RCC (M20 minimum for RCC)
Standard concrete	M25 to M55	25–55	RCC buildings, bridges, prestressed work
High-strength concrete	M60 and above	60–100	Tall buildings, long-span bridges

In M20, "M" stands for mix and 20 is the characteristic compressive strength of 150 mm cubes at 28 days in N/mm² (the strength below which not more than 5% of results are expected to fall).

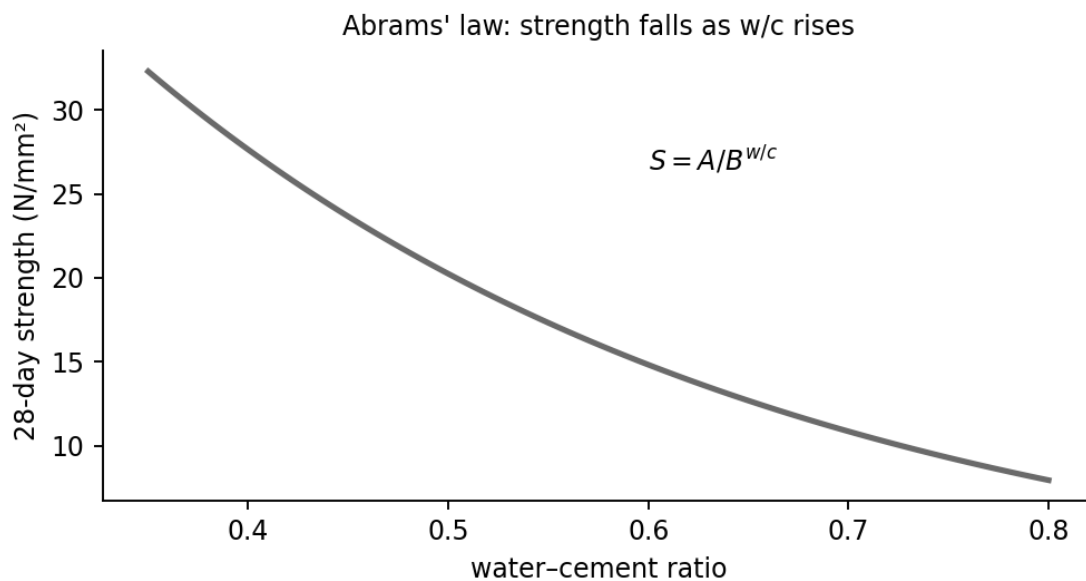


Figure 2.3: Abrams' law. For fully compacted concrete, strength depends mainly on the water-cement ratio: $S = A/B^{w/c}$.

Water-cement ratio: the ratio of the mass of water to the mass of cement. About 0.23–0.25 is needed for complete hydration; extra water gives workability but leaves pores, lowering strength and durability. IS 456 limits the maximum w/c to 0.45–0.55 depending on exposure condition.

Curing: keeping concrete moist for at least 7 days (OPC) to 10–14 days (blended cements) by ponding, wet gunny bags, membranes or steam. Concrete gains about 65–70% of its 28-day strength in 7 days.

2.19 Mechanical behaviour of steel

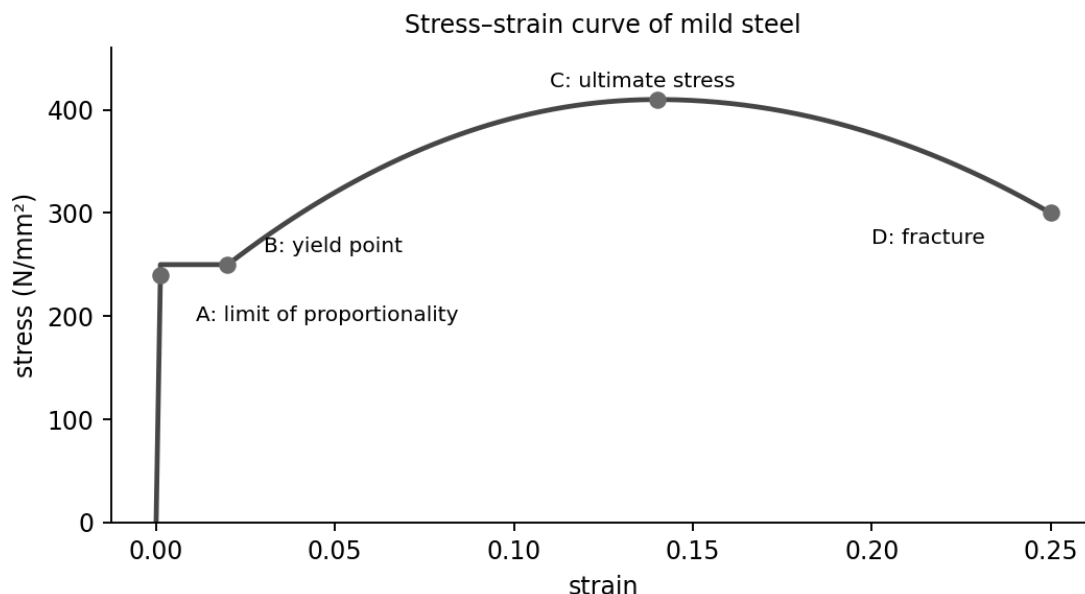


Figure 2.4: Stress-strain curve of mild steel under tension, showing the elastic range, yielding, strain hardening and necking.

- **Up to A (limit of proportionality):** stress $\propto$ strain (Hooke's law). Modulus of elasticity $E \approx 2 \times 10^5$ N/mm².
- **At B (yield point):** strain increases with little increase in stress. Yield stress of mild steel (Fe 250) is 250 N/mm².
- **B to C (strain hardening):** the steel gains strength until the **ultimate stress** (about 410 N/mm² for mild steel).
- **C to D (necking):** cross-section reduces locally until fracture. Mild steel is **ductile**: elongation at fracture 20–25%.

Steel	Yield or 0.2% proof stress (N/mm ²)	Use
Mild steel (Fe 250)	250	Structural sections, stirrups, small works
HYSD / TMT Fe 415	415	RCC reinforcement
TMT Fe 500, Fe 550	500, 550	RCC in multistorey buildings
Prestressing wires and strands	1500–1860	Prestressed concrete

Structural steel sections: I-sections (ISMB), channels (ISMC), angles (ISA), T-sections, plates, tubes and flats. **Non-ferrous metals:** aluminium (light, corrosion-resistant: windows, cladding), copper (electrical wiring, water pipes), zinc (galvanising), lead (flashing, radiation shielding).

2.20 Selection of construction materials

The choice of material for a work depends on:

- **Strength and durability** required for the load and exposure.
- **Availability and cost** near the site (local stone and laterite in Odisha, fly-ash bricks near thermal power plants).
- **Workability and speed of construction.**
- **Appearance (aesthetics)** and finishing needs.



- **Fire resistance, thermal and sound insulation.**
- **Environmental impact:** embodied energy, recyclability, use of industrial wastes (fly ash, slag).

Eco-friendly materials: fly-ash bricks, AAC (autoclaved aerated concrete) blocks, PPC and PSC cements, bamboo, recycled aggregates, and ferrocement.

2.21 Solved numericals: Module II

Problem 1. A brick weighs 3.00 kg when dry and 3.45 kg after 24 hours of immersion in water. Find its water absorption. Is it acceptable as a first-class brick?

$$\text{Water absorption} = (3.45 - 3.00)/3.00 \times 100 = 15\%.$$

Answer: 15%. It is below the 20% limit, so it is acceptable (first-class bricks usually absorb less than 20%, preferably below 15%).

Problem 2. A stone sample has a dry mass of 500 g, a saturated mass of 510 g and a volume of 190 cm³. Find its water absorption, bulk density and porosity (assume water fills all pores).

$$\text{Water absorption} = (510 - 500)/500 \times 100 = 2\%.$$

$$\text{Bulk density} = 500/190 = 2.63 \text{ g/cm}^3 = 2630 \text{ kg/m}^3.$$

$$\text{Volume of pores} = \text{volume of absorbed water} = 10 \text{ cm}^3. \text{ Porosity} = 10/190 \times 100 = 5.3\%.$$

Answer: 2%; 2630 kg/m³; 5.3%. (Good building stone.)

Problem 3. Calculate the quantities of cement (in bags), sand and coarse aggregate for 1 m³ of M20 concrete of nominal mix 1:1.5:3.

$$\text{Dry volume} = 1.54 \times \text{wet volume} = 1.54 \text{ m}^3 \text{ (to allow for voids and shrinkage). Sum of ratio} = 1 + 1.5 + 3 = 5.5.$$

$$\text{Cement} = 1.54/5.5 = 0.28 \text{ m}^3. \text{ Bags} = 0.28 \times 1440/50 = 8.06 \approx 8 \text{ bags (1 bag} = 50 \text{ kg} = 0.0347 \text{ m}^3).$$

$$\text{Sand} = 0.28 \times 1.5 = 0.42 \text{ m}^3. \text{ Coarse aggregate} = 0.28 \times 3 = 0.84 \text{ m}^3.$$

Answer: About 8 bags of cement, 0.42 m³ of sand and 0.84 m³ of coarse aggregate.

Problem 4. Find the materials needed for 2.5 m³ of M15 concrete (1:2:4).

$$\text{Dry volume} = 1.54 \times 2.5 = 3.85 \text{ m}^3. \text{ Sum} = 7. \text{ Cement} = 0.55 \text{ m}^3 = 15.8 \text{ bags} \approx 16 \text{ bags.}$$

$$\text{Sand} = 1.10 \text{ m}^3; \text{ coarse aggregate} = 2.20 \text{ m}^3.$$

Answer: 16 bags of cement, 1.1 m³ of sand and 2.2 m³ of aggregate.

Problem 5. How much water is needed for the M20 concrete of the earlier problem (1 m³) if the water-cement ratio is 0.5?

$$\text{Mass of cement} = 8.06 \times 50 = 403 \text{ kg. Water} = 0.5 \times 403 = 201.6 \text{ kg.}$$

Answer: About 202 litres.

Problem 6. Find the number of modular bricks ($190 \times 90 \times 90$ mm, 10 mm joints) and the quantity of 1:6 cement mortar for a wall 5 m long, 3 m high and 200 mm thick.

Wall volume = $5 \times 3 \times 0.2 = 3 \text{ m}^3$. Volume of one brick with mortar = $0.2 \times 0.1 \times 0.1 = 0.002 \text{ m}^3$. Bricks = $3/0.002 = 1500$.

Actual volume of bricks = $1500 \times 0.19 \times 0.09 \times 0.09 = 2.31 \text{ m}^3$. Wet mortar = $3 - 2.31 = 0.69 \text{ m}^3$. Dry mortar = $1.27 \times 0.69 = 0.88 \text{ m}^3$.

Cement = $0.88/7 = 0.126 \text{ m}^3 = 3.6$ bags; sand = $0.126 \times 6 = 0.75 \text{ m}^3$.

Answer: 1500 bricks (add 5% for wastage ≈ 1575), about 3.6 bags of cement and 0.75 m^3 of sand.

Problem 7. Find the weight of 100 m of 12 mm diameter steel bars and of one 12 m length of a 16 mm bar.

Weight per metre = $d^2/162 \text{ kg}$ (d in mm). 12 mm: $144/162 = 0.889 \text{ kg/m} \Rightarrow 88.9 \text{ kg}$ for 100 m.

16 mm: $256/162 = 1.58 \text{ kg/m} \Rightarrow 1.58 \times 12 = 18.96 \text{ kg}$.

Answer: 88.9 kg; about 19 kg.

Problem 8. A 150 mm concrete cube fails at a load of 506 kN. Find its compressive strength. Does it satisfy M20?

Area = $150 \times 150 = 22500 \text{ mm}^2$. Strength = $506000/22500 = 22.5 \text{ N/mm}^2$.

Answer: $22.5 \text{ N/mm}^2 \geq 20 \text{ N/mm}^2$, so it satisfies the M20 requirement for a single cube (acceptance is based on the average of groups of cubes as per IS 456).

Problem 9. Dry sand of 1 m^3 bulks by 25% when moist. How much moist sand must be measured to get 1 m^3 of dry sand?

Moist volume = 1×1.25 .

Answer: 1.25 m^3 .

Problem 10. A steel bar of 20 mm diameter carries a tensile load of 100 kN. Find the stress. Is it safe for Fe 415 steel with a permissible stress of 230 N/mm^2 ?

Area = $\pi \times 20^2/4 = 314.2 \text{ mm}^2$. Stress = $100000/314.2 = 318 \text{ N/mm}^2$.

Answer: $318 \text{ N/mm}^2 > 230 \text{ N/mm}^2$, so it is not safe; a 25 mm bar (491 mm^2 , stress 204 N/mm^2) would be safe.

2.22 Practice problems with solutions: Module II

Q1. How many 50 kg bags of cement are in 1 m^3 of cement?

$1440/50$.

Answer: 28.8 bags (≈ 29).



Q2. Find the materials for 1 m³ of 1:4 cement mortar.

Dry volume = 1.27 m³ (some books use 1.33); cement = $1.27/5 = 0.254 \text{ m}^3 = 7.3$ bags; sand = 1.016 m³.

Answer: ≈ 7.3 bags of cement, 1.02 m³ of sand.

Q3. What is the approximate number of modular bricks per m³ of brickwork?

$1/(0.2 \times 0.1 \times 0.1)$.

Answer: 500 bricks.

Q4. The 7-day strength of a concrete is 14 N/mm². Estimate its 28-day strength.

7-day strength $\approx 67\%$ of 28-day strength.

Answer: About 21 N/mm².

2.23 MCQs: Module II

1. Granite is a

- (a) metamorphic rock (b) organic rock (c) igneous rock (d) sedimentary rock
☐ (c) — Formed from magma.

2. Marble is formed from

- (a) granite (b) shale (c) sandstone (d) limestone
☐ (d) — Metamorphic.

3. Slate is formed from

- (a) shale (b) limestone (c) basalt (d) granite
☐ (a) — Metamorphic.

4. The water absorption of good building stone should be less than

- (a) 50% (b) 30% (c) 20% (d) 5%
☐ (d) — Durability.

5. The standard modular brick size is

- (a) $230 \times 115 \times 75 \text{ mm}$ (b) $190 \times 90 \times 90 \text{ mm}$ (c) $200 \times 100 \times 50 \text{ mm}$ (d) $250 \times 120 \times 80 \text{ mm}$
☐ (b) — IS 1077 actual size.

6. The nominal size of a modular brick (with mortar) is

- (a) $190 \times 90 \times 90 \text{ mm}$ (b) $210 \times 100 \times 70 \text{ mm}$ (c) $230 \times 115 \times 75 \text{ mm}$ (d) $200 \times 100 \times 100 \text{ mm}$
☐ (d) — Includes 10 mm joints.

7. Good bricks should not absorb more than

- (a) 5% (b) 20% (c) 50% (d) 40%
☐ (b) — After 24 h immersion.

8. The ingredient of brick earth that gives red colour is

- (a) alumina (b) iron oxide (c) lime (d) silica
☐ (b) — Fe_2O_3 .

9. Efflorescence in bricks is caused by

- (a) iron oxide (b) soluble salts (alkalis) (c) burning (d) excess silica
☐ (b) — White deposits.



- 10.** Over-burnt bricks are called
(a) fly-ash bricks (b) jhama bricks (c) fire bricks (d) first-class bricks
☐ (b) — Used as aggregate.
- 11.** Gypsum is added to cement to
(a) control setting time (b) increase strength (c) reduce cost (d) give colour
☐ (a) — Retards flash set.
- 12.** The compound responsible for early strength of cement is
(a) C_4AF (b) C_3A (c) C_3S (d) C_2S
☐ (c) — Tricalcium silicate.
- 13.** The initial setting time of OPC should be at least
(a) 10 min (b) 30 min (c) 60 min (d) 600 min
☐ (b) — IS requirement.
- 14.** The final setting time of OPC should not exceed
(a) 1000 min (b) 30 min (c) 24 h (d) 600 min
☐ (d) — 10 hours.
- 15.** The setting time of cement is found with the
(a) slump cone (b) Le Chatelier apparatus (c) Los Angeles machine (d) Vicat apparatus
☐ (d) — Needle penetration.
- 16.** Soundness of cement is tested with the
(a) Le Chatelier apparatus (b) Vicat apparatus (c) sieve (d) slump test
☐ (a) — Expansion test.
- 17.** The grade 43 of OPC means
(a) 28-day strength of 43 N/mm² (b) 43% lime (c) setting time 43 min (d) 43 kg per bag
☐ (a) — Strength grade.
- 18.** Cement used for mass concrete in dams is
(a) white cement (b) low-heat cement (c) quick-setting (d) rapid-hardening
☐ (b) — Less heat of hydration.
- 19.** Cement recommended for sulphate-bearing soils is
(a) sulphate-resisting cement (b) rapid hardening (c) OPC 53 (d) white cement
☐ (a) — Low C_3A .
- 20.** Fine aggregate passes through
(a) 4.75 mm sieve (b) 10 mm sieve (c) 20 mm sieve (d) 75 micron sieve
☐ (a) — IS definition.
- 21.** Increase in volume of moist sand is called
(a) bulking (b) bleeding (c) creep (d) segregation
☐ (a) — Due to moisture films.
- 22.** The proportion of cement mortar for ordinary brickwork is usually
(a) 1:6 (b) 1:20 (c) 1:1 (d) 1:12
☐ (a) — 1:5 to 1:6.
- 23.** The nominal mix for M20 concrete is
(a) 1:1:2 (b) 1:1.5:3 (c) 1:3:6 (d) 1:2:4
☐ (b) — Approximate.
- 24.** In M25, 25 denotes
(a) w/c ratio (b) aggregate size (c) characteristic compressive strength in N/mm² (d) cement content
☐ (c) — 28-day strength.



- 25.** The minimum grade of concrete for RCC as per IS 456 is
(a) M10 (b) M15 (c) M30 (d) M20
☐ (d) — Durability requirement.
- 26.** Workability of concrete is measured by the
(a) Le Chatelier test (b) abrasion test (c) Vicat test (d) slump test
☐ (d) — Slump cone.
- 27.** As the water-cement ratio increases, concrete strength
(a) increases (b) doubles (c) remains constant (d) decreases
☐ (d) — Abrams' law.
- 28.** Curing of concrete is done to
(a) speed up setting only (b) keep it moist for hydration and strength gain (c) reduce weight (d) increase slump
☐ (b) — At least 7 days.
- 29.** The dry volume of concrete materials is taken as about
(a) $0.5 \times$ wet volume (b) $2 \times$ wet volume (c) $1.54 \times$ wet volume (d) $1.0 \times$ wet volume
☐ (c) — Voids and wastage.
- 30.** The weight of 1 m of a steel bar of diameter d mm is about
(a) $d^2/162$ kg (b) $162/d^2$ kg (c) $d/162$ kg (d) $d^3/162$ kg
☐ (a) — Standard formula.
- 31.** TMT bars of grade Fe 500 have yield strength
(a) 5000 N/mm^2 (b) 500 N/mm^2 (c) 50 N/mm^2 (d) 500 kg/cm^2
☐ (b) — Grade number.
- 32.** Concrete is weak in
(a) both (b) compression (c) tension (d) neither
☐ (c) — Hence steel reinforcement.
- 33.** Seasoning of timber means
(a) soaking in oil (b) painting it (c) removing excess moisture (d) cutting it
☐ (c) — Improves strength and durability.
- 34.** Teak is a
(a) softwood (b) hardwood (c) composite (d) plastic
☐ (b) — Broad-leaved tree.
- 35.** The part of paint that forms the film is the
(a) drier (b) base (c) vehicle (binder) (d) solvent
☐ (c) — e.g. linseed oil.
- 36.** Turpentine in paint acts as a
(a) pigment (b) thinner (solvent) (c) base (d) drier
☐ (b) — Adjusts consistency.
- 37.** PVC is a
(a) ceramic (b) thermoplastic (c) metal (d) thermosetting plastic
☐ (b) — Can be remoulded.
- 38.** Glass that breaks into small blunt pieces is
(a) tinted glass (b) wired glass (c) toughened glass (d) float glass
☐ (c) — Safety glass.
- 39.** Aluminium is preferred for window frames because it is
(a) light and corrosion resistant (b) magnetic (c) heavy (d) cheap and brittle
☐ (a) — Properties.

- 40.** Galvanising steel means coating it with
(a) copper (b) tin (c) zinc (d) lead
□ (c) — Corrosion protection.
- 41.** Ferrocement consists of
(a) bitumen and sand (b) glass fibres in resin (c) timber and steel (d) cement mortar with wire mesh
□ (d) — Thin elements.
- 42.** Which is a composite material?
(a) steel (b) glass (c) RCC (d) cement
□ (c) — Concrete + steel.
- 43.** Vitrified tiles are known for
(a) very low water absorption and high strength (b) low cost only (c) roofing use (d) high water absorption
□ (a) — Dense body.
- 44.** Epoxy adhesives are used for
(a) making bricks (b) structural repair and bonding (c) roofing (d) painting
□ (b) — Strong bond.
- 45.** Ductility is the property of
(a) conducting heat (b) breaking suddenly (c) resisting scratches (d) undergoing large deformation before failure
□ (d) — Mild steel.

2.24 More solved numericals: Module II

Problem 1. Find the quantities of cement (bags) and sand for 12 mm thick 1:6 cement plaster on a wall 10 m × 3 m.

Wet volume = $30 \times 0.012 = 0.36 \text{ m}^3$. Dry volume = $1.27 \times 0.36 = 0.457 \text{ m}^3$ (27% extra for voids, wastage and uneven surface).

Cement = $0.457/7 = 0.0653 \text{ m}^3 = 0.0653 \times 1440 = 94 \text{ kg} \approx 1.9 \text{ bags}$. Sand = $0.457 \times 6/7 = 0.392 \text{ m}^3$.

Answer: About 2 bags of cement and 0.39 m³ of sand.

Problem 2. An RCC slab 4 m × 5 m × 120 mm is cast in M20 (1:1.5:3) with 1% steel by volume. Find the concrete volume, cement bags and mass of steel.

Volume = $4 \times 5 \times 0.12 = 2.4 \text{ m}^3$. Dry volume = $1.54 \times 2.4 = 3.70 \text{ m}^3$.

Cement = $3.70/5.5 = 0.672 \text{ m}^3 \Rightarrow 0.672 \times 1440/50 = 19.4 \text{ bags}$.

Steel = $0.01 \times 2.4 \times 7850 \text{ kg/m}^3 = 188 \text{ kg}$.

Answer: 2.4 m³ concrete; about 20 bags of cement; about 188 kg of steel.

Problem 3. Six 150 mm cubes of a concrete gave 28-day strengths of 24.5, 26.0, 22.8, 25.4, 23.9 and 27.1 N/mm². Find the mean, standard deviation and characteristic strength ($f_{ck} = \text{mean} - 1.65s$).

Mean = $149.7/6 = 24.95 \text{ N/mm}^2$. Standard deviation $s = 1.54 \text{ N/mm}^2$.

$f_{ck} = 24.95 - 1.65 \times 1.54 = 22.4 \text{ N/mm}^2$.

Answer: Characteristic strength $\approx 22.4 \text{ N/mm}^2$ — the concrete satisfies M20.



Problem 4. How many 600×600 mm vitrified tiles are needed for a $4 \text{ m} \times 5 \text{ m}$ floor, allowing 5% wastage?

Area of one tile = 0.36 m^2 . Number = $20/0.36 = 55.6$. With 5% wastage = 58.3.

Answer: 59 tiles.

Problem 5. A timber beam $100 \text{ mm} \times 200 \text{ mm} \times 4 \text{ m}$ long has a density of 650 kg/m^3 (seasoned). Find its mass. If its moisture content was 30% before seasoning (on dry mass basis), what was its mass then?

Volume = $0.1 \times 0.2 \times 4 = 0.08 \text{ m}^3$. Dry mass = $0.08 \times 650 = 52 \text{ kg}$.

Green mass = $52 \times 1.30 = 67.6 \text{ kg}$.

Answer: 52 kg seasoned; 67.6 kg green.

Problem 6. Find the number of bricks in 1 m^3 of brickwork using modular bricks ($190 \times 90 \times 90 \text{ mm}$, 10 mm joints).

Nominal size with mortar = $200 \times 100 \times 100 \text{ mm} = 0.002 \text{ m}^3$.

Answer: $1/0.002 = 500$ bricks per m^3 (plus about 5% wastage in practice).

Problem 7. The initial setting time of a cement is 25 minutes and the Le Chatelier expansion is 12 mm. Should it be accepted?

IS limits: initial setting time $\geq 30 \text{ min}$; soundness expansion $\leq 10 \text{ mm}$.

Answer: Reject: it sets too quickly and is unsound.

Problem 8. A 16 mm TMT bar 12 m long is tested in tension and yields at 90 kN. Find the yield stress and state whether it is Fe 415.

Area = $\pi \times 16^2/4 = 201 \text{ mm}^2$. Yield stress = $90,000/201 = 447.6 \text{ N/mm}^2$.

Answer: About $448 \text{ N/mm}^2 \geq 415 \text{ N/mm}^2$: satisfies Fe 415.

Problem 9. 100 kg of sand passes the following cumulative percentages retained on IS sieves 4.75 mm, 2.36, 1.18, 0.6, 0.3 and 0.15 mm: 2, 10, 30, 55, 80, 96. Find the fineness modulus.

FM = sum of cumulative % retained/100 = $(2 + 10 + 30 + 55 + 80 + 96)/100 = 273/100$.

Answer: FM = 2.73 (medium sand).

Problem 10. Mortar is to be prepared in the ratio 1:4 for 0.5 m^3 of wet mortar. Find the cement and sand.

Dry volume = $1.27 \times 0.5 = 0.635 \text{ m}^3$. Cement = $0.635/5 = 0.127 \text{ m}^3 = 183 \text{ kg} \approx 3.7$ bags. Sand = 0.508 m^3 .

Answer: About 3.7 bags of cement and 0.51 m^3 of sand.

2.25 Short questions with answers: Module II

Q1. Why is gypsum added to cement?



About 3–5% gypsum is ground with clinker to retard the flash setting of tricalcium aluminate (C_3A), giving time to place the concrete.

Q2. What is the frog of a brick?

A depression on the top face that forms a key for mortar and reduces weight.

Q3. What is seasoning of timber?

Reducing the moisture content of timber to about 10–12% (in equilibrium with the surroundings) to prevent shrinkage, warping and decay.

Q4. What are the main compounds (Bogue compounds) of cement?

C_3S (early strength), C_2S (later strength), C_3A (flash setting, heat) and C_4AF .

Q5. Define workability of concrete.

The ease with which concrete can be mixed, transported, placed and compacted without segregation; measured by the slump test.

Q6. What is the difference between OPC and PPC?

PPC contains 15–35% fly ash (pozzolana). It has lower heat of hydration, better durability and slower early strength gain than OPC.

Q7. Why is curing of concrete necessary?

To keep enough moisture for hydration of cement, so that the concrete gains strength and durability and does not crack due to early drying.

Q8. What is a composite material? Give two examples used in construction.

A material made of two or more constituents with different properties that work together, e.g. reinforced concrete, fibre-reinforced polymer (FRP), ferrocement.

Q9. Name the ingredients of paint.

Base (white lead, zinc oxide, titanium dioxide), vehicle (linseed oil), pigment, drier, thinner (turpentine) and extender.

Q10. What is bulking of sand?

The increase in volume of sand due to surface moisture films that push particles apart; maximum at about 4–6% moisture.

Module III: Transportation Engineering

3.1 Importance of transportation

Transportation is the movement of people and goods from one place to another. It is the backbone of economic and social development.

- **Economic:** links production centres with markets; reduces cost of goods; enables specialisation and trade; supports agriculture (farm-to-market roads), industry and tourism.
- **Social:** access to education, health care and jobs; cultural exchange; national integration.
- **Political and strategic:** administration, defence and border connectivity; relief during disasters.
- **Urbanisation:** determines the growth pattern of cities; mass transit reduces congestion and pollution.

3.2 Modes of transportation

Mode	Basic characteristics	Advantages	Disadvantages
Highway (road)	Flexible door-to-door service; vehicles on roads	Flexible routes and timing; low initial cost; serves remote and hilly areas; feeder for other modes	Less safe (accidents); higher energy per tonne-km; pollution; limited capacity
Railway	Fixed track; long trains; high capacity	Economical for bulk goods over long distances; safe; energy efficient; less pollution per tonne-km	High initial cost; fixed routes and schedules; needs road feeder
Airways	Fastest mode; aircraft on air routes	Very high speed; no physical route needed; reaches inaccessible areas; good for perishables and valuables	Most expensive; limited load; weather dependent; needs airports
Waterways (inland and ocean)	Ships and boats on rivers, canals and seas	Cheapest for heavy bulk cargo over long distances; large capacity	Slowest; limited to waterways; seasonal (inland); needs ports
Pipeline	Continuous flow of fluids through pipes	Cheapest for liquids and gases (oil, gas, water); continuous, safe, weather independent	Only for fluids/slurries; high initial cost; inflexible
Conveyor / ropeway	Belt or cable systems	Useful in mines, factories and hilly terrain	Short distances; specific use

3.3 Indian road transport system

India has one of the largest road networks in the world (over 6 million km). Road development was planned through a series of plans: the **Nagpur Road Plan (1943-63)**,

the **Bombay Road Plan (1961-81)**, the **Lucknow Road Plan (1981-2001)** and later vision documents. Important agencies and programmes:

- **Indian Roads Congress (IRC):** sets standards and codes for road design and construction.
- **Ministry of Road Transport and Highways (MoRTH)** and **National Highways Authority of India (NHAI):** develop and maintain national highways.
- **Programmes:** Golden Quadrilateral and North-South/East-West corridors (NHDP), **Bharatmala Pariyojana** (economic corridors, expressways), **Pradhan Mantri Gram Sadak Yojana (PMGSY)** (all-weather rural roads).

Types of roads (by all-weather usability and surface): all-weather roads, fair-weather roads; paved (surfaced: bituminous or cement concrete) and unpaved (earth, gravel, WBM) roads.

Classification of roads (Nagpur Road Plan / IRC):

Class	Function	Connects
National Highways (NH)	Main arterial roads of the country	State capitals, major ports, industrial and tourist centres, neighbouring countries
State Highways (SH)	Arterial roads of a state	District headquarters and important cities of the state with NHs
Major District Roads (MDR)	Important roads within a district	Production and market centres, taluk headquarters with SH/NH
Other District Roads (ODR)	Roads serving rural areas	Villages/groups of villages with markets and MDRs
Village Roads (VR)	Roads within rural areas	Villages to each other and to the nearest road of higher category

Third Road Plan (Lucknow) classification: primary system (expressways, NH), secondary system (SH, MDR), tertiary system (ODR, VR, i.e. rural roads).

Expressways: high-speed, access-controlled divided highways with grade-separated interchanges (e.g. Mumbai-Pune, Delhi-Mumbai expressways).

3.4 Urban roads: basic requirements and classification

Classification (IRC):

- **Arterial roads:** main roads for through traffic across the city; high speed; limited access; connect with highways.
- **Sub-arterial roads:** carry traffic between arterials and collectors; slightly lower speed.
- **Collector streets:** collect traffic from local streets and feed it to arterials; provide access to residential and commercial areas.
- **Local streets:** give direct access to houses and properties; low speed and traffic.

Basic requirements of urban roads: adequate width and number of lanes for traffic, footpaths and cycle tracks, proper drainage (side drains, cross slope), street lighting, road markings and signs, intersections and traffic signals, parking provisions, bus bays, space for utilities (water, sewer, electricity, telecom cables) in the right of way, safe

pedestrian crossings, trees and landscaping.

3.5 Basic components of a road

A road consists of the following elements (see the typical cross-section figure):

- **Subgrade:** the natural soil or compacted fill on which the pavement rests. It is the foundation of the road and must be well compacted and drained. Its strength is measured by the **California Bearing Ratio (CBR)** test.
- **Sub-base course:** a layer of granular material (gravel, moorum, crushed stone) above the subgrade that distributes load and provides drainage.
- **Base course:** a strong layer (water-bound macadam WBM, wet mix macadam WMM, crushed stone) that carries the main load from the surface.
- **Surface course (wearing course):** the top layer in contact with traffic; provides a smooth, skid-resistant, waterproof surface (bituminous concrete or cement concrete).
- **Carriageway:** the width of the road used by vehicles (standard lane width 3.5 m; two-lane road 7.0 m).
- **Shoulders:** strips on either side of the carriageway for emergency stopping, lateral support and drainage (usually 2.5 m wide on highways).
- **Camber (cross slope):** the transverse slope given to the road surface to drain rainwater to the sides (e.g. 1.7–2.0% for bituminous surfaces, 1.7% for concrete, 2.5–3% for WBM, 3–4% for earth roads).
- **Kerbs:** raised edges separating the carriageway from footpaths or shoulders (urban roads).
- **Footpaths (sidewalks), cycle tracks** (urban roads).
- **Median (central divider):** separates opposing traffic on divided highways.
- **Side drains:** carry surface water away from the road.
- **Right of way (land width):** the total land acquired for the road, including space for future widening and utilities.
- **Formation width (roadway width):** carriageway + shoulders.
- **Road margins:** parking lanes, frontage roads, guard rails, embankment slopes.
- **Traffic control devices:** signs, road markings, signals.

Geometric design terms (for awareness): gradient (longitudinal slope, e.g. ruling gradient 1 in 30 in plains), super-elevation (banking on curves), sight distance (stopping and overtaking), horizontal and vertical curves, widening on curves.

3.6 Types of pavements: flexible and rigid

A **pavement** is the layered structure that carries traffic loads and spreads them to the subgrade.

Flexible pavement: made of bituminous (asphalt) surface layers over granular base and sub-base courses. It has low flexural strength; loads are transmitted to lower layers by **grain-to-grain contact**, spreading over a wider area with depth, so the layer quality decreases from top to bottom.

Rigid pavement: made of **cement concrete slabs** (plain or reinforced) on a base course. It has high flexural strength and distributes loads over a wide area by **slab (beam) action**. Joints are provided to allow expansion and contraction.



Aspect	Flexible pavement	Rigid pavement
Surface material	Bituminous (asphalt)	Cement concrete
Load transfer	Grain-to-grain; depends on subgrade and layer strength	Slab action; distributes load over a wide area
Flexural strength	Low	High
Design life	10–15 years	20–40 years
Initial cost	Lower	Higher
Maintenance cost	Higher (frequent resurfacing)	Lower
Effect of temperature	Softens in heat; less affected by stresses	Temperature stresses; needs joints
Joints	Not required	Expansion and contraction joints required
Opening to traffic	Soon after construction	After curing (about 28 days, unless early-strength concrete)
Repairs	Easy (patching)	Difficult and costly
Night visibility	Poor (dark surface)	Good (light surface)
Riding quality	Smooth	Good, but joints cause some discomfort
Suitability	Most roads, especially where subgrade may settle	Heavy traffic, poor drainage areas, bus bays, toll plazas, industrial roads

Other road surfaces: earth roads, gravel roads, water-bound macadam (WBM) roads, interlocking concrete block pavements (urban streets, parking), and composite pavements.

3.7 Railways, airways and waterways: basic characteristics (brief)

- **Railways:** components are rails, sleepers (concrete, wooden, steel), ballast (crushed stone), fastenings and formation. Gauges in India: broad gauge 1676 mm (being adopted network-wide under Project Unigauge), metre gauge 1000 mm, narrow gauge 762 mm and 610 mm. Dedicated freight corridors, high-speed rail and metro systems are recent developments.
- **Airways:** airports with runways (oriented along the prevailing wind), taxiways, aprons, terminal buildings and air-traffic control; classified by runway length and traffic.
- **Waterways:** ports and harbours (major ports such as Paradip in Odisha), inland waterways (National Waterways on the Ganga, Brahmaputra, Mahanadi system etc.), coastal shipping.

3.8 Cross-section of a road (illustrated)

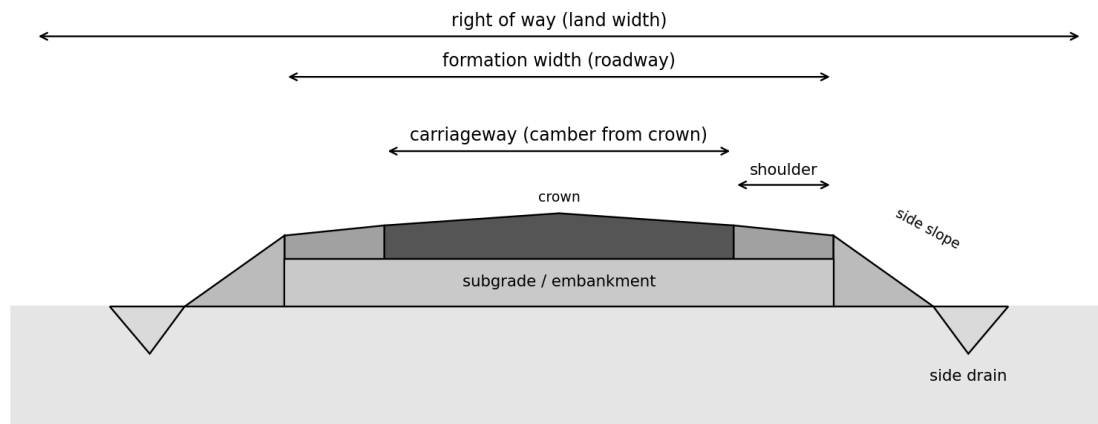


Figure 3.1: Typical cross-section of a two-lane highway on an embankment.

- **Carriageway:** the paved width used by moving vehicles. Single lane 3.75 m; two-lane 7.0 m; multilane 3.5 m per lane (IRC).
- **Camber (cross slope):** the transverse slope from the crown (centre) to the edges to drain rainwater. IRC values: 1.7–2.0% for cement concrete and high-type bituminous surfaces, 2.5–3.0% for WBM and gravel, 3.0–4.0% for earth roads. Heavier rainfall and rougher surfaces need more camber.
- **Shoulders:** strips beside the carriageway (minimum 2.5 m each side on highways) for stopped vehicles, emergency use and lateral support to the pavement.
- **Formation width (roadway width):** carriageway + both shoulders (12 m for a two-lane NH or SH in plain terrain).
- **Side slopes and side drains:** give stability to the embankment and remove surface water.
- **Right of way (land width):** the total land acquired for the road, including space for future widening (45 m normal for NH/SH in open areas).
- **Kerbs, footpaths, cycle tracks, medians (dividers) and guard rails:** provided on urban roads and divided highways.

3.9 Pavement structure (illustrated)

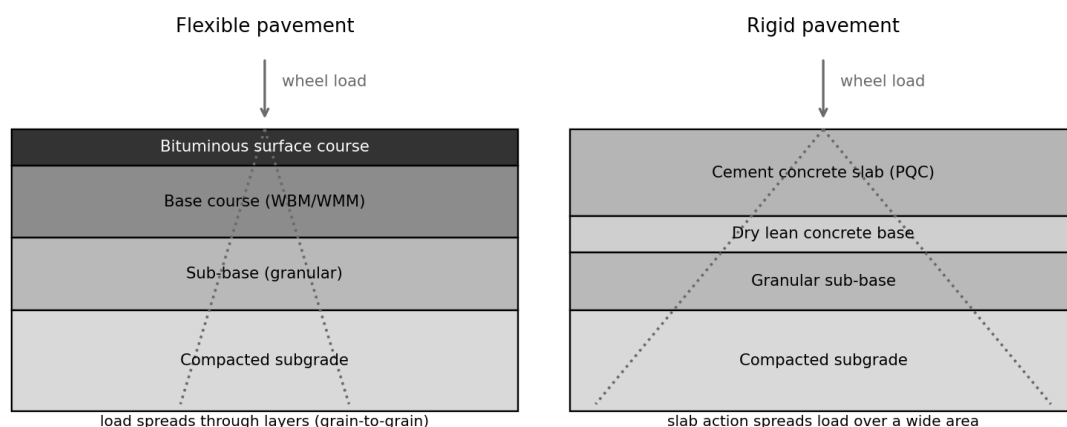


Figure 3.2: Layers of flexible and rigid pavements and the way each spreads a wheel load.

Functions of each layer:

- **Subgrade:** the compacted natural soil or embankment on which the pavement rests; its strength is measured by the California Bearing Ratio (CBR).
- **Sub-base:** granular material (gravel, moorum) that spreads the load and acts as a drainage layer; prevents fine soil from moving up.
- **Base course:** high-quality aggregate layer (WBM — water bound macadam, WMM — wet mix macadam) or dry lean concrete; the main load-spreading layer.
- **Surface (wearing) course:** bituminous concrete or cement concrete slab; gives a smooth, skid-resistant, waterproof surface and resists wear.

Feature	Flexible pavement	Rigid pavement
Surface	Bituminous	Cement concrete slab (PQC)
Load transfer	Grain-to-grain through layers	Slab (beam) action over a wide area
Design based on	Subgrade CBR and traffic	Flexural strength of concrete, modulus of subgrade reaction
Initial cost	Low	High
Maintenance	Frequent (resurfacing, patching)	Very little
Life	10-15 years	20-40 years
Effect of temperature	Softens in heat	Needs expansion and contraction joints
Opening to traffic	Soon after rolling	After 14-28 days of curing
Night visibility	Poor (dark)	Good (light colour)

3.10 Geometric design elements of highways

1. Gradient: the rate of rise or fall along the road length, expressed as 1 in n or as a percentage.

Terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain and rolling	3.3% (1 in 30)	5% (1 in 20)	6.7% (1 in 15)
Mountainous	5% (1 in 20)	6% (1 in 16.7)	7% (1 in 14.3)
Steep (above 3000 m)	6% (1 in 16.7)	7%	8%

2. Sight distance: the length of road visible ahead to the driver.

Stopping sight distance $SSD = 0.278 V t + V^2/(254 f)$ (V in km/h, t = reaction time ≈ 2.5 s, f = coefficient of friction 0.35-0.40)

- The first term is the **lag distance** (travelled during perception and reaction); the second is the **braking distance**.
- **Overtaking sight distance (OSD):** needed on two-lane roads for safe overtaking; much larger than SSD.

3. Super-elevation (banking): raising the outer edge of the road on a horizontal curve to counteract centrifugal force.

$e + f = V^2/(127 R)$ (V in km/h, R in m); IRC design value $e = V^2/(225 R)$, limited to a maximum of 7% (10% in hills)

4. Extra widening on curves: vehicles occupy more width on curves (off-tracking of rear wheels) and drivers keep away from the edge.

$$W_e = n l^2 / (2R) + V / (9.5\sqrt{R}) \quad (n = \text{number of lanes, } l = \text{wheel base} \approx 6 \text{ m})$$

5. Transition curves (spirals) introduce the curvature and super-elevation gradually. **6. Vertical curves** (summit and valley) join different gradients smoothly.

3.11 Road development plans and IRC classification

Nagpur Road Plan (1943-63): the first road development plan of India. It classified roads into five categories and aimed at a road density of 16 km per 100 km² of area.

Category	Function	Authority
National Highways (NH)	Connect state capitals, ports, major cities; national importance	Central government (NHAI, MoRTH)
State Highways (SH)	Connect district headquarters and important towns within a state	State PWD
Major District Roads (MDR)	Connect production and market centres within a district	District authorities / PWD
Other District Roads (ODR)	Serve rural areas, connect villages to MDR	District authorities
Village Roads (VR)	Connect villages to each other and to the nearest higher road	Panchayats, PMGSY

Later plans: the Bombay Plan (1961-81) and the Lucknow Plan (1981-2001). Modern programmes include the **Golden Quadrilateral, North-South and East-West corridors, Bharatmala Pariyojana**, and **Pradhan Mantri Gram Sadak Yojana (PMGSY)** for all-weather rural connectivity.

Urban roads (IRC): arterial roads (through traffic, high speed), sub-arterial roads, collector streets (collect traffic from local streets) and local streets (access to property). Expressways are divided highways with full control of access.

Road patterns: rectangular (block), radial, hexagonal and grid-radial patterns; Chandigarh and Bhubaneswar use grid layouts.

3.12 Highway materials and road drainage

Materials:

- **Soil:** subgrade; tested for CBR, compaction (Proctor test) and plasticity.
- **Aggregates:** stone chips for base and surface courses; tested for crushing, impact, abrasion and shape.
- **Bitumen:** a black binder obtained from petroleum refining; grades by penetration (e.g. 60/70, 80/100) or viscosity (VG 10, VG 30, VG 40). Also used as cutbacks and emulsions.
- **Cement concrete:** for rigid pavements (M40 pavement quality concrete).
- **Modern materials:** fly ash in embankments, geosynthetics, plastic-modified bitumen, recycled asphalt.

Road drainage: water is the main enemy of roads; it weakens the subgrade and causes potholes.

- **Surface drainage:** camber, side drains (kutchra or lined), catch pits and culverts.
- **Subsurface drainage:** lowering the water table with longitudinal drains and filter layers; drainage layers in the sub-base.
- **Cross-drainage works:** culverts (span up to 6 m) and bridges carry streams across the road.

3.13 Traffic control devices and road safety

- **Traffic signs (IRC 67):** regulatory (mandatory — stop, speed limit, one-way), warning (cautionary — curves, school ahead) and informatory (direction, facilities).
- **Road markings:** centre lines, lane lines, stop lines, pedestrian crossings (zebra), edge lines.
- **Traffic signals:** control conflicting movements at intersections; fixed-time or vehicle-actuated.
- **Intersections:** at-grade (T, Y, cross, rotary or roundabout) and grade-separated (flyovers, interchanges such as cloverleaf).
- **Road safety measures:** proper geometric design, crash barriers, street lighting, speed calming, enforcement and education (the 4 Es: engineering, enforcement, education, emergency care).

3.14 Railways, airways and waterways: more details

Railways:

- **Gauges in India:** broad gauge 1676 mm (standard for most lines, Project Unigauge), metre gauge 1000 mm, narrow gauges 762 and 610 mm (hill railways).
- **Permanent way components:** rails (flat-footed), sleepers (concrete, steel, wood), ballast (crushed stone that distributes load and drains water), fastenings and formation.
- **Advantages:** economical for bulk goods and long distances, energy efficient, safe, less polluting; **dedicated freight corridors** and high-speed rail are under development.

Airways: fastest mode; airport components include runway (oriented along the prevailing wind), taxiways, apron, terminal building, hangars and control tower. Suitable for passengers, perishable and high-value goods, and remote areas.

Waterways: cheapest mode for bulky goods; inland waterways (National Waterway 1 on the Ganga, NW 5 in Odisha along the Brahmani and Mahanadi delta) and ocean transport through major ports such as Paradip.

Mode	Speed	Cost per tonne-km	Flexibility	Best for
Road	Medium	Medium-high	Very high (door to door)	Short and medium distances
Rail	Medium-high	Low	Fixed routes	Bulk goods, long distances, mass passenger transport

Mode	Speed	Cost per tonne-km	Flexibility	Best for
Air	Very high	Very high	Airport to airport	Passengers, urgent and valuable cargo
Water	Low	Lowest	Limited to waterways	Heavy bulk cargo, international trade

3.15 Common mistakes to avoid in Module III

- Writing that flexible pavements distribute load by slab action (that is rigid pavements).
- Confusing camber (cross slope for drainage) with gradient (longitudinal slope) and super-elevation (banking on curves).
- Mixing up the order of the Nagpur classification: NH > SH > MDR > ODR > VR.
- Calling carriageway width the right of way.

3.16 Solved numericals: Module III

Problem 1. A two-lane road has a carriageway width of 7.0 m and a straight-line camber of 2%. Find the height of the crown above the edges.

Half width = 3.5 m. Crown height = $3.5 \times 0.02 = 0.07$ m.

Answer: 70 mm.

Problem 2. A WBM road 3.8 m wide is given a camber of 1 in 36. Find the rise of the crown.

Rise = $(3.8/2) \times (1/36) = 1.9/36 = 0.0528$ m.

Answer: About 53 mm.

Problem 3. A road rises 12 m over a horizontal length of 480 m. Express the gradient as 1 in n and as a percentage. Is it within a ruling gradient of 1 in 30?

Gradient = $12/480 = 1/40 = 2.5\%$.

Answer: 1 in 40 (2.5%); it is flatter than 1 in 30 (3.33%), so it is acceptable.

Problem 4. Find the super-elevation needed on a horizontal curve of radius 300 m for a design speed of 80 km/h (IRC formula $e = V^2/225R$ for plain terrain).

$e = 80^2/(225 \times 300) = 6400/67500 = 0.095$.

This exceeds the maximum of 7% for plain terrain, so provide $e = 0.07$ and check the friction needed (or restrict speed).

Answer: Calculated $e = 9.5\%$; provide the maximum of 7%.

Problem 5. Find the stopping sight distance for a design speed of 100 km/h, reaction time 2.5 s and coefficient of friction 0.35 ($SSD = 0.278Vt + V^2/(254f)$).



Lag distance = $0.278 \times 100 \times 2.5 = 69.5$ m.

Braking distance = $100^2 / (254 \times 0.35) = 10000 / 88.9 = 112.5$ m.

Answer: SSD $\approx$ 182 m.

Problem 6. Find the SSD for 65 km/h ($t = 2.5$ s, $f = 0.40$).

Lag = $0.278 \times 65 \times 2.5 = 45.2$ m. Braking = $65^2 / (254 \times 0.40) = 4225 / 101.6 = 41.6$ m.

Answer: SSD $\approx$ 87 m.

Problem 7. The capacity of one lane is about 1800 vehicles per hour. How many lanes (one direction) are needed for a peak flow of 4500 vehicles per hour?

Lanes = $4500 / 1800 = 2.5 = 3$ lanes.

Answer: 3 lanes in each direction (a six-lane divided road).

Problem 8. A national highway section has a formation width of 12 m (7 m carriageway + shoulders). Find the width of each shoulder.

Shoulders = $(12 - 7) / 2$.

Answer: 2.5 m each.

3.17 Practice problems with solutions: Module III

Q1. Convert a gradient of 3% to the form 1 in n.

$3/100 = 1/33.3$.

Answer: About 1 in 33.

Q2. A road of 10.5 m (three lanes) has a camber of 1.7%. Find the crown height.

5.25×0.017 .

Answer: About 89 mm.

Q3. Which pavement would you recommend for (a) a toll plaza, (b) a rural road with expansive subgrade, (c) a city bus bay? Give reasons.

(a) Rigid: heavy braking loads, oil spillage. (b) Flexible: can adjust to some subgrade movement and is easier to repair. (c) Rigid: repeated heavy stationary loads cause rutting in bituminous surfaces.

Answer: Rigid, flexible, rigid.

3.18 MCQs: Module III

1. The cheapest mode for transporting crude oil and gas over long distances is

(a) air (b) road (c) rail (d) pipeline

☐ (d) — Continuous flow.



- 2.** The fastest mode of transport is
(a) air (b) rail (c) water (d) road
☐ (a) — Airways.
- 3.** The cheapest mode for bulk cargo over very long distances is
(a) road (b) air (c) pipeline for solids (d) waterways
☐ (d) — Ships.
- 4.** The most flexible mode offering door-to-door service is
(a) air (b) rail (c) water (d) road
☐ (d) — Highways.
- 5.** The first road development plan of India was the
(a) Delhi plan (b) Lucknow plan (c) Nagpur plan (d) Bombay plan
☐ (c) — 1943-63.
- 6.** The highest category of roads in the Nagpur classification is
(a) ODR (b) MDR (c) State Highway (d) National Highway
☐ (d) — Arterial roads of the country.
- 7.** Roads connecting district headquarters within a state are
(a) ODR (b) SH (c) NH (d) VR
☐ (b) — State Highways.
- 8.** Roads connecting villages to each other are
(a) VR (b) SH (c) MDR (d) NH
☐ (a) — Village roads.
- 9.** Standards for road design in India are published by
(a) CPWD (b) Indian Roads Congress (c) NHAI (d) BIS only
☐ (b) — IRC codes.
- 10.** PMGSY is a programme for
(a) national highways (b) railways (c) rural roads (d) ports
☐ (c) — All-weather rural connectivity.
- 11.** In urban roads, streets giving direct access to houses are
(a) local streets (b) sub-arterial (c) expressways (d) arterial
☐ (a) — Lowest category.
- 12.** The natural soil layer supporting the pavement is the
(a) sub-base (b) subgrade (c) wearing course (d) base
☐ (b) — Foundation.
- 13.** The strength of subgrade is evaluated by the
(a) Marshall test only (b) CBR test (c) slump test (d) Vicat test
☐ (b) — California Bearing Ratio.
- 14.** Camber is provided for
(a) strength (b) surface drainage (c) sight distance (d) banking on curves
☐ (b) — Cross slope.
- 15.** The typical width of a single traffic lane is
(a) 7 m (b) 2.5 m (c) 3.5 m (d) 5 m
☐ (c) — IRC standard.
- 16.** The width of a two-lane carriageway is
(a) 5.5 m (b) 7.0 m (c) 3.5 m (d) 10.5 m
☐ (b) — 2×3.5 m.



- 17.** The total land acquired for a road is called
(a) shoulder (b) formation width (c) carriageway (d) right of way
☐ (d) — Land width.
- 18.** A median separates
(a) footpath and carriageway (b) opposing streams of traffic (c) lanes in the same direction (d) shoulders and drains
☐ (b) — Central divider.
- 19.** Flexible pavements transfer load by
(a) grain-to-grain contact (b) tension only (c) slab action (d) beam action of steel
☐ (a) — Layered system.
- 20.** Rigid pavements are made of
(a) cement concrete (b) earth (c) bitumen (d) gravel
☐ (a) — Concrete slabs.
- 21.** Joints are required in
(a) earth roads (b) rigid pavements (c) gravel roads (d) flexible pavements
☐ (b) — Expansion and contraction.
- 22.** The design life of rigid pavements is about
(a) 20–40 years (b) 100 years (c) 5 years (d) 2 years
☐ (a) — Long life.
- 23.** Initial cost is higher for
(a) rigid pavement (b) flexible pavement (c) gravel road (d) earth road
☐ (a) — Concrete is costlier.
- 24.** Maintenance cost is higher for
(a) flexible pavement (b) both equally (c) rigid pavement (d) neither
☐ (a) — Frequent resurfacing.
- 25.** Night visibility is better on
(a) earth road (b) rigid pavement (c) flexible pavement (d) none
☐ (b) — Light-coloured surface.
- 26.** Super-elevation is provided on
(a) bridges only (b) intersections only (c) straight roads (d) horizontal curves
☐ (d) — Counteracts centrifugal force.
- 27.** Stopping sight distance includes
(a) lag (reaction) distance and braking distance (b) overtaking distance (c) only braking distance (d) camber
☐ (a) — $SSD = \text{lag} + \text{braking}$.
- 28.** The broad gauge width in India is
(a) 1000 mm (b) 1676 mm (c) 762 mm (d) 1435 mm
☐ (b) — 1.676 m.
- 29.** The layer in contact with traffic is the
(a) subgrade (b) sub-base (c) base (d) wearing (surface) course
☐ (d) — Top layer.
- 30.** WBM stands for
(a) wet bitumen mix (b) water-bound macadam (c) wide base material (d) water-based mortar
☐ (b) — Road construction method.

3.19 More solved numericals: Module III

Problem 1. Find the stopping sight distance for a design speed of 80 km/h with a reaction time of 2.5 s and a coefficient of friction of 0.35.

$$\text{Lag distance} = 0.278 V t = 0.278 \times 80 \times 2.5 = 55.6 \text{ m.}$$

$$\text{Braking distance} = V^2/(254 f) = 6400/(254 \times 0.35) = 72.0 \text{ m.}$$

Answer: SSD = 55.6 + 72.0 = 127.6 m (adopt 130 m).

Problem 2. Find the SSD for a speed of 60 km/h ($t = 2.5 \text{ s}$, $f = 0.40$). What would it be on a road with a 3% downgrade?

$$\text{Level: } 0.278 \times 60 \times 2.5 + 3600/(254 \times 0.40) = 41.7 + 35.4 = 77.1 \text{ m.}$$

$$\text{On a downgrade, braking distance} = V^2/[254(f - 0.01n)] = 3600/(254 \times 0.37) = 38.3 \text{ m.}$$
$$\text{SSD} = 41.7 + 38.3 = 80.0 \text{ m.}$$

Answer: 77 m on level; 80 m on a 3% downgrade.

Problem 3. A horizontal curve of radius 250 m is designed for 80 km/h. If the lateral friction is 0.15, find the super-elevation needed.

$$e + f = V^2/(127 R) = 6400/(127 \times 250) = 0.2016.$$

$$e = 0.2016 - 0.15 = 0.0516.$$

Answer: $e \approx 5.2\%$ (within the 7% limit).

Problem 4. A curve of radius 120 m on a highway has a design speed of 65 km/h. Find the design super-elevation by the IRC formula and state what you would provide.

$$e = V^2/(225 R) = 4225/(225 \times 120) = 0.156.$$

$$\text{This exceeds the maximum } 0.07, \text{ so provide } e = 0.07 \text{ and check friction: } f = V^2/(127R) - e = 0.277 - 0.07 = 0.207 > 0.15.$$

Answer: Provide 7% super-elevation; since f needed exceeds 0.15, the speed must be restricted on this curve (or the radius increased).

Problem 5. Find the extra widening on a two-lane road curve of radius 100 m for a design speed of 60 km/h (wheel base 6 m).

$$\text{Mechanical widening} = n l^2/(2R) = 2 \times 36/200 = 0.36 \text{ m.}$$

$$\text{Psychological widening} = V/(9.5\sqrt{R}) = 60/(9.5 \times 10) = 0.63 \text{ m.}$$

Answer: Total extra widening $\approx 1.0 \text{ m}$.

Problem 6. A two-lane road with 7 m carriageway has a parabolic camber of 1 in 50. Find the height of the crown above the edge.

$$\text{Half width} = 3.5 \text{ m. Height} = 3.5/50 = 0.07 \text{ m.}$$

Answer: 70 mm.

Problem 7. A traffic count gives 300 cars (PCU 1), 200 buses and trucks (PCU 3), 500 two-wheelers (PCU 0.5) and 100 bullock carts (PCU 4.5) per hour. Find the traffic volume in PCU/h.



$$300 \times 1 + 200 \times 3 + 500 \times 0.5 + 100 \times 4.5 = 300 + 600 + 250 + 450.$$

Answer: 1600 PCU per hour.

Problem 8. A road climbs from RL 102.50 m to RL 108.50 m over 300 m. Find the gradient and check it against the ruling gradient in plain terrain.

$$\text{Rise} = 6 \text{ m. Gradient} = 6/300 = 1/50 = 2\%.$$

Answer: 1 in 50 (2%), flatter than the ruling gradient of 1 in 30 — acceptable.

Problem 9. A vehicle moving at 72 km/h brakes to a stop in 50 m on a level road. Find the coefficient of friction developed (ignore reaction time).

$$v = 20 \text{ m/s; braking distance} = v^2/(2gf) \Rightarrow f = 400/(2 \times 9.81 \times 50).$$

Answer: $f \approx 0.41$.

Problem 10. Under the Nagpur plan a district of 5000 km² should have a road length of 16 km per 100 km². Find the target road length.

$$\text{Length} = 16 \times 5000/100.$$

Answer: 800 km.

3.20 Short questions with answers: Module III

Q1. What is camber and why is it provided?

The transverse slope of the road surface from the crown to the edges; it drains rainwater quickly off the pavement.

Q2. What is super-elevation?

Raising the outer edge of the road above the inner edge on a curve to counteract centrifugal force.

Q3. Define stopping sight distance.

The minimum distance visible ahead that allows a driver moving at design speed to stop safely before an obstruction; = lag distance + braking distance.

Q4. What is CBR?

California Bearing Ratio: the ratio of the load needed to penetrate a soil sample by a plunger to the load for a standard crushed stone at the same penetration (2.5 or 5 mm), in %. It measures subgrade strength for pavement design.

Q5. Differentiate between WBM and WMM.

In water bound macadam the aggregates are bound by stone dust and water after rolling; in wet mix macadam the graded aggregates and water are premixed in a plant and laid with a paver, giving better quality.

Q6. What are the gauges used in Indian Railways?



Broad gauge 1676 mm, metre gauge 1000 mm and narrow gauges 762 mm and 610 mm.

Q7. What is PMGSY?

Pradhan Mantri Gram Sadak Yojana (2000): a central scheme to provide all-weather road connectivity to unconnected villages.

Q8. What are expansion joints in rigid pavements?

Gaps across the concrete slab, filled with compressible filler and sealed, that allow the slab to expand with temperature without cracking or buckling.

Module IV: Water Supply Engineering

4.1 Sources of water

Surface sources:

- **Rivers and streams:** perennial rivers provide large quantities but water is often turbid and polluted; needs full treatment.
- **Natural lakes and ponds:** quality usually better than rivers (settling), but may contain algae.
- **Impounding reservoirs:** artificial lakes formed by dams across rivers; store water in the rainy season for year-round supply.
- **Sea water:** plentiful but needs costly desalination (reverse osmosis, distillation).
- **Rainwater (rainwater harvesting):** collecting roof and surface runoff for use or for recharging groundwater.

Subsurface (groundwater) sources:

- **Springs:** natural outflow of groundwater at the surface.
- **Wells:** open (dug) wells, tube wells (shallow and deep), artesian wells (water rises under natural pressure).
- **Infiltration galleries and wells:** horizontal perforated conduits or wells in river beds collecting filtered water.

Groundwater is usually clear and free of bacteria (filtered by soil) but may be hard or contain dissolved salts, iron, fluoride or arsenic.

Surface water	Groundwater
Large quantity	Limited quantity; depends on aquifer
Turbid; bacterial contamination likely	Clear; usually free of bacteria
Low dissolved salts (soft)	High dissolved salts (hard; may contain iron, fluoride)
Needs complete treatment	Often needs only disinfection (and specific treatment)
Easily polluted	Protected, but over-extraction lowers the water table

4.2 Quantity of water: per capita demand

The **per capita demand** (q) is the average quantity of water required per person per day (litres per capita per day, lpcd), including all uses in the town divided by the population.

$$\text{Per capita demand } q = \frac{\text{total annual water requirement (litres)}}{(365 \times \text{population})}$$

Components of total demand:

- **Domestic demand:** drinking, cooking, bathing, washing clothes and utensils, flushing toilets, gardening (about 50–60% of total). IS 1172 recommends a domestic demand of about 135 lpcd for houses with full flushing.
- **Commercial and industrial demand:** shops, offices, hotels, factories.
- **Institutional demand:** schools, hospitals, hostels, offices.

- **Public (civic) demand:** street washing, public parks, fountains, public toilets, sewer flushing.
- **Fire demand:** water for fire fighting (small in total quantity but needed at high rate).
- **Losses and wastes:** leakage from pipes, unauthorised connections, meter errors (15–20% is common; to be minimised).

Recommended per capita supply (CPHEEO guidelines, India):

Type of community	Recommended supply (lpcd)
Towns with piped supply but without sewerage	70
Cities with piped supply and sewerage (existing or planned)	135
Metropolitan and mega cities with sewerage	150
Rural areas (Jal Jeevan Mission functional household tap connection)	55

(These figures exclude unaccounted-for water; about 15% may be added for losses.)

Factors affecting per capita demand: size of the city and standard of living; climate (hot, dry climates need more); industries and commerce; quality of water (good quality increases use); pressure in the distribution system (higher pressure → more use and leakage); metering and water pricing (metering reduces waste); sewerage system (flush toilets increase demand); habits of people; conservation measures.

Variations in demand. Demand varies seasonally, daily and hourly (peaks in the morning and evening).

Maximum daily demand $\approx 1.8 \times$ average daily demand; maximum hourly demand $\approx 1.5 \times$ maximum daily hourly rate $\approx 2.7 \times$ average hourly demand

Sources and intake works are designed for the maximum daily demand, and distribution systems for the maximum hourly demand (plus fire demand).

Fire demand (Kuichling's formula, for awareness): $Q = 3182\sqrt{P}$ litres/min, where P is the population in thousands.

Population forecasting (needed to design for 20–30 years ahead):

Arithmetic increase: $P_n = P_0 + n \bar{x}$ ($\bar{x}$ = average increase per decade)
 Geometric increase: $P_n = P_0(1 + r)^n$ (r = average growth rate per decade)
 Incremental increase: $P_n = P_0 + n \bar{x} + [n(n + 1)/2] \bar{y}$ ($\bar{y}$ = average incremental increase)

The arithmetic method suits old, stable cities (gives low values); the geometric method suits young, rapidly growing cities (gives high values); the incremental method gives intermediate values.

4.3 Drinking water standards

Water supplied for drinking must be **potable**: free from pathogenic organisms, harmful chemicals, and objectionable colour, taste and odour. The Indian standard is **IS 10500:2012**.

Parameter	Acceptable limit	Permissible limit (no alternative source)
pH	6.5–8.5	No relaxation
Turbidity	1 NTU	5 NTU
Colour	5 Hazen units	15 Hazen units
Taste and odour	Agreeable	Agreeable
Total dissolved solids (TDS)	500 mg/L	2000 mg/L
Total hardness (as CaCO ₃)	200 mg/L	600 mg/L
Chloride	250 mg/L	1000 mg/L
Fluoride	1.0 mg/L	1.5 mg/L
Nitrate	45 mg/L	No relaxation
Iron	1.0 mg/L	No relaxation
Arsenic	0.01 mg/L	No relaxation (0.05 in earlier edition)
Residual free chlorine	0.2 mg/L (minimum)	1 mg/L
E. coli / thermotolerant coliforms	Shall not be detectable in any 100 mL sample	—

Significance: high fluoride causes dental and skeletal fluorosis; excess nitrate causes methaemoglobinaemia (blue-baby syndrome); arsenic causes skin lesions and cancer; hardness wastes soap and causes scaling; turbidity shelters bacteria; E. coli indicates faecal contamination.

Water-borne diseases: cholera, typhoid, dysentery, hepatitis A and E, diarrhoea, jaundice; hence disinfection is essential.

4.4 Public water supply system: necessity and basic layout

Necessity of a public water supply: safe water in adequate quantity for health and hygiene (prevents water-borne diseases); convenience and saving of time (especially for women and children who otherwise fetch water); fire protection; supports industries, commerce and urban growth; better sanitation (sewerage needs water); economic development.

Basic layout (from source to consumer):

- **Source:** river, lake, reservoir or groundwater.
- **Intake structure:** collects water from the source through screened openings (river intake, reservoir intake tower, canal intake).
- **Pumping station (raw water pumps):** lifts water.
- **Conveyance (transmission main / rising main):** pipes or canals carrying raw water to the treatment plant.
- **Water treatment plant:** removes impurities to make water potable.
- **Clear water reservoir:** stores treated water at the plant.
- **Pumping (clear water pumps) and feeder mains.**
- **Service (distribution) reservoirs:** elevated service reservoirs (overhead tanks, ESR) or ground-level reservoirs (GSR) that balance the difference between constant supply and fluctuating demand, maintain pressure, and store water for fire fighting and

emergencies.

- **Distribution system:** network of mains, sub-mains, branches and service connections with valves (sluice valves, air valves, scour valves), fire hydrants and meters, delivering water to consumers.

Layouts of distribution systems:

Layout	Description	Merits	Demerits
Dead-end (tree) system	One main with sub-mains and branches ending in dead ends	Simple, cheap; easy design	Stagnant water at dead ends; whole area beyond a repair is cut off
Grid-iron (reticulation) system	Mains and branches interconnected like a grid	Water circulates freely; supply from several directions; fewer shutdowns	More pipes and valves; complex design; costlier
Ring (circular) system	Mains laid in rings around blocks	Supply to every point from two directions; good for well-planned towns	Needs more pipes and valves
Radial system	Area divided into zones, each fed radially from a central reservoir	High pressure and quick service	Needs many reservoirs

Systems of supply: continuous (24 × 7, preferred: better quality and pressure) and intermittent (only a few hours a day: water may become contaminated due to negative pressure; needs storage by consumers).

4.5 Conventional water treatment process (working principles only)

Raw surface water contains suspended solids (silt, clay), colloids, colour, bacteria, algae, dissolved gases and minerals. A conventional treatment plant removes these in stages:

- **Screening:** coarse screens (bars) and fine screens at the intake remove floating matter (leaves, plastics, dead animals, fish).
- **Plain sedimentation:** water is held quietly in a large tank (detention time 3–4 h, low velocity) so that heavy suspended particles settle by gravity. It removes about 60–70% of suspended solids but not fine colloidal clay. Tanks may be rectangular (horizontal flow) or circular (radial flow); settled sludge is removed periodically.
- **Sedimentation aided with coagulation:** fine and colloidal particles carry negative charges and do not settle. A **coagulant** (most commonly **alum**, $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$; also ferric chloride, ferrous sulphate, PAC) is added. Steps:
 - **Rapid (flash) mixing** of the coagulant for 30–60 s to disperse it uniformly;
 - **Flocculation:** slow, gentle mixing (20–40 min) in which the neutralised particles collide and form large **flocs**;
 - **Clarification:** flocs settle in a clarifier (detention 2–4 h). Alum reacts with natural alkalinity to form aluminium hydroxide flocs that trap impurities and bacteria. The optimum dose (typically 10–30 mg/L) is found by the **jar test**.
 - **Filtration:** water passes through a bed of sand (and gravel) that removes remaining fine suspended matter, flocs and many bacteria (by straining, sedimentation, adsorption and biological action).

- **Slow sand filters:** fine sand; filtration rate about 100–200 L/m²/h; a biological layer (schmutzdecke) forms on top and removes bacteria very effectively; large area; cleaned by scraping the top layer. Suitable for small towns and less turbid water.
- **Rapid sand filters (rapid gravity filters):** coarser sand; rate about 3000–6000 L/m²/h (30–40 times the slow rate); used after coagulation-sedimentation; cleaned by **backwashing** (reversing flow of water and air); compact; used in large cities.
- **Pressure filters:** rapid filters in closed steel tanks under pressure; used for swimming pools, industries and small installations.
- **Disinfection:** kills remaining pathogenic bacteria and viruses. The most common method is **chlorination** (chlorine gas, bleaching powder or sodium hypochlorite), because it is cheap, effective and leaves a **residual** that protects water in the distribution system (0.2 mg/L free chlorine at the consumer end). **Breakpoint chlorination:** chlorine is added until all demand (ammonia, organic matter) is satisfied and free residual appears. Other methods: boiling (household), UV radiation, ozonation, silver ionisation.
- **Additional treatments (as needed):** aeration (removes gases, taste and odour; oxidises iron and manganese), softening (lime-soda or ion exchange for hard water), defluoridation (Nalgonda technique, activated alumina), removal of arsenic and iron, fluoridation, and reverse osmosis/desalination.

Typical flow sheet: intake with screens → raw water pumps → aeration (optional) → flash mixer (alum) → flocculator → clarifier (sedimentation tank) → rapid sand filter → chlorination → clear water reservoir → pumps → service reservoirs → distribution.

4.6 Public water supply scheme (illustrated)

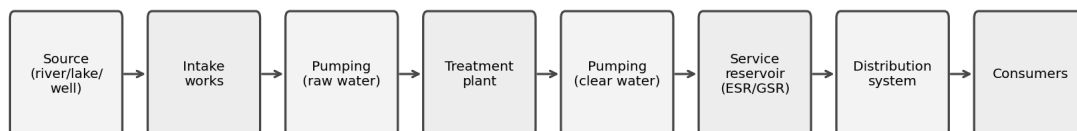


Figure 4.1: Flow diagram of a public water supply scheme from the source to the consumer.

- **Intake works:** structures (intake towers, cribs, pipes with screens) that draw water from the source. They are located upstream of any sewage outfall and where water is deep enough in the dry season.
- **Conveyance:** raw water flows to the treatment plant by gravity (canals, aqueducts, pipes) or by pumping through rising mains.
- **Treatment plant:** makes the water safe and pleasant (Section 4.7).
- **Clear-water reservoir and pumping station:** store treated water and pump it to service reservoirs.
- **Service reservoirs:** elevated (ESR) or ground-level (GSR) tanks that balance the steady supply against the fluctuating demand, keep the pressure in the mains and store water for fire fighting.
- **Distribution system:** mains, sub-mains, branches, valves, hydrants and house service connections that carry water to every consumer.

4.7 Water treatment flow sheet (illustrated)

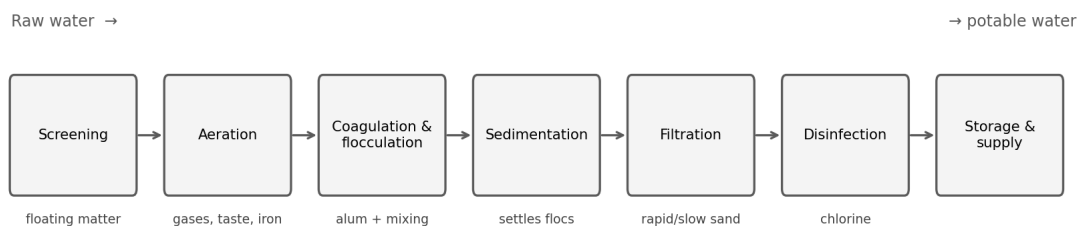


Figure 4.2: Conventional water treatment for surface water. Each unit removes a particular type of impurity.

Unit	Purpose	Impurities removed
Screening (coarse and fine screens)	Protect pumps and pipes	Floating matter: leaves, wood, plastics, fish
Aeration (cascades, spray, trays)	Bring water into contact with air	Dissolved gases (CO_2 , H_2S), taste and odour; oxidises iron and manganese
Plain sedimentation	Settles heavy particles by gravity	Sand, silt
Coagulation (flash mixing with alum)	Neutralises the charge on colloids	Fine clay, colour
Flocculation (slow mixing)	Builds large flocs	—
Sedimentation with coagulation (clarifier)	Settles the flocs	Turbidity reduced to 10–20 NTU
Filtration (rapid or slow sand filter)	Passes water through sand beds	Remaining turbidity, some bacteria (slow sand: up to 99%)
Disinfection (chlorination)	Kills pathogens	Bacteria and viruses; leaves a protective residual
Softening, fluoride and arsenic removal (special)	Only when needed	Hardness, excess fluoride, arsenic, iron

Rapid sand filter versus slow sand filter:

Feature	Slow sand filter	Rapid sand filter
Rate of filtration	100–200 L/m ² /h	3000–6000 L/m ² /h
Area needed	Very large	Small
Pre-treatment	Plain sedimentation only	Coagulation and sedimentation essential
Cleaning	Scraping the top layer (weeks to months)	Back-washing (every 1–2 days)
Bacterial removal	Very good (biological layer)	Less; needs disinfection
Use	Small towns, villages	Cities

4.8 Population forecasting methods

Water supply schemes are designed for a future period (the **design period**, usually 30 years), so the population at the end of that period must be forecast from past census data.

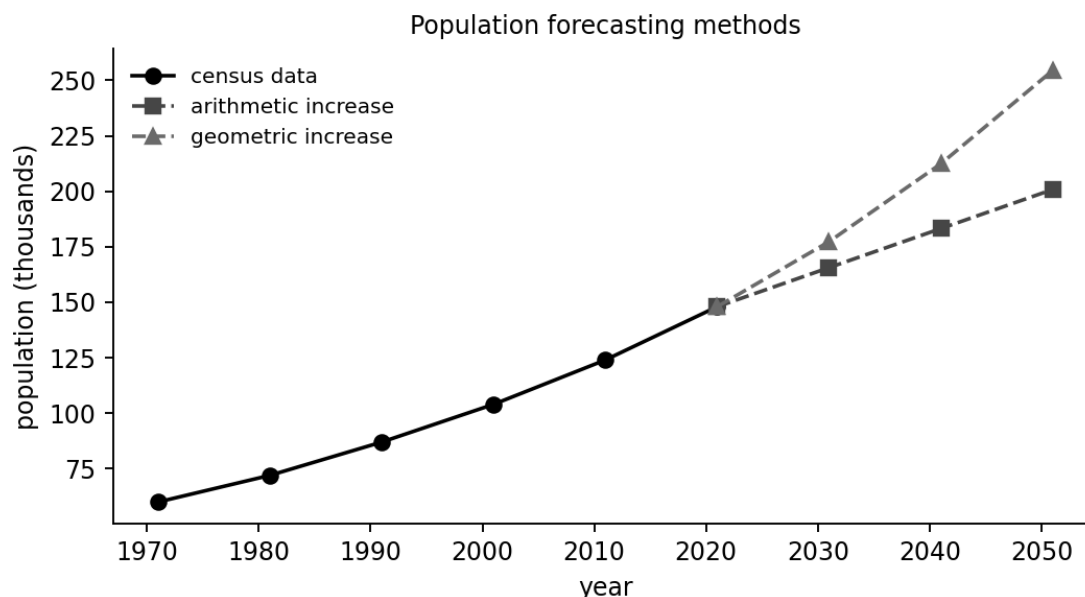


Figure 4.3: Census data of a town (thousands) extrapolated by the arithmetic and geometric increase methods. The geometric method gives higher values.

1. Arithmetic increase method: assumes the population grows by a constant amount each decade. Suitable for large, old, established cities.

$$P_n = P_0 + n \bar{x} \quad (\bar{x} = \text{average increase per decade, } n = \text{number of decades})$$

2. Geometric increase method: assumes a constant percentage growth rate. Suitable for young, rapidly growing towns; may overestimate for old cities.

$$P_n = P_0(1 + r)^n, \quad r = \text{geometric mean of decadal growth rates} = (P_{\text{last}}/P_{\text{first}})^{1/t} - 1$$

3. Incremental increase method: the average increase is itself assumed to change by a constant increment each decade. Gives values between the other two; widely used for medium cities.

$$P_n = P_0 + n \bar{x} + [n(n + 1)/2] \bar{y} \quad (\bar{y} = \text{average of the increments of increase})$$

4. Other methods: decreasing rate of growth, simple graphical method, comparative graphical method (comparison with similar cities), master plan (zoning) method, logistic curve method.

Worked data (used in Figure 4.3): census population (thousands) in 1971-2021 = 60, 72, 87, 104, 124, 148.

Year	Arithmetic	Incremental	Geometric
2031	165.6	168.6	177.3
2041	183.2	192.2	212.4
2051	200.8	218.8	254.4

Increases per decade: 12, 15, 17, 20, 24 ($\bar{x} = 17.6$); increments of increase: 3, 2, 3, 4 ($\bar{y} = 3$); geometric growth rate $r = (148/60)^{1/5} - 1 = 19.8\%$ per decade.

4.9 Variations in demand and design capacities

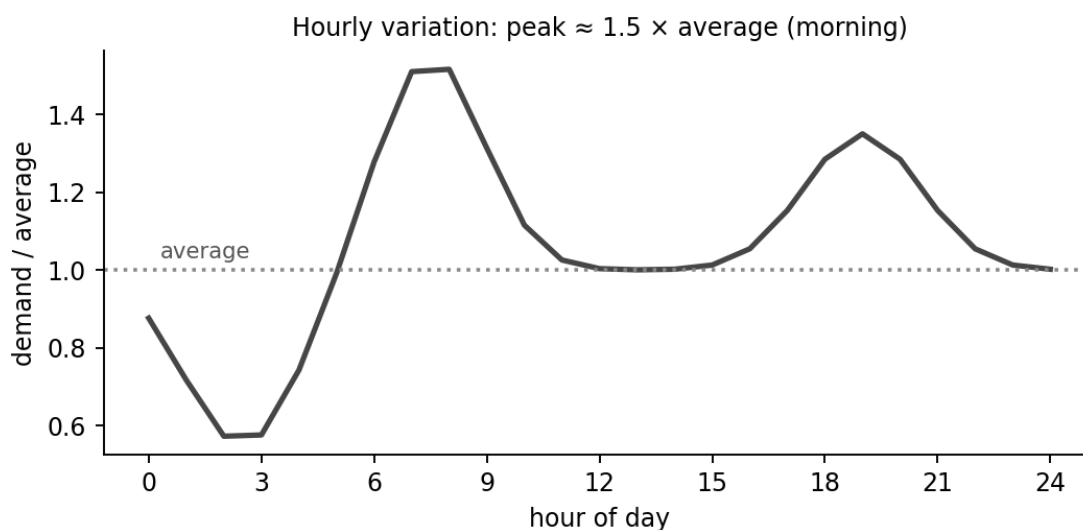


Figure 4.4: Typical hourly variation of water demand in an Indian town: a morning peak, a smaller evening peak and a night-time minimum.

Quantity	Relation to average daily demand	Used to design
Maximum daily demand	$1.8 \times$ average daily	Intake, raw-water pumps, treatment units
Maximum hourly demand (peak)	$1.5 \times$ average hourly of the maximum day = $2.7 \times$ average	Distribution mains, pumps to the network
Seasonal variation	Summer demand higher than average by 10-30%	Storage

Coincident draft: maximum daily demand + fire demand; the distribution system is checked for the larger of coincident draft and maximum hourly demand.

4.10 Distribution systems: methods and layouts

Methods of supply:

- **Gravity system:** the source (lake, reservoir) is at a height above the town; water flows by gravity. Most economical and reliable.
- **Pumping system:** water is pumped directly into the mains; needs continuous power; pressure varies with demand.
- **Combined gravity and pumping (dual) system:** water is pumped to elevated reservoirs, from which it flows by gravity. Most common in Indian towns.

Continuous and intermittent supply: 24×7 supply keeps water fresh and pipes under pressure (no contamination from outside); intermittent supply (a few hours a day) is common but allows back-siphonage of polluted water.

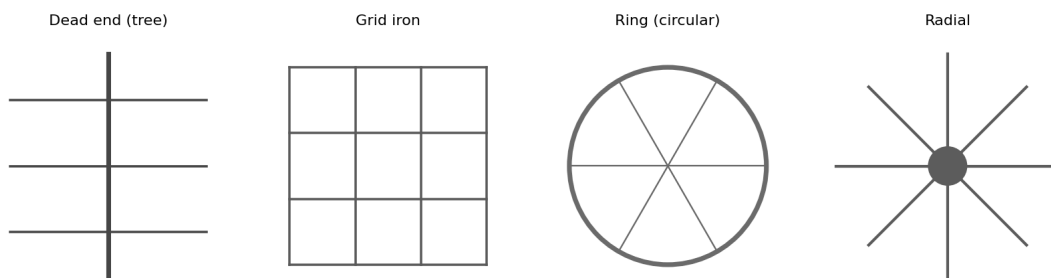


Figure 4.5: Layouts of distribution networks.

Layout	Description	Advantages	Disadvantages
Dead-end (tree)	One main with branches ending in dead ends	Simple, cheap; easy to design	Stagnant water at dead ends; whole area cut off during repair
Grid iron (interlaced)	Mains and branches interconnected in a grid	Water reaches every point from more than one direction; no dead ends; good for fire	More pipes and valves; complex design
Ring (circular)	A ring main around the area with cross connections	Good pressure everywhere; reliable	Longer pipe lengths
Radial	Area divided into zones, each fed from a central reservoir	High pressure; quick service	Needs many reservoirs

Appurtenances: sluice (gate) valves to isolate sections, air valves at summits, scour valves at low points, check (reflux) valves, pressure-relief valves, fire hydrants and water meters.

4.11 Water quality parameters (what each test tells us)

Parameter	IS 10500 acceptable (permissible) limit	Significance
Turbidity	1 NTU (5 NTU)	Suspended matter; protects bacteria from chlorine
pH	6.5–8.5	Low pH corrodes pipes; high pH gives bitter taste and scaling
Total dissolved solids	500 mg/L (2000 mg/L)	Taste; laxative effect at high levels
Total hardness (as CaCO ₃)	200 mg/L (600 mg/L)	Wastes soap; forms scale in boilers
Chloride	250 mg/L (1000 mg/L)	Salty taste; sea-water intrusion
Fluoride	1.0 mg/L (1.5 mg/L)	Excess causes dental and skeletal fluorosis
Nitrate	45 mg/L	Blue-baby syndrome (methaemoglobinaemia)
Iron	1.0 mg/L	Red colour, staining, metallic taste

Parameter	IS 10500 acceptable (permissible) limit	Significance
Arsenic	0.01 mg/L (0.05)	Toxic, carcinogenic
Residual free chlorine	0.2 mg/L minimum	Shows disinfection is effective
Coliform bacteria	Not detectable in 100 mL	Indicates faecal contamination

Water-borne diseases: cholera, typhoid, dysentery, hepatitis A, diarrhoea — prevented by protecting sources, treatment, disinfection and safe storage.

4.12 Rainwater harvesting and water conservation

- **Roof-top rainwater harvesting:** rain on roofs is led through gutters and down-pipes, filtered (first-flush diverter, sand-gravel filter) and stored in tanks or used to recharge groundwater through recharge pits or wells.
- **Potential:** volume harvested = roof area $\times$ rainfall $\times$ runoff coefficient (0.8–0.9 for RCC roofs).
- **Surface run-off harvesting:** check dams, percolation tanks, farm ponds and restoration of traditional tanks.
- **Conservation at home:** fixing leaks, low-flow taps and dual-flush cisterns, reusing grey water for gardens, metering and fair pricing.

4.13 Common mistakes to avoid in Module IV

- Writing that plain sedimentation removes colloidal particles. Colloids need coagulation.
- Mixing up slow and rapid sand filters: slow filters are cleaned by scraping, rapid filters by backwashing.
- Forgetting the residual chlorine requirement (0.2 mg/L) at the consumer end.
- Designing the distribution system for average demand. It must be designed for peak (maximum hourly) demand plus fire demand.

4.14 Solved numericals: Module IV

Problem 1. The census population of a town was 40,000 (1980), 46,000 (1990), 53,000 (2000), 62,000 (2010) and 72,000 (2020). Forecast the population in 2030, 2040 and 2050 by the arithmetic increase method.

Increases per decade: 6000, 7000, 9000, 10000. Average $\bar{x} = 32000/4 = 8000$.

$P_n = P_0 + n \bar{x}$ with $P_0 = 72,000$: 2030: 80,000; 2040: 88,000; 2050: 96,000.

Answer: 80,000; 88,000; 96,000.

Problem 2. For the same data, forecast the population by the incremental increase method.

Incremental increases: $7000 - 6000 = 1000$; $9000 - 7000 = 2000$; $10000 - 9000 = 1000$. Average $\bar{y} = 4000/3 = 1333$.

$P_n = 72000 + 8000n + [n(n+1)/2] \times 1333$.

$n = 1$: $72000 + 8000 + 1333 = 81,333$. $n = 2$: $72000 + 16000 + 3 \times 1333 = 92,000$.

$n = 3$: $72000 + 24000 + 6 \times 1333 = 104,000$.

Answer: About 81,300 (2030), 92,000 (2040), 104,000 (2050).

Problem 3. For the same data, forecast the population by the geometric increase method.

Growth rates: $6000/40000 = 15.0\%$; $7000/46000 = 15.2\%$; $9000/53000 = 17.0\%$; $10000/62000 = 16.1\%$. Average $r \approx 15.8\%$ (the geometric mean $(72000/40000)^{1/4} - 1$ also gives 15.8%).

$P_n = 72000 \times 1.158^n$: 2030: 83,400; 2040: 96,600; 2050: 111,900.

Answer: About 83,400; 96,600; 111,900. (As expected, geometric > incremental > arithmetic.)

Problem 4. A town of 1,00,000 people is to be supplied at 135 lpcd. Find the average daily demand and the maximum daily demand.

Average = $1,00,000 \times 135 = 13.5 \times 10^6$ L/day = 13.5 MLD.

Maximum daily = $1.8 \times 13.5 = 24.3$ MLD.

Answer: 13.5 MLD average; 24.3 MLD maximum daily.

Problem 5. Find the fire demand for a city of 1,00,000 population using Kuichling's formula.

$P = 100$ (thousands). $Q = 3182\sqrt{100} = 31,820$ L/min.

Answer: About 31,800 L/min (≈ 0.53 m³/s).

Problem 6. A plant treats 10 MLD using an alum dose of 20 mg/L. Find the daily requirement of alum.

Alum = $20 \text{ mg/L} \times 10 \times 10^6 \text{ L/day} = 200 \times 10^6 \text{ mg/day} = 200 \text{ kg/day}$.

Answer: 200 kg per day (about 73 tonnes per year).

Problem 7. Find the filter area required for 10 MLD with (a) rapid sand filters at 5000 L/m²/h, (b) slow sand filters at 150 L/m²/h.

Flow = $10 \times 10^6/24 = 4.17 \times 10^5$ L/h.

(a) Area = $4.17 \times 10^5/5000 = 83.3 \text{ m}^2$ (e.g. 4 beds of about 21 m^2 plus a standby).

(b) Area = $4.17 \times 10^5/150 = 2778 \text{ m}^2$.

Answer: 83.3 m² (rapid) vs about 2780 m² (slow): slow sand filters need about 33 times more area.

Problem 8. Design the dimensions of a rectangular sedimentation tank for 10 MLD with a detention time of 4 hours, depth 3 m and length:width = 4:1.

Flow = $10,000 \text{ m}^3/\text{day}$. Volume = $10,000 \times 4/24 = 1666.7 \text{ m}^3$.

Plan area = $1666.7/3 = 555.6 \text{ m}^2$. $4B^2 = 555.6 \Rightarrow B = 11.8 \text{ m}$, $L = 47.1 \text{ m}$.

Answer: About 47 m $\times$ 12 m $\times$ 3 m deep.

Problem 9. A service reservoir must store water for 8 hours of average demand of a town using 12 MLD, plus 1000 m³ for fire. Find its capacity.



Balancing storage (simplified as 8 h of average flow) = $12,000 \times 8/24 = 4000 \text{ m}^3$.
Add fire reserve 1000 m^3 .

Answer: 5000 m^3 (5 ML).

4.15 Practice problems with solutions: Module IV

Q1. A town uses 18 MLD for a population of 1,20,000. Find the per capita demand.

$$q = 18 \times 10^6 / 1,20,000.$$

Answer: 150 lpcd.

Q2. A water sample has TDS 650 mg/L and fluoride 1.2 mg/L. Is it acceptable as per IS 10500?

TDS: above the acceptable 500 but within the permissible 2000 mg/L. Fluoride: above the acceptable 1.0 but within the permissible 1.5 mg/L.

Answer: Usable only if no better source is available (within permissible limits).

Q3. How much bleaching powder (25% available chlorine) is needed per day to dose 5 MLD at 2 mg/L chlorine?

$$\text{Chlorine} = 2 \times 5 \times 10^6 \text{ mg} = 10 \text{ kg/day. Bleaching powder} = 10/0.25.$$

Answer: 40 kg per day.

Q4. Which distribution layout would you choose for (a) an old unplanned town, (b) a well-planned new town with a grid of roads? Why?

(a) Dead-end (tree) system: suits irregular road layouts. (b) Grid-iron system: water can reach any point from several directions; no dead ends.

Answer: Dead-end; grid-iron.

4.16 MCQs: Module IV

1. Which is a subsurface source of water?

- (a) river (b) tube well (c) lake (d) reservoir

☐ (b) — Groundwater.

2. Groundwater usually contains more

- (a) algae (b) turbidity (c) bacteria (d) dissolved salts (hardness)

☐ (d) — Dissolves minerals.

3. The recommended supply for cities with sewerage (CPHEEO) is

- (a) 500 lpcd (b) 70 lpcd (c) 40 lpcd (d) 135 lpcd

☐ (d) — Standard value.

4. Maximum daily demand is about

- (a) $5 \times \text{average}$ (b) $1.8 \times \text{average}$ (c) $1.2 \times \text{average}$ (d) $2.7 \times \text{average}$

☐ (b) — Design of intake and treatment.

5. Maximum hourly demand is about

- (a) $10 \times \text{average}$ (b) $2.7 \times \text{average}$ (c) $1.8 \times \text{average}$ (d) $1.2 \times \text{average}$

☐ (b) — Design of distribution.



- 6.** The population forecast method suitable for old, stable cities is
(a) arithmetic increase (b) geometric (c) incremental (d) logistic only
☐ (a) — Gives lower values.
- 7.** The geometric increase method is suitable for
(a) deserted towns (b) young, rapidly growing cities (c) villages (d) old cities
☐ (b) — Compounding growth.
- 8.** The Indian standard for drinking water is
(a) IS 875 (b) IS 456 (c) IS 1077 (d) IS 10500
☐ (d) — Drinking water specification.
- 9.** The acceptable pH range of drinking water is
(a) 9–10 (b) 7 only (c) 5–6 (d) 6.5–8.5
☐ (d) — IS 10500.
- 10.** The acceptable limit of TDS in drinking water is
(a) 5000 mg/L (b) 500 mg/L (c) 100 mg/L (d) 2000 mg/L
☐ (b) — Permissible 2000 mg/L.
- 11.** The acceptable limit of fluoride in drinking water is
(a) 10 mg/L (b) 5 mg/L (c) 0.1 mg/L (d) 1.0 mg/L
☐ (d) — Permissible 1.5.
- 12.** Excess fluoride in water causes
(a) goitre (b) fluorosis (c) cholera (d) blue-baby syndrome
☐ (b) — Teeth and bones.
- 13.** Excess nitrate in water causes
(a) methaemoglobinaemia (blue-baby syndrome) (b) fluorosis (c) rickets (d) typhoid
☐ (a) — Infants affected.
- 14.** The presence of *E. coli* in water indicates
(a) faecal contamination (b) hardness (c) high pH (d) chlorine
☐ (a) — Indicator organism.
- 15.** The minimum residual free chlorine at the consumer's tap should be
(a) 0 (b) 10 mg/L (c) 5 mg/L (d) 0.2 mg/L
☐ (d) — Protection in pipes.
- 16.** Screens in water treatment remove
(a) bacteria (b) dissolved salts (c) colour (d) floating matter
☐ (d) — First step.
- 17.** Plain sedimentation removes
(a) heavy suspended particles (b) colloidal particles (c) viruses (d) dissolved gases
☐ (a) — Settle by gravity.
- 18.** The most common coagulant is
(a) alum (b) lime (c) bleaching powder (d) chlorine
☐ (a) — Aluminium sulphate.
- 19.** The optimum coagulant dose is found by the
(a) CBR test (b) Vicat test (c) jar test (d) slump test
☐ (c) — Laboratory test.
- 20.** Gentle slow mixing to form flocs is called
(a) filtration (b) aeration (c) flocculation (d) flash mixing
☐ (c) — Floc formation.

- 21.** The biological layer on a slow sand filter is called
(a) scum (b) floc (c) schmutzdecke (d) sludge
☐ (c) — Removes bacteria.
- 22.** Rapid sand filters are cleaned by
(a) chlorination (b) scraping (c) burning (d) backwashing
☐ (d) — Reverse flow.
- 23.** The rate of filtration of a rapid sand filter compared with a slow sand filter is about
(a) 30–40 times higher (b) the same (c) 10 times lower (d) half
☐ (a) — Compact design.
- 24.** The most common disinfection method is
(a) ozone (b) chlorination (c) boiling (d) UV
☐ (b) — Cheap, residual.
- 25.** Breakpoint chlorination ensures
(a) colour addition (b) zero chlorine (c) free residual chlorine after satisfying demand (d) hardness removal
☐ (c) — Definition.
- 26.** Aeration of water removes
(a) hardness completely (b) fluoride (c) dissolved gases, taste and odour; oxidises iron (d) bacteria
☐ (c) — Air contact.
- 27.** The distribution layout with dead ends and stagnant water is
(a) tree (dead-end) system (b) ring system (c) radial system (d) grid-iron
☐ (a) — Branches end.
- 28.** The distribution layout best for well-planned towns is
(a) grid-iron (b) dead-end (c) radial only (d) none
☐ (a) — Interconnected.
- 29.** Elevated service reservoirs are provided to
(a) remove hardness (b) treat water (c) balance demand and maintain pressure (d) filter water
☐ (c) — Storage and pressure.
- 30.** Nalgonda technique is used for
(a) softening (b) disinfection (c) defluoridation (d) desalination
☐ (c) — Fluoride removal.

4.17 More solved numericals: Module IV

Problem 1. Using the census data 60, 72, 87, 104, 124 and 148 thousand (1971–2021), forecast the population in 2031, 2041 and 2051 by the arithmetic, incremental and geometric increase methods.

Increases per decade: 12, 15, 17, 20, 24; $\bar{x} = 88/5 = 17.6$ thousand.

Arithmetic: $P_{2031} = 148 + 17.6 = 165.6$; $P_{2041} = 183.2$; $P_{2051} = 200.8$ thousand.

Increments of increase: 3, 2, 3, 4; $\bar{y} = 3$. Incremental: $P_n = 148 + 17.6n + 3n(n + 1)/2 \Rightarrow 168.6, 192.2, 218.8$ thousand.

Geometric: $r = (148/60)^{1/5} - 1 = 0.198 \Rightarrow 148 \times 1.198^n = 177.3, 212.4, 254.4$ thousand.

Answer: See the table in Section 4.8; the incremental method gives the most reasonable estimate (about 2.19 lakh in 2051).

Problem 2. A town with a design population of 1,00,000 is to be supplied at 135 lpcd. Find the average daily, maximum daily and maximum hourly demands.

Average daily = $1,00,000 \times 135 = 13.5 \times 10^6 \text{ L/day} = 13.5 \text{ MLD}$.

Maximum daily = $1.8 \times 13.5 = 24.3 \text{ MLD}$.

Maximum hourly = $2.7 \times 13.5 = 36.45 \text{ MLD rate (1.52 ML/h)}$.

Answer: 13.5 MLD; 24.3 MLD; 36.5 MLD (as a rate).

Problem 3. Find the fire demand for a town of 50,000 population by Kuichling's formula.

$Q = 3182\sqrt{P}$ with P in thousands = $3182\sqrt{50} = 3182 \times 7.071$.

Answer: About 22,500 L/min (22.5 m³/min).

Problem 4. A pipeline must carry 0.2 m³/s at a velocity of 1.0 m/s. Find the pipe diameter.

Area A = $Q/V = 0.2 \text{ m}^2$. $D = \sqrt{(4A/\pi)} = \sqrt{(0.2546)}$.

Answer: D = 0.505 m, so provide a 500 mm diameter pipe (velocity 1.02 m/s).

Problem 5. A pump lifts 0.1 m³/s of water against a total head of 40 m. Find the power required if the pump efficiency is 70%.

Water power = $\gamma QH = 9.81 \times 0.1 \times 40 = 39.24 \text{ kW}$.

Shaft power = $39.24/0.7 = 56.1 \text{ kW}$.

Answer: About 56 kW ($\approx 75 \text{ hp}$).

Problem 6. A house has a roof area of 100 m² and the annual rainfall is 1500 mm. Find the rainwater that can be harvested with a runoff coefficient of 0.85.

Volume = $\text{area} \times \text{rainfall} \times \text{coefficient} = 100 \times 1.5 \times 0.85 = 127.5 \text{ m}^3$.

Answer: 127.5 m³ = 1,27,500 litres per year.

Problem 7. A service reservoir must store 5 hours of average demand for a town using 6 MLD. Find its capacity and the side of a square tank 4 m deep.

Storage = $6000 \text{ m}^3/\text{day} \times 5/24 = 1250 \text{ m}^3$.

Area = $1250/4 = 312.5 \text{ m}^2$; side = $\sqrt{312.5} = 17.7 \text{ m}$.

Answer: 1250 m³ (1.25 ML); about 17.7 m $\times$ 17.7 m $\times$ 4 m.

Problem 8. A family of 5 uses water as follows per day: drinking and cooking 50 L, bathing 250 L, washing clothes 100 L, utensils 50 L, toilet flushing 150 L, house cleaning 50 L. Find their per capita consumption.

Total = 650 L/day . Per capita = $650/5$.

Answer: 130 lpcd (close to the IS 1172 value of 135 lpcd).



Problem 9. Water from a well has a hardness of 450 mg/L (as CaCO₃) and fluoride of 2.0 mg/L. Comment on its suitability as per IS 10500.

Hardness: acceptable 200, permissible 600 mg/L $\Rightarrow$ within the permissible limit but hard.

Fluoride: permissible limit 1.5 mg/L $\Rightarrow$ exceeds.

Answer: Not fit for drinking without defluoridation (e.g. Nalgonda technique or activated alumina); softening is desirable.

Problem 10. A slow sand filter operates at 150 L/m²/h. What area is needed for a village requiring 0.5 MLD?

Hourly flow = $5,00,000/24 = 20,833$ L/h. Area = $20,833/150$.

Answer: About 139 m² (e.g. two beds of 70 m² each).

4.18 Short questions with answers: Module IV

Q1. Define per capita demand.

The average quantity of water required by one person per day, in litres per capita per day (lpcd).

Q2. Why is chlorine the most used disinfectant?

It is cheap, easily available, effective against most pathogens and leaves a residual that protects water in the distribution system.

Q3. What is the design period of a water supply scheme?

The number of years for which the scheme is designed to serve adequately, usually 30 years for most components.

Q4. What is the purpose of coagulation?

To destabilise and combine fine colloidal particles (which do not settle by themselves) into large flocs that settle quickly; alum is the common coagulant.

Q5. What is the function of a service reservoir?

To balance the constant supply rate against the fluctuating demand, maintain pressure in the mains and store water for fire and emergencies.

Q6. Give two advantages of the grid-iron system.

Water reaches any point from more than one direction, so repairs affect a small area; there are no dead ends, so water does not stagnate.

Q7. What is breakpoint chlorination?

Adding chlorine beyond the point where it has oxidised ammonia and organic matter, after which free residual chlorine increases in proportion to the dose.

Q8. Why is groundwater often preferred for small towns?



It is naturally filtered, clear and free of bacteria, so it usually needs only disinfection, and it is available near the town.

Module V: Irrigation Engineering

5.1 Importance of irrigation

Irrigation is the artificial application of water to land to meet the water requirements of crops when rainfall is insufficient or untimely.

Necessity in India: rainfall is seasonal (most of it in the four monsoon months), unevenly distributed in space and time, and uncertain; some crops (rice, sugarcane) need more water than rainfall provides; a second crop in the dry season (rabi) needs irrigation; increasing population needs more food.

Benefits: increased crop yield and cropping intensity (two or three crops a year); protection against famine and drought; cultivation of cash crops; hydroelectric power and domestic/industrial water from multipurpose projects; navigation; employment; general prosperity (the Green Revolution); recharge of groundwater.

Ill effects (if not managed): waterlogging and salinity (from over-irrigation and seepage from canals), breeding of mosquitoes (malaria), damp climate, loss of land to canals and reservoirs, displacement of people.

5.2 Classification of irrigation projects

By culturable command area (CCA) (Planning Commission, India):

Class	Culturable command area
Major irrigation project	More than 10,000 ha
Medium irrigation project	2,000 to 10,000 ha
Minor irrigation project	Less than 2,000 ha

By purpose: single-purpose (only irrigation) and multipurpose projects.

Command area terms:

- **Gross command area (GCA):** total area that can be irrigated by a canal system, including roads, villages, ponds and uncultivable land.
- **Culturable command area (CCA):** the part of GCA on which cultivation is possible (GCA minus unculturable area).
- **Intensity of irrigation:** percentage of CCA actually irrigated in a season.

5.3 Irrigation systems: types

(a) Flow (gravity) irrigation: water flows to the fields by gravity.

- **Perennial irrigation:** water is available throughout the crop period, from reservoirs created by dams or barrages on perennial rivers.
- **Inundation irrigation:** fields are flooded during high river stages (floods); canals take off without weirs; uncertain supply.
- **Direct irrigation:** water taken directly from a river by a diversion weir or barrage into canals, without storage.
- **Storage irrigation:** a dam stores water in a reservoir, which is released into canals as required.

(b) Lift irrigation: water is lifted (by pumps, Persian wheels, or older devices) from wells, tube wells, rivers or canals to the fields. Tube-well irrigation is the major source in north India.

(c) Surface vs subsurface:

- **Surface irrigation:** water is applied on the soil surface: flooding (free, border strip, check basin), furrow irrigation.
- **Subsurface irrigation:** water is applied below the ground surface to the root zone through perforated pipes or by raising the water table.

(d) Micro/pressurised irrigation (modern, water-saving):

- **Sprinkler irrigation:** water is sprayed into the air like rain through nozzles; suitable for uneven land and sandy soils; saves 25–50% water.
- **Drip (trickle) irrigation:** water is applied drop by drop directly to the root zone through emitters on plastic pipes; efficiency up to 90%; saves 30–70% water; ideal for orchards, vegetables, sugarcane, arid areas.

5.4 Field water distribution (methods of applying water)

- **Free flooding (wild flooding):** water flows over the field without control; cheap but wasteful and uneven.
- **Border strip flooding:** field divided into long narrow strips separated by low ridges (borders); water flows down each strip.
- **Check basin flooding:** field divided into level basins surrounded by small bunds; water fills each basin (rice, wheat).
- **Basin (ring) irrigation:** a circular basin around each tree (orchards).
- **Furrow irrigation:** water runs in small channels (furrows) between crop rows (maize, cotton, sugarcane, vegetables).
- **Sprinkler and drip:** described above.

5.5 Water requirement of crops: duty, delta and base period

- **Base period (B):** the whole period from the first watering at sowing to the last watering before harvest (days).
- **Crop period:** time from sowing to harvesting (slightly longer than B).
- **Delta (Δ):** the total depth of water required by a crop during its base period, if the water were spread uniformly over the area (m or cm). Typical: rice 120–150 cm, sugarcane 90–120 cm, wheat 40–45 cm.
- **Duty (D):** the area (hectares) that can be irrigated by a continuous flow of 1 cumec (1 m³/s) throughout the base period (ha/cumec).

Relation between duty, delta and base period: $\Delta = 8.64 B/D$ (Δ in m, B in days, D in ha/cumec)

Derivation. 1 cumec for B days supplies $1 \times 86,400 \times B$ m³ of water to D hectares = $D \times 10^4$ m². Depth $\Delta = 86400B/(10^4D) = 8.64B/D$ m.

Factors affecting duty: type of crop, climate and season, soil type, method of irrigation, canal losses, quality of water, skill of cultivators. Duty is increased by lining canals, using efficient methods (drip, sprinkler), proper ploughing, and scheduling irrigation.

5.6 Multipurpose river valley projects

A **multipurpose project** uses the water of a river basin for several purposes simultaneously: irrigation, hydroelectric power, flood control, drinking and industrial water supply, navigation, fisheries, recreation, afforestation and soil conservation.

Examples in India: Hirakud Dam (Mahanadi, Odisha: irrigation, power, flood control), Bhakra-Nangal (Sutlej, Punjab/Himachal), Damodar Valley Corporation (Jharkhand/West Bengal: flood control, power, irrigation), Sardar Sarovar (Narmada, Gujarat), Nagarjuna Sagar (Krishna), Tehri (Bhagirathi), Rengali (Brahmani, Odisha), Upper Indravati (Odisha).

Advantages: efficient, integrated use of water; economic development of the region; control of floods; cheaper power. **Problems:** displacement and rehabilitation of people, submergence of forests and land, silting of reservoirs, ecological impact, earthquake risk (reservoir-induced seismicity), inter-state disputes.

5.7 Dams: purpose and types

A **dam** is a barrier constructed across a river or stream to store water (reservoir), raise the water level for diversion, or both.

Purposes: storage for irrigation and water supply; hydroelectric power generation; flood control (flood moderation); navigation; recreation and fisheries.

Types based on material and structural action:

Type	Material and action	Suitable conditions	Examples
Gravity dam	Concrete or masonry; resists water pressure by its own weight	Strong rock foundation; narrow or wide valleys	Bhakra (concrete), Nagarjuna Sagar (masonry)
Earth (embankment) dam	Compacted earth with an impervious clay core; resists by weight and wide base	Weaker foundations; plenty of earth; wide valleys	Hirakud (with concrete/masonry sections), Tehri (earth and rockfill)
Rockfill dam	Dumped rock with an impervious core or membrane	Rock readily available	Tehri (earth and rockfill)
Arch dam	Curved in plan; transfers water load to the valley sides (abutments) by arch action	Narrow gorges with strong rock sides	Idukki (Kerala)
Buttress dam	Sloping deck supported by a series of buttresses	Less concrete; moderate foundations	Few in India

Components: body of the dam, spillway (to pass excess flood water safely), sluices and outlets, gates, galleries (inspection, drainage), foundation and cut-off, freeboard.

Weir and barrage: low structures built to raise the water level for diverting water into canals (a barrage has gates across its full length). Unlike dams, they provide little storage.

5.8 Canal irrigation system: layout, components and definitions

A **canal** is an artificial channel that carries water from a river, weir, barrage or reservoir to the fields.

Hierarchy of a canal system (from head to fields):

- **Head works (diversion or storage works):** weir/barrage or dam with head regulator, which diverts water into the main canal.
- **Main canal:** carries water from the head works; usually no direct irrigation from it (capacity > 10 cumec).
- **Branch canals:** take off from the main canal to serve different parts of the command area (5–10 cumec).
- **Major distributaries:** take off from branch canals and supply water to minors and outlets (0.25–3 cumec).
- **Minor distributaries (minors):** smaller channels supplying water to watercourses (< 0.25 cumec).
- **Watercourses (field channels):** small channels maintained by farmers, taking water from outlets to the individual fields.
- **Outlets:** small structures that transfer water from a distributary to a watercourse.

Alignment of canals:

- **Watershed (ridge) canal:** aligned along the ridge (watershed) line between two drainage valleys; can irrigate both sides by gravity and avoids crossing drains (no cross-drainage works). Most main canals in plains are ridge canals.
- **Contour canal:** aligned nearly parallel to the contours; irrigates only one side (the lower side); used in hilly areas; crosses many drainages.
- **Side-slope canal:** aligned roughly at right angles to the contours, along the side slope; neither on the ridge nor in a valley; does not intercept drainage.

Canal structures (components):

- **Head regulator:** controls entry of water into a canal at its head.
- **Cross regulator:** raises water level in the parent canal to feed off-taking channels.
- **Distributary head regulator:** controls supply into a distributary.
- **Canal falls (drops):** provided where the ground slope is steeper than the canal bed slope, to drop the water level safely.
- **Escapes:** remove excess water from the canal (safety valve).
- **Cross-drainage works:** where a canal crosses a natural drain or river: aqueduct (canal over the drain), syphon aqueduct, super-passage (drain over the canal), level crossing, inlets and outlets.
- **Bridges, culverts, outlets, gauges, silt ejectors and excluders.**

Canal lining: lining with concrete, bricks, stone or plastic films reduces seepage losses (which can be 25–40% in unlined canals), prevents waterlogging, allows higher velocities and smaller sections, reduces maintenance and weed growth.

Definitions (commonly asked):

- **Full supply level (FSL):** the water level in a canal when it carries its full design discharge.
- **Freeboard:** vertical distance between FSL and the top of the canal bank.
- **Berm:** a horizontal strip between the canal and the bank.
- **Kharif and rabi:** kharif crops are sown with the monsoon (June–July) and harvested in autumn (rice, maize, cotton); rabi crops are sown in winter (October–November) and harvested in spring (wheat, gram, mustard).
- **Outlet factor:** the duty at the outlet.

- **Time factor:** ratio of the number of days the canal actually runs to the number of days of the irrigation period.
- **Capacity factor:** ratio of the average discharge to the full supply discharge of a canal.

5.9 Canal system layout (illustrated)

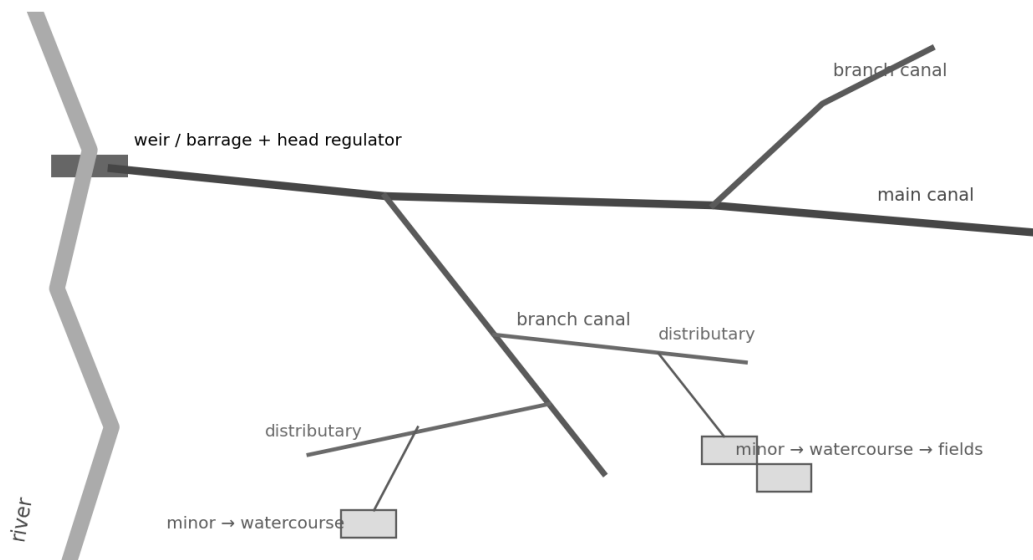


Figure 5.1: Typical layout of a canal irrigation system: head works on the river, main canal, branch canals, distributaries, minors and watercourses leading to the fields.

The discharge carried reduces at each level of the system as water is delivered to the fields. Head regulators at each off-take control the supply, and cross regulators in the parent canal raise the water level so that off-taking channels can draw water.

5.10 Modern methods of applying water (illustrated)

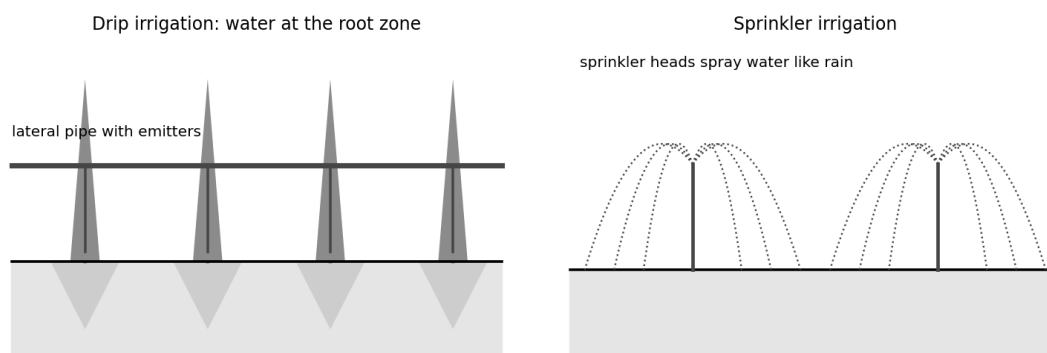


Figure 5.2: Drip irrigation delivers water drop by drop to the root zone; sprinkler irrigation sprays water like rain over the crop.

Method	Efficiency	Suitable for	Advantages	Limitations
Surface flooding (basin, border, furrow)	40–60%	Level land; rice, wheat, row crops	Low cost; simple	Large losses; waterlogging; needs levelling
Sprinkler	70–80%	Undulating land, sandy soils, vegetables, tea, lawns	Uniform application; no levelling; can apply fertiliser	High initial cost; wind drift; needs pressure

Method	Efficiency	Suitable for	Advantages	Limitations
Drip (trickle)	85–95%	Orchards, vegetables, sugarcane, dry regions	Highest water saving; weed control; fertigation; suits saline water	High cost; clogging of emitters; needs filters
Subsurface	—	Where water table can be controlled	No surface loss	Limited to special soils

Government schemes such as **Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)** — "Har Khet Ko Pani" and "More Crop Per Drop" — subsidise drip and sprinkler systems.

5.11 Dams: sections and components (illustrated)

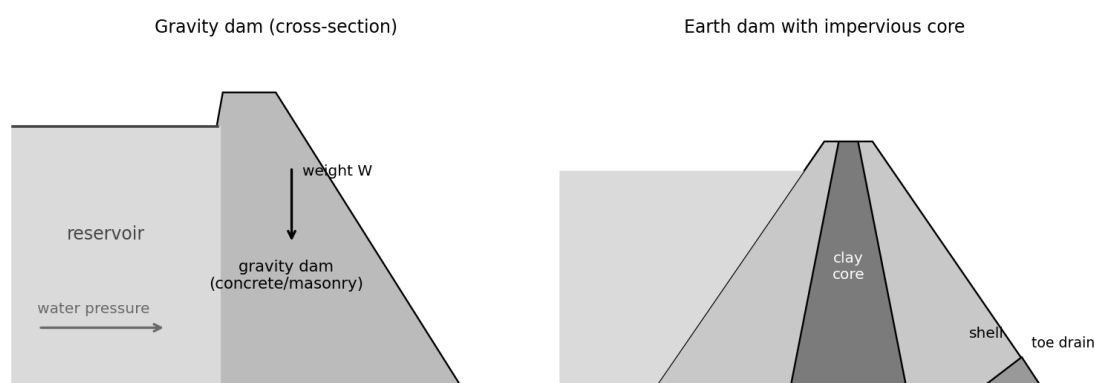


Figure 5.3: Cross-sections of a gravity dam (resists water pressure by its weight) and an earth dam with an impervious clay core.

Main components of a dam:

- **Body of the dam** with **heel** (upstream contact with the ground) and **toe** (downstream contact).
- **Crest and freeboard:** the top of the dam and the margin between the maximum water level and the crest to prevent overtopping by waves.
- **Spillway:** passes surplus flood water safely (ogee, chute, side channel, siphon spillways); essential for safety — most earth dam failures are due to overtopping.
- **Sluices and outlets:** release water for irrigation, water supply and power.
- **Galleries:** inspection tunnels inside concrete dams to observe seepage and uplift.
- **Cut-off wall and grout curtain:** reduce seepage under the dam.
- **Toe drain and filters** (earth dams): collect seepage safely without washing out soil (piping).

Forces on a gravity dam: water pressure (horizontal), self-weight, uplift pressure from seepage below the base, silt pressure, wave pressure, ice pressure and earthquake forces.

Selection of dam site: a narrow valley opening into a wide basin upstream (large storage for small dam length), sound rock foundation, availability of materials, a suitable spillway site, minimum submergence of villages and forest, and good access.

Type	Material	Suitable site	Example
Gravity dam	Concrete or masonry	Good rock foundation; any valley shape	Nagarjuna Sagar (masonry), Bhakra (concrete)
Earth dam	Soil (with core)	Weak foundations, wide valleys; materials available locally	Hirakud (earth + concrete + masonry, one of the longest in the world)
Rock-fill dam	Rock with impervious membrane or core	Where rock is plentiful	Tehri
Arch dam	Concrete	Narrow gorges with strong rock sides	Idukki
Buttress dam	Concrete slab supported by buttresses	Wide valleys with rock; saves concrete	—

5.12 Weirs and barrages

- A **weir** is a low wall across a river that raises the water level so that water can be diverted into a canal; surplus water flows over its crest. It has little or no storage.
- A **barrage** has a low crest with a series of **gates** across the full width; the pond level is controlled by operating the gates, so afflux during floods is small.
- **Head works (diversion head works)** include the weir or barrage, divide wall, fish ladder, undersluices, canal head regulator, silt excluder and river training works (guide banks).

Weir	Barrage
Raises water level by a solid crest	Controls level by gates
Higher afflux (rise in flood level upstream)	Less afflux
Cheaper	Costlier
Silting upstream more	Silt can be flushed through gates

5.13 Ill effects of irrigation and their remedies

- **Waterlogging:** the water table rises close to the ground surface due to over-irrigation and canal seepage, so the root zone becomes saturated and crops suffocate.
Remedies: lining of canals, controlled irrigation, surface and subsurface drains, pumping of groundwater (conjunctive use), crop rotation.
- **Salinity and alkalinity:** salts rise with capillary water and are left on the surface.
Remedies: leaching with good water, drainage, gypsum application, salt-tolerant crops.
- **Breeding of mosquitoes** in stagnant water (malaria), and **damp climate**.
- **Over-exploitation of groundwater** in lift irrigation, lowering the water table.
- **Social and environmental issues** from large projects: displacement of people, submergence of forests, siltation of reservoirs.

5.14 Irrigation in Odisha (case study)

- **Hirakud dam** on the Mahanadi near Sambalpur (completed 1957): a multipurpose project for flood control, irrigation (about 1.5 lakh hectares in kharif and 1 lakh

hectares in rabi), hydropower and fisheries. The main earth dam with its dykes is over 25 km long.

- **Rengali** multipurpose project on the Brahmani, **Upper Indravati**, **Upper Kolab** and **Balimela** projects serve irrigation and power in southern and western Odisha.
- **Mahanadi delta canal system** (Taldanda, Kendrapara canals) from the Mahanadi barrage at Cuttack, one of the oldest canal systems of eastern India.
- **Minor irrigation and lift irrigation** schemes (Odisha Lift Irrigation Corporation) and the **Parbati Giri Mega Lift** scheme supplement the major projects.

5.15 Common mistakes to avoid in Module V

- Using $\Delta = 8.64D/B$ instead of $\Delta = 8.64B/D$.
- Confusing duty (area per unit discharge) with delta (depth of water).
- Calling a contour canal a ridge canal: only the ridge canal irrigates both sides by gravity.
- Writing that aqueducts carry the drain over the canal. An aqueduct carries the canal over the drain; a super-passage carries the drain over the canal.

5.16 Solved numericals: Module V

Problem 1. Find the delta for a crop with a duty of 1728 ha/cumec and a base period of 120 days.

$$\Delta = 8.64B/D = 8.64 \times 120/1728 = 0.6 \text{ m.}$$

Answer: $\Delta = 60 \text{ cm}$.

Problem 2. Rice requires a total depth of 120 cm of water over a base period of 120 days. Find its duty.

$$D = 8.64B/\Delta = 8.64 \times 120/1.2 = 864 \text{ ha/cumec.}$$

Answer: 864 ha/cumec.

Problem 3. Wheat has a delta of 45 cm and a base period of 120 days. Find the duty and the area that 5 cumec can irrigate.

$$D = 8.64 \times 120/0.45 = 2304 \text{ ha/cumec. Area} = 5 \times 2304 = 11,520 \text{ ha.}$$

Answer: Duty 2304 ha/cumec; 11,520 ha.

Problem 4. The gross command area of a canal is 50,000 ha, of which 20% is unculturable. The intensity of irrigation is 60% for rabi (wheat, duty 1800 ha/cumec). Find the discharge needed at the head of the canal if losses are 15%.

$$CCA = 0.8 \times 50,000 = 40,000 \text{ ha. Area irrigated} = 0.6 \times 40,000 = 24,000 \text{ ha.}$$

$$\text{Discharge at field} = 24,000/1800 = 13.33 \text{ cumec. At the head: } 13.33/0.85 = 15.7 \text{ cumec.}$$

Answer: About 15.7 cumec.

Problem 5. A distributary serves kharif rice on 4000 ha (duty 800 ha/cumec) and rabi wheat on 6000 ha (duty 1800 ha/cumec). Find the design discharge.



Kharif: $4000/800 = 5.0$ cumec. Rabi: $6000/1800 = 3.33$ cumec.

The canal must carry the larger of the two.

Answer: 5.0 cumec (governed by kharif rice; add losses for the head).

Problem 6. The duty of a crop at the field is 1500 ha/cumec. If conveyance losses between the head and the field are 20%, what is the duty at the head of the canal?

Only 80% of the water reaches the fields, so 1 cumec at the head irrigates 0.8×1500 ha.

Answer: 1200 ha/cumec (duty decreases towards the head).

Problem 7. Sugarcane with a delta of 1.2 m is grown on 100 ha. Find the total volume of water required.

Volume = area $\times$ depth = $100 \times 10^4 \times 1.2 = 1.2 \times 10^6$ m³.

Answer: 1.2 million m³ (1.2×10^9 litres).

Problem 8. A canal delivers 10 cumec at its head, but only 7 cumec reaches the fields. Find the conveyance efficiency and the water lost per day.

Efficiency = $7/10 \times 100 = 70\%$. Loss = $3 \text{ m}^3/\text{s} \times 86,400 = 2.59 \times 10^5$ m³/day.

Answer: 70%; about 2.6×10^5 m³ per day (lining the canal would reduce this loss).

Problem 9. A reservoir has a live storage of 500 million m³. How many hectares of rice ($\Delta = 1.2$ m) can it irrigate, assuming 20% losses?

Usable water = $0.8 \times 500 \times 10^6 = 400 \times 10^6$ m³. Area = $400 \times 10^6/1.2 = 3.33 \times 10^8$ m² = 33,333 ha.

Answer: About 33,300 ha.

5.17 Practice problems with solutions: Module V

Q1. Find the base period of a crop with duty 1000 ha/cumec and delta 1.0 m.

$B = \Delta D/8.64 = 1.0 \times 1000/8.64$.

Answer: About 116 days.

Q2. Classify irrigation projects with CCA of (a) 1500 ha, (b) 8000 ha, (c) 50,000 ha.

< 2000 ha minor; 2000–10,000 medium; > 10,000 major.

Answer: Minor, medium, major.

Q3. Which irrigation method is most water-efficient for an orchard in a dry area? Why?

Drip irrigation applies water directly to the root zone, minimising evaporation and deep percolation (efficiency up to 90%).



Answer: Drip irrigation.

Q4. Which canal alignment can irrigate both sides by gravity?

A canal on the watershed (ridge) line, since land slopes away on both sides.

Answer: Watershed (ridge) canal.

5.18 MCQs: Module V

1. Irrigation is

- (a) artificial application of water to crops (b) rain harvesting only (c) drainage of excess water (d) flood control only

☐ (a) — Definition.

2. A major irrigation project has CCA of

- (a) more than 10,000 ha (b) 2000–10,000 ha (c) less than 2000 ha (d) exactly 5000 ha

☐ (a) — Planning Commission.

3. A minor irrigation project has CCA of

- (a) 2000–10,000 ha (b) less than 2000 ha (c) more than 10,000 ha (d) none

☐ (b) — Small schemes.

4. The area that can be irrigated including roads and villages is the

- (a) intensity (b) GCA (c) duty (d) CCA

☐ (b) — Gross command area.

5. The relation between duty D, delta Δ and base period B is

- (a) $\Delta = 8.64D/B$ (b) $\Delta = 8.64B/D$ (c) $B = 8.64D\Delta$ (d) $D = 8.64\Delta B$

☐ (b) — Δ in m, B in days.

6. Duty is expressed in

- (a) m (b) ha/cumec (c) days (d) cumec

☐ (b) — Area per unit discharge.

7. Delta is expressed in

- (a) depth (m or cm) (b) ha (c) m^3/s per ha (d) cumec

☐ (a) — Total depth of water.

8. The crop with the largest delta among these is

- (a) rice (b) mustard (c) wheat (d) gram

☐ (a) — About 120 cm or more.

9. Duty increases (improves) when

- (a) evaporation increases (b) soil is sandy and porous (c) canal losses increase (d) canals are lined and efficient methods are used

☐ (d) — Less water needed per ha.

10. Duty at the head of a canal compared with the field is

- (a) smaller (b) zero (c) equal (d) larger

☐ (a) — Losses in transit.

11. Kharif crops are sown in

- (a) winter (b) spring (c) summer only (d) the monsoon (June–July)

☐ (d) — e.g. rice.

12. Rabi crops include

- (a) rice (b) maize (c) wheat (d) cotton

☐ (c) — Winter crops.



- 13. Perennial irrigation provides water**
(a) only in winter (b) throughout the crop period (c) only in floods (d) once a year
□ (b) — Storage/diversion works.
- 14. Inundation irrigation depends on**
(a) sprinklers (b) high river stages (floods) (c) reservoirs (d) tube wells
□ (b) — Uncertain supply.
- 15. Lifting water by pumps from wells is**
(a) lift irrigation (b) flow irrigation (c) subsurface (d) inundation
□ (a) — Mechanical lifting.
- 16. The most water-efficient irrigation method is**
(a) drip irrigation (b) furrow (c) border strip (d) flooding
□ (a) — Up to 90% efficiency.
- 17. Sprinkler irrigation is suitable for**
(a) level clay soils only (b) rice fields (c) flooded land (d) uneven land and sandy soils
□ (d) — Water sprayed like rain.
- 18. Furrow irrigation is suitable for**
(a) row crops like maize and cotton (b) orchards only (c) lawns (d) rice
□ (a) — Water in channels between rows.
- 19. Check basin flooding is commonly used for**
(a) coconut (b) sugarcane in furrows (c) rice and wheat (d) tea
□ (c) — Level basins.
- 20. Waterlogging is caused by**
(a) drip irrigation (b) under-irrigation (c) over-irrigation and canal seepage (d) drought
□ (c) — Rising water table.
- 21. A multipurpose project in Odisha on the Mahanadi is**
(a) Idukki (b) Hirakud (c) Tehri (d) Bhakra
□ (b) — Irrigation, power, flood control.
- 22. A gravity dam resists water pressure by**
(a) cables (b) buttresses (c) arch action (d) its own weight
□ (d) — Massive section.
- 23. An arch dam is suitable for**
(a) sandy rivers (b) flat plains (c) narrow gorges with strong rock abutments (d) wide valleys with weak foundations
□ (c) — Transfers load to sides.
- 24. An earth dam is suitable for**
(a) narrow rock gorges only (b) underwater only (c) weak foundations and wide valleys (d) none
□ (c) — Wide base.
- 25. The structure that passes excess flood water safely from a reservoir is the**
(a) spillway (b) outlet (c) sluice (d) gallery
□ (a) — Safety structure.
- 26. A barrage differs from a weir in that it**
(a) is only for power (b) stores large water (c) has gates across its full length (d) is made of earth
□ (c) — Controlled pond level.



- 27.** The smallest channel of a canal system, maintained by farmers, is the
(a) main canal (b) distributary (c) watercourse (field channel) (d) branch canal
☐ (c) — Outlet to fields.
- 28.** A canal aligned along the ridge line is a
(a) drain (b) contour canal (c) side-slope canal (d) watershed (ridge) canal
☐ (d) — Irrigates both sides.
- 29.** A contour canal irrigates
(a) only its bed (b) only one side (c) both sides (d) no side
☐ (b) — Lower side only.
- 30.** A structure carrying a canal over a natural drain is
(a) an aqueduct (b) a level crossing (c) a super-passage (d) an escape
☐ (a) — Canal above.
- 31.** A structure carrying a drain over a canal is
(a) a fall (b) a super-passage (c) an aqueduct (d) a syphon
☐ (b) — Drain above.
- 32.** A canal fall is provided when
(a) the canal ends (b) the canal crosses a river (c) water is excess (d) the ground slope is steeper than the canal bed slope
☐ (d) — Drops water level.
- 33.** Canal escapes are provided to
(a) measure flow (b) lift water (c) dispose of excess water safely (d) add water
☐ (c) — Safety valve.
- 34.** Canal lining mainly reduces
(a) seepage losses (b) rainfall (c) evaporation (d) crop yield
☐ (a) — Also prevents waterlogging.
- 35.** Freeboard in a canal is the height between
(a) bank and berm (b) bed and FSL (c) ground and bed (d) FSL and top of bank
☐ (d) — Safety margin.

5.19 More solved numericals: Module V

Problem 1. A crop has a base period of 110 days and a delta of 80 cm. Find its duty.

$$D = 8.64B/\Delta = 8.64 \times 110/0.8.$$

Answer: 1188 ha/cumec.

Problem 2. A canal with a discharge of 20 cumec serves a CCA of 40,000 ha. The crops are wheat (duty 1800 ha/cumec, intensity 40%) and sugarcane (duty 730 ha/cumec, intensity 15%) in the same season. Is the discharge enough?

$$\text{Wheat area} = 0.40 \times 40,000 = 16,000 \text{ ha} \Rightarrow Q = 16,000/1800 = 8.89 \text{ cumec.}$$

$$\text{Sugarcane area} = 0.15 \times 40,000 = 6000 \text{ ha} \Rightarrow Q = 6000/730 = 8.22 \text{ cumec.}$$

$$\text{Total needed} = 17.1 \text{ cumec} < 20 \text{ cumec.}$$

Answer: Yes; 20 cumec is enough (about 2.9 cumec margin for losses).

Problem 3. Water is delivered to a field at 0.5 cumec for 8 hours. Measurements show that 10,000 m³ is stored in the root zone. Find the water application efficiency.

$$\text{Water delivered} = 0.5 \text{ m}^3/\text{s} \times 8 \times 3600 \text{ s} = 14,400 \text{ m}^3.$$

$$\text{Efficiency} = \text{water stored}/\text{water delivered} = 10,000/14,400.$$

Answer: About 69% (the remaining 31% is lost to deep percolation and surface runoff).

Problem 4. A field of 2 ha needs a depth of 8 cm of water per irrigation. How long will a tube well of 30 L/s take?

$$\text{Volume} = 2 \times 10^4 \times 0.08 = 1600 \text{ m}^3. \text{ Time} = 1600/0.030 = 53,333 \text{ s}.$$

Answer: About 14.8 hours.

Problem 5. A drip system saves 40% of the water used by flooding. If flooding needs 1.2 m depth for a crop on 50 ha, how much water does drip save?

$$\text{Flooding volume} = 50 \times 10^4 \times 1.2 = 6 \times 10^5 \text{ m}^3. \text{ Saving} = 0.4 \times 6 \times 10^5.$$

Answer: $2.4 \times 10^5 \text{ m}^3$ (enough to irrigate about 33 ha more by drip).

Problem 6. The time factor of a canal is 0.6 and its full supply discharge is 10 cumec. It runs at an average of 7 cumec when open. Find the capacity factor and the days it runs in a 120-day period.

$$\text{Days run} = 0.6 \times 120 = 72 \text{ days}. \text{ Capacity factor} = 7/10 = 0.7.$$

Answer: 72 days; capacity factor 0.7.

Problem 7. A reservoir loses 2 mm of water per day by evaporation over a surface area of 50 km². Find the daily loss.

$$\text{Volume} = 50 \times 10^6 \text{ m}^2 \times 0.002 \text{ m} = 10^5 \text{ m}^3/\text{day}.$$

Answer: 1,00,000 m³ per day ($\approx$ 1.16 cumec continuously).

5.20 Short questions with answers: Module V

Q1. Define duty and delta.

Duty is the area irrigated per unit discharge running continuously for the base period (ha/cumec). Delta is the total depth of water required by a crop over its base period.

Q2. What is the relation between duty, delta and base period?

$$\Delta = 8.64B/D, \text{ where } \Delta \text{ is in metres, } B \text{ in days and } D \text{ in ha/cumec.}$$

Q3. What is the difference between a weir and a barrage?

A weir raises the water level by a solid crest; a barrage controls the level with a series of gates, giving less afflux.



Q4. What is waterlogging and how is it prevented?

The saturation of the root zone due to a high water table; prevented by canal lining, controlled irrigation, drainage and conjunctive use of groundwater.

Q5. What is a spillway?

A structure that passes surplus flood water safely from a reservoir, preventing overtopping of the dam.

Q6. What is a multipurpose project? Give an example from Odisha.

A river valley project serving several purposes such as irrigation, hydropower, flood control and water supply, e.g. the Hirakud dam on the Mahanadi.



Two-Mark Questions with Answers (University Pattern)

Module I

Q1. What is the scope of civil engineering?

Planning, design, construction and maintenance of buildings, roads, railways, bridges, dams, canals, water supply, sewerage, ports and airports — the physical infrastructure of society.

Q2. Name any four disciplines of civil engineering.

Structural, geotechnical, transportation and environmental engineering (also water resources, surveying, construction management, town planning).

Q3. How does NBC classify buildings by occupancy?

Group A residential, B educational, C institutional, D assembly, E business, F mercantile, G industrial, H storage, J hazardous.

Q4. What is the difference between substructure and superstructure?

The substructure is the part below plinth level (foundation) that transfers load to the soil; the superstructure is the part above the plinth (walls, floors, roof).

Q5. List four factors for selection of a residential site.

Good bearing soil and drainage, availability of water and electricity, good access and transport, healthy surroundings away from nuisances (also cost, future development, pleasant view).

Q6. What is the function of a lintel?

To carry the load of the wall above a door or window opening and transfer it to the walls on either side.

Q7. What is differential settlement?

Unequal settlement of different parts of a structure, which causes cracks and distress; it is reduced by uniform pressure design and raft foundations.

Q8. What is the meaning of "interdisciplinary nature" of construction projects?

A project needs civil, architectural, mechanical, electrical, environmental and management expertise working together, e.g. a hospital building needs structures, HVAC, electrical, plumbing and fire services.

Module II

Q1. Give four qualities of a good building stone.

High crushing strength, low water absorption (< 5%), durability and resistance to weathering, and good appearance and workability.



Q2. What are the standard dimensions of a modular brick?

190 × 90 × 90 mm (nominal 200 × 100 × 100 mm with mortar).

Q3. What are the grades of OPC?

33, 43 and 53 grades — the 28-day compressive strength in N/mm².

Q4. What is the difference between fine and coarse aggregate?

Fine aggregate (sand) passes the 4.75 mm IS sieve; coarse aggregate is retained on it.

Q5. What is the function of sand in mortar?

It acts as an inert filler, reduces shrinkage and cracking, increases volume (economy) and helps setting by allowing air and water movement.

Q6. What is RCC?

Reinforced cement concrete: concrete with steel bars placed where tension develops; concrete resists compression and steel resists tension.

Q7. Why is steel used with concrete?

Concrete is weak in tension; steel is strong in tension, bonds well with concrete and has nearly the same coefficient of thermal expansion.

Q8. What is glass made of?

Mainly silica (sand), soda ash and lime, melted at about 1500 °C and cooled.

Module III

Q1. Give four advantages of road transport.

Door-to-door service, flexibility of routes and timing, suitable for short distances and perishable goods, feeds other modes (rail, air, water).

Q2. What is the Golden Quadrilateral?

A highway network (about 5846 km) connecting Delhi, Mumbai, Chennai and Kolkata under the National Highways Development Project.

Q3. What are the components of a road?

Subgrade, sub-base, base course, surface course, shoulders, camber, side drains, kerbs and right of way.

Q4. Differentiate between flexible and rigid pavements in one line each.

Flexible: bituminous layers transfer load grain to grain; rigid: a concrete slab transfers load by slab action over a wide area.

Q5. What is the ruling gradient?



The maximum gradient within which the designer attempts to design the vertical profile (1 in 30 in plain terrain).

Q6. What is ballast in railways?

Crushed stone below and around the sleepers that distributes load to the formation, holds sleepers in position and provides drainage.

Module IV

Q1. Name the surface and underground sources of water.

Surface: rivers, lakes, ponds, reservoirs, sea. Underground: springs, open wells, tube wells, infiltration galleries.

Q2. What is the per capita demand recommended by IS 1172 for houses with full flushing?

135 lpcd (the CPHEEO manual recommends 135–150 lpcd for metropolitan cities).

Q3. What are the acceptable limits of pH and turbidity for drinking water?

pH 6.5–8.5; turbidity 1 NTU (permissible 5 NTU) as per IS 10500.

Q4. What is the purpose of aeration?

To remove dissolved gases (CO_2 , H_2S), tastes and odours, and to oxidise iron and manganese.

Q5. What is alum? Why is it used?

Aluminium sulphate, $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$, the most common coagulant; it forms gelatinous flocs that trap fine particles.

Q6. What is a dead end in a distribution system?

The end of a branch pipe with no further connection, where water stagnates; typical of the tree system.

Module V

Q1. Define irrigation.

The artificial application of water to land for raising crops, when rainfall is insufficient or irregular.

Q2. Classify irrigation projects based on CCA.

Major (> 10,000 ha), medium (2000–10,000 ha) and minor (< 2000 ha).

Q3. Define gross command area and culturable command area.

GCA is the total area that can be irrigated by a canal system including roads, villages and ponds. CCA is the part of GCA that is fit for cultivation.



Q4. What is intensity of irrigation?

The percentage of the CCA that is irrigated in a particular season.

Q5. What is an aqueduct?

A cross-drainage work in which the canal is carried over a natural drain on a bridge-like structure.

Q6. What is canal lining? Give two advantages.

A layer of concrete, bricks, stone or plastic on the bed and sides of a canal. It reduces seepage losses and prevents waterlogging.



Long-Answer Questions with Model Answers

These answers are written at the length expected for 8–10 marks. Draw the figure mentioned wherever possible; it earns marks.

Module I

Q1. Explain the role of civil engineering in the infrastructure development of a nation. (8 marks)

Introduction: Infrastructure — the basic physical systems that a society needs — is planned, built and maintained by civil engineers. It includes transport, water, energy, housing and communication structures.

Transport: roads, railways, bridges, ports and airports connect production centres to markets, reduce travel time and cost, and open up rural areas (PMGSY, Bharatmala, dedicated freight corridors).

Water resources: dams, canals and irrigation systems increase agricultural production and give hydropower and flood control (Hirakud, Bhakra). Water supply and sewerage protect public health.

Housing and buildings: homes, schools, hospitals, offices and factories; smart cities and affordable housing schemes (PMAY).

Energy infrastructure: foundations and structures for power plants, transmission towers, wind and solar farms.

Economic and social benefits: infrastructure creates jobs, attracts industry, improves quality of life and supports disaster resilience (cyclone shelters in coastal Odisha).

Conclusion: economic growth is closely linked to infrastructure; hence civil engineering is called the backbone of national development.

Q2. Describe the basic components of a building with a neat sketch and state the requirements of each. (10 marks)

Draw Figure 1.2 (building cross-section). Describe: foundation (safe transfer of load, adequate depth, no excessive settlement); plinth (height 450–600 mm, prevents entry of water and insects); DPC (continuous, impervious); walls (strength, stability, weather resistance, insulation); columns (strength, slenderness limits); floors (strong, durable, level, non-slippery, easy to clean); doors and windows (adequate size, light, ventilation, security); lintels and sills; stairs (rise 150–175 mm, tread 250–300 mm, handrail, headroom 2.1 m); roof (waterproof, strong, insulating, drains water); parapet (safety, about 1 m high); building finishes (plaster, paint).

Q3. What are the factors considered in selecting a site for a residential building? (8 marks)

Soil and bearing capacity; level and drainage (site slightly higher than surroundings, not waterlogged or filled ground); availability of water, electricity, sewerage and roads; access to schools, hospitals, markets and workplace; surroundings free from noise, smoke, factories, swamps; orientation for sun and breeze; size and shape of plot allowing future expansion; legal aspects (clear title, bye-laws); cost of land and construction; natural hazards (flood lines, landslide, seismic zone).

Q4. Classify foundations. Explain with sketches the conditions in which isolated, combined, raft and pile foundations are used. (10 marks)

Draw Figure 1.3. Shallow ($D \leq B$): spread/strip, isolated, combined, strap, raft. Deep: pile, well, pier. Isolated — individual columns with moderate loads on good soil; combined — columns close together or near the boundary; raft — weak soil or heavy loads where footings would cover more than half the area; pile — weak soil at shallow depth with a firm stratum below, or heavy loads, water-logged sites, bridges. Mention end-bearing and friction piles, and the comparison table of shallow versus deep foundations.

Q5. Define bearing capacity and related terms. How can the bearing capacity of soil be improved? (8 marks)

Define ultimate (q_u), net ultimate ($q_{nu} = q_u - \gamma D_f$), net safe (q_{nu}/F), safe ($q_{nu}/F + \gamma D_f$) and allowable bearing pressure (considering settlement). Give typical values (table in Section 1.11). Improvement: increasing depth, compaction, drainage, confinement, soil replacement, grouting and chemical stabilisation, sand piles and vibroflotation. Include one numerical example.

Module II

Q1. What are the characteristics of good bricks? Describe the tests conducted on bricks. (8 marks)

Characteristics: uniform size and colour, sharp edges, ringing sound, compressive strength $\geq 3.5 \text{ N/mm}^2$ (≥ 10.5 for first class), water absorption $\leq 20\%$, no efflorescence, no cracks or lumps, should not break when dropped. Tests: compressive strength, water absorption, efflorescence, dimension tolerance, hardness and soundness field tests (Section 2.16). Mention the modular size and classification of bricks.

Q2. Describe the manufacture of cement by the dry process with a flow diagram and list the tests on cement. (10 marks)

Raw materials: limestone (calcareous) and clay/shale (argillaceous). Dry process: crushing $\rightarrow$ proportioning $\rightarrow$ grinding to raw meal $\rightarrow$ blending $\rightarrow$ burning in a rotary kiln at $1400\text{--}1500^\circ\text{C}$ to form clinker $\rightarrow$ cooling $\rightarrow$ grinding with 3–5% gypsum $\rightarrow$ packing in 50 kg bags. Compounds C_3S , C_2S , C_3A , C_4AF . Tests: fineness, consistency, setting time, soundness, compressive strength, heat of hydration (Section 2.15).

Q3. What is concrete? Explain its ingredients, properties and the importance of the water-cement ratio and curing. (10 marks)



Concrete = cement + fine aggregate + coarse aggregate + water (+ admixtures). Properties of fresh concrete: workability, segregation, bleeding; hardened: strength, durability, shrinkage, creep. Grades (Section 2.18). Abrams' law and Figure 2.3; limits on w/c. Curing methods and duration. Advantages and uses of PCC and RCC.

Q4. Discuss the properties and uses of steel, timber, glass and plastics in construction. (8 marks)

Steel: high tensile and compressive strength, ductility, weldability; reinforcement, structural frames (Figure 2.4, table of grades). Timber: light, good insulator, easy to work, needs seasoning and preservation; doors, windows, formwork. Glass: transparent, brittle, weather resistant; windows, facades (toughened, laminated, double-glazed). Plastics: light, corrosion-free, mouldable; pipes (PVC, HDPE), water tanks, doors, sheets.

Module III

Q1. Explain the importance of transportation and compare the different modes of transportation. (8 marks)

Importance: economic development, movement of goods and people, national integration, defence, access to services, employment. Compare road, rail, air and water on speed, cost, flexibility, capacity, safety and suitability (table in Section 3.14). Conclude that an integrated multimodal system is best.

Q2. Classify roads according to the Nagpur plan and IRC. Explain the functions of each. (8 marks)

NH, SH, MDR, ODR, VR (table in Section 3.11); urban roads: arterial, sub-arterial, collector, local streets; expressways. Mention the road development plans and current programmes.

Q3. Draw the typical cross-section of a highway and explain its components. (10 marks)

Draw Figure 3.1 and Figure 3.2. Explain carriageway, camber, shoulders, formation width, side slopes, side drains, right of way, kerbs, medians; pavement layers — subgrade, sub-base, base, surface — with their functions and materials.

Q4. Compare flexible and rigid pavements in detail. (8 marks)

Use the table in Section 3.9 (surface material, load transfer, design basis, cost, maintenance, life, temperature effects, joints, opening to traffic, visibility) with the sketch of load distribution.

Module IV

Q1. What are the sources of water? Compare surface water and groundwater. (8 marks)

List surface and subsurface sources with a line each (Section 4.1), then give the comparison table: quantity, quality, dissolved salts, bacterial contamination, treatment needed, reliability and cost.

Q2. What is per capita demand? Explain the factors affecting it and the variations in demand. (8 marks)

Definition and formula; components (domestic, commercial, industrial, public, fire, losses); factors (size, climate, standard of living, industries, pressure, metering, quality, sewerage); variations — seasonal, daily, hourly (Figure 4.4) and design values (1.8 and 2.7 times average).

Q3. Draw a neat flow diagram of a conventional water treatment plant and explain the function of each unit. (10 marks)

Draw Figure 4.2. Explain screening, aeration, plain sedimentation, coagulation-flocculation (alum), clarifier, rapid sand filter (with back-washing), chlorination (residual, breakpoint), clear-water storage. Add the comparison of slow and rapid sand filters.

Q4. Explain the layouts of distribution systems with sketches. (8 marks)

Draw Figure 4.5. Describe dead-end, grid-iron, ring and radial systems with advantages and disadvantages (table in Section 4.10); mention gravity, pumping and combined methods of supply and continuous versus intermittent supply.

Module V

Q1. What is irrigation? Explain its necessity, advantages and ill effects. (8 marks)

Definition; necessity — insufficient, uneven or uncertain rainfall, growing more than one crop, high-value crops; advantages — higher yield, food security, drought protection, hydropower, water supply, employment; ill effects — waterlogging, salinity, mosquito breeding, displacement from projects; remedies (Section 5.13).

Q2. Define duty, delta and base period and derive the relation between them. (8 marks)

Definitions with units. Consider D hectares irrigated by 1 cumec for B days: volume = $1 \times 86,400 \times B \text{ m}^3$; depth over D ha = $86,400B/(D \times 10^4) = 8.64B/D \text{ metres} = \Delta$. Factors affecting duty and methods of improving it; a worked example.

Q3. Explain the types of dams with neat sketches and the factors governing the selection of a dam site. (10 marks)

Draw Figure 5.3. Gravity, earth, rock-fill, arch, buttress dams with suitable sites and examples; components (spillway, sluices, galleries, freeboard, cut-off); forces on a gravity dam; site selection factors (Section 5.11).



Q4. Draw the layout of a canal irrigation system and explain its components. (8 marks)

Draw Figure 5.1. Head works, main canal, branch canals, distributaries, minors, watercourses, outlets; alignment (ridge, contour, side-slope); regulators, falls, escapes, cross-drainage works; canal lining.



Model Question Papers with Answer Keys

Model paper 1 (Full marks 100, time 3 hours)

Part I: Answer all questions ($2 \times 10 = 20$ marks)

- (a) Name the NBC occupancy groups for a school and a hospital.
- (b) What is the purpose of a damp-proof course?
- (c) Define safe bearing capacity.
- (d) What is the function of gypsum in cement?
- (e) State Abrams' water-cement ratio law.
- (f) What is camber? Give its value for a bituminous road.
- (g) Differentiate between NH and SH.
- (h) What is the per capita demand recommended by IS 1172?
- (i) Define duty of water.
- (j) What is a super-passage?

Part II: Answer any eight ($6 \times 8 = 48$ marks)

- (a) Explain the interdisciplinary nature of construction projects with an example.
- (b) Find the size of a square footing for a column load of 900 kN on soil with a safe bearing capacity of 180 kN/m² (self-weight 10%).
- (c) Describe any three tests on cement.
- (d) Calculate the materials for 3 m³ of M20 (1:1.5:3) concrete.
- (e) Compare flexible and rigid pavements.
- (f) Find the SSD for 80 km/h ($t = 2.5$ s, $f = 0.35$).
- (g) Explain the layout of a public water supply system.
- (h) Forecast the population for the next two decades by the geometric method from 40,000, 48,000 and 57,600 in the last three censuses.
- (i) Explain the methods of field water distribution.
- (j) Find the delta for a crop with duty 1500 ha/cumec and base period 120 days.

Part III: Answer any two ($16 \times 2 = 32$ marks)

- (a) Classify foundations and explain raft and pile foundations with sketches.
- (b) Draw the flow diagram of a water treatment plant and explain each unit.
- (c) Explain the types of dams with sketches and the components of a canal system.

Answer key for the numericals of Model paper 1

Problem 1. Part II (b): square footing for 900 kN, $q = 180$ kN/m².

Total load = 990 kN; area = $990/180 = 5.5$ m²; side = $\sqrt{5.5} = 2.35$ m.

Answer: 2.35 m $\times$ 2.35 m (say 2.4 m square).

Problem 2. Part II (d): materials for 3 m³ of M20 (1:1.5:3).

Dry volume = $1.54 \times 3 = 4.62$ m³; sum of ratio = 5.5.

Cement = 0.84 m³ = 24.2 bags; sand = 1.26 m³; coarse aggregate = 2.52 m³.

Answer: About 24 bags of cement, 1.26 m³ sand, 2.52 m³ coarse aggregate.

Problem 3. Part II (f): SSD for 80 km/h.



$$0.278 \times 80 \times 2.5 + 80^2/(254 \times 0.35) = 55.6 + 72.0.$$

Answer: 127.6 m.

Problem 4. Part II (h): geometric method with 40,000, 48,000, 57,600.

Growth rates: $8000/40,000 = 20\%$; $9600/48,000 = 20\%$; $r = 0.20$.

Next census: $57,600 \times 1.2 = 69,120$; the one after: $69,120 \times 1.2 = 82,944$.

Answer: 69,120 and 82,944.

Problem 5. Part II (j): delta for D = 1500 ha/cumec, B = 120 days.

$$\Delta = 8.64 \times 120/1500.$$

Answer: 0.691 m $\approx$ 69 cm.

Model paper 2 (Full marks 100, time 3 hours)

Part I ($2 \times 10 = 20$ marks)

- (a) List four disciplines of civil engineering.
- (b) What is FAR?
- (c) What are the standard dimensions of a modular brick?
- (d) What is seasoning of timber?
- (e) Name the layers of a flexible pavement.
- (f) What are the gauges of Indian Railways?
- (g) Give the acceptable limit of fluoride in drinking water.
- (h) What is breakpoint chlorination?
- (i) Define CCA and intensity of irrigation.
- (j) Distinguish between a weir and a barrage.

Part II: any eight ($6 \times 8 = 48$ marks)

- (a) Explain the planning principles of a residential building (aspect, prospect, privacy, grouping, circulation).
- (b) The net ultimate bearing capacity of a soil is 600 kN/m^2 . Find the safe bearing capacity for $D_f = 1 \text{ m}$, $\gamma = 18 \text{ kN/m}^3$ and $F = 3$.
- (c) Describe the qualities and uses of good building stones.
- (d) Find the number of bricks and the mortar needed for a $4 \text{ m} \times 3 \text{ m} \times 0.2 \text{ m}$ wall.
- (e) Explain the geometric design elements: gradient, sight distance and super-elevation.
- (f) Find the super-elevation for $V = 80 \text{ km/h}$ and $R = 250 \text{ m}$ with $f = 0.15$.
- (g) Compare surface water and groundwater.
- (h) Find the average and maximum daily demand of a town of 60,000 people at 135 lpcd.
- (i) Explain waterlogging, its causes and remedies.
- (j) A canal has a CCA of 30,000 ha; intensity for rice is 50% with duty 900 ha/cumec. Find the discharge at the head with 20% losses.

Part III: any two ($16 \times 2 = 32$ marks)

- (a) Discuss the properties and uses of cement, concrete and steel.



- (b) Draw the cross-section of a highway and explain its components; classify roads as per the Nagpur plan.
- (c) Explain the necessity of irrigation, types of irrigation systems and modern methods (drip, sprinkler).

Answer key for the numericals of Model paper 2

Problem 1. Part II (b): $q_{nu} = 600 \text{ kN/m}^2$, $D_f = 1 \text{ m}$, $\gamma = 18 \text{ kN/m}^3$, $F = 3$.

$$q_s = 600/3 + 18 \times 1 = 200 + 18.$$

Answer: 218 kN/m^2 .

Problem 2. Part II (d): wall $4 \text{ m} \times 3 \text{ m} \times 0.2 \text{ m}$ with modular bricks.

$$\text{Volume} = 2.4 \text{ m}^3; \text{bricks} = 2.4/0.002 = 1200.$$

$$\text{Brick volume} = 1200 \times 0.001539 = 1.847 \text{ m}^3; \text{wet mortar} = 0.553 \text{ m}^3; \text{dry mortar} = 1.27 \times 0.553 = 0.702 \text{ m}^3.$$

Answer: 1200 bricks; about 0.70 m^3 of dry mortar (for 1:6, cement $0.10 \text{ m}^3 \approx 2.9$ bags, sand 0.60 m^3).

Problem 3. Part II (f): e for $V = 80 \text{ km/h}$, $R = 250 \text{ m}$, $f = 0.15$.

$$e = V^2/(127R) - f = 0.2016 - 0.15.$$

Answer: $e \approx 0.052$ (5.2%).

Problem 4. Part II (h): 60,000 people at 135 lpcd.

$$\text{Average} = 60,000 \times 135 = 8.1 \text{ MLD}; \text{maximum daily} = 1.8 \times 8.1.$$

Answer: 8.1 MLD average; 14.58 MLD maximum daily.

Problem 5. Part II (j): CCA 30,000 ha, intensity 50%, duty 900 ha/cumec, losses 20%.

$$\text{Area} = 15,000 \text{ ha}; \text{field discharge} = 15,000/900 = 16.67 \text{ cumec}.$$

$$\text{Head discharge} = 16.67/0.8 = 20.8 \text{ cumec}.$$

Answer: About 20.8 cumec.



Quick-Revision Formula Sheet

Topic	Formula	Units / notes
Net ultimate bearing capacity	$q_{nu} = q_u - \gamma D_f$	kN/m ²
Net safe bearing capacity	$q_{ns} = q_{nu}/F$	F = 2.5 to 3
Safe bearing capacity	$q_s = q_{nu}/F + \gamma D_f$	kN/m ²
Area of footing	$A = (P + \text{self-weight})/q_s$	m ²
Floor area ratio	FAR = total floor area/plot area	—
Staircase rule	$2R + T = 550 \text{ to } 600 \text{ mm}$	R = rise, T = tread
Water absorption	$(W_{wet} - W_{dry})/W_{dry} \times 100$	%
Dry volume of concrete	$1.54 \times \text{wet volume}$	1.52-1.57 used
Dry volume of mortar	$1.27 \times \text{wet volume}$ (1.33 in some books)	—
Cement bags	$\text{volume (m}^3) \times 1440/50$	1 bag = 50 kg = 0.0347 m ³
Bricks per m ³	$1/(0.2 \times 0.1 \times 0.1) = 500$	modular bricks
Compressive strength	load/area	N/mm ² ; 150 mm cube area = 22,500 mm ²
Characteristic strength	$f_{ck} = f_{mean} - 1.65s$	5% defectives
Mass of steel bar	$d^2/162 \text{ kg per m}$	d in mm
Camber rise	$(W/2) \times \text{camber slope}$	W = carriageway width
Gradient	rise/horizontal length	1 in n or %
Stopping sight distance	$0.278Vt + V^2/(254f)$	m; V in km/h
Super-elevation	$e + f = V^2/(127R)$; IRC $e = V^2/(225R) \leq 0.07$	—
Extra widening	$nl^2/(2R) + V/(9.5\sqrt{R})$	m
Per capita demand	total annual water/(365 × population)	lpcd
Maximum daily demand	$1.8 \times \text{average daily}$	—
Maximum hourly demand	$2.7 \times \text{average hourly}$	—
Fire demand (Kuichling)	$Q = 3182\sqrt{P}$	L/min; P in thousands
Arithmetic increase	$P_n = P_0 + n\bar{x}$	n = decades
Geometric increase	$P_n = P_0(1 + r)^n$	r per decade
Incremental increase	$P_n = P_0 + n\bar{x} + n(n+1)\bar{y}/2$	—
Pipe discharge	$Q = AV = (\pi D^2/4)V$	m ³ /s
Pump power	$P = \gamma QH/\eta$	kW with $\gamma = 9.81 \text{ kN/m}^3$
Duty-delta relation	$\Delta = 8.64B/D$	Δ in m, B in days, D in ha/cumec
Discharge for an area	$Q = \text{area/duty}$	cumec
Culturable command area	CCA = GCA – unculturable area	ha
Head discharge	field discharge/conveyance efficiency	—



Topic	Formula	Units / notes
1 cumec for 1 day	$86,400 \text{ m}^3$	—



Glossary of Important Terms

Term	Meaning
Aggregate	Inert granular material (sand, gravel, crushed stone) mixed with cement to make concrete
Aqueduct	Cross-drainage work carrying a canal over a drain
Arterial road	Urban road carrying through traffic at high speed
Ballast	Crushed stone bed below railway sleepers
Barrage	Gated structure across a river to control water level
Base period	Time between the first and last watering of a crop
Bearing capacity	Load per unit area that soil can carry without failure
Bond	Arrangement of bricks that breaks vertical joints
Camber	Transverse slope of a road for drainage
Carriageway	Width of road used by moving vehicles
CBR	California Bearing Ratio, a measure of subgrade strength
Coagulation	Adding chemicals (alum) to combine fine particles into flocs
Composite	Material made of two or more constituents acting together
Culvert	Small cross-drainage structure (span up to 6 m) under a road
Curing	Keeping concrete moist for hydration
Delta	Total depth of water required by a crop
DPC	Damp-proof course at plinth level
Duty	Area irrigated per cumec of continuous flow
Efflorescence	White salt deposit on masonry
FAR	Floor area ratio
Flocculation	Gentle mixing to form large settleable flocs
Footing	Widened base of a foundation
Freeboard	Height above the water level to the top of a bank or dam
Grid iron system	Interconnected network of water mains
Header	Brick laid with its end on the face of the wall
Kharif	Monsoon crop season (June–October)
Lintel	Beam over an opening
Mortar	Paste of binder (cement or lime), sand and water for joining masonry



Term	Meaning
Pile	Long slender deep foundation member
Plinth	Part of a building between ground level and floor level
Rabi	Winter crop season (October–March)
Raft	Slab foundation covering the whole building area
Right of way	Total land acquired for a road
Seasoning	Drying of timber to a suitable moisture content
Setback	Minimum open space between a building and the plot boundary
Shoulder	Strip along the edge of the carriageway
Slump	Measure of workability of fresh concrete
Spillway	Structure that passes surplus flood water from a reservoir
Stretcher	Brick laid with its length along the face of the wall
Subgrade	Compacted soil on which a pavement rests
Super-elevation	Banking of a road on a curve
Turbidity	Cloudiness of water due to suspended particles
Waterlogging	Saturation of the crop root zone due to a high water table
Weir	Solid barrier across a river to raise the water level
Workability	Ease of placing and compacting concrete