MODULE – 1: INTRODUCTION

ENERGY IN BUILDING MATERIALS AND BUILDING

All types of construction activities involve expenditure of energy in one form or the other. In traditional construction, the source of energy was either animate energy which used the muscle power of human beings and animals or biomass energy which was used as a source of thermal energy. After the advent of Industrial revolution, human society is increasingly dependent on fossil fuels for energy. Modern construction employs significant amounts of energy whether it is thermal energy or energy for transportation.

It is useful to recognize different categories of energy consumption in a building,

This may be listed as follows

a) Embodied energy in building materials.
b) Energy consumption during building construction.
c) Energy utilized for maintenance during the life span of a building.
d) Energy spent in demolition of the building at the end of its life.

Four categories of energies listed above constitute the life cycle energy cost of a building

- Energies in (a) & (b) together the will constitute the energy embodied in a building.

- In item (b), one can consider energy spent in 1) transporting materials to site 2) energy spent in hoisting materials / water 3) energy spent in concrete mixing 4) floor polishing etc.
- Item c) refers to the energy spent to meet the needs of the occupant of building. Very often, this is mostly electrical energy.
- The electrical energy may be used in lighting, air-conditioning, water pumping, and elevators, in residential buildings, use of ovens, water heaters, TV, entertainment electronics, computers etc.
- There is a need to understand the nature of energy utilization in embodied energy and maintenance energy in buildings since developing countries like India have limited energy resources vis- a vis the large population

ENERGY IN BUILDING MATERIALS

- The primary use of energy in building materials is in the production of the building material. For instance, bricks and tiles are produced by burning coal or firewood in kilns.
- cement and lime are again produced by heating clay and limestone using coal.
- Steel is also produced by using coking coal as the fuel.
- In all these cases, the basic energy use in the form of thermal energy.
- Many materials also need mechanical processing through electricity energy. For instance, pugging of clay bricks may use electricity. Grinding the raw materials and clinker in the case of cement manufacture needs electricity.
- Some materials like sand essentially need transportation energy for procurement at site.

Table-1: List of Typical Building Materials and Their Energy Content Per Unit of Measurement

Material	Unit	Energy per unit, MJ	Type of Energy
Burnt brick	One brick	3.75-4.5	Coal/Wood/Rice Husk
Cement	1 kg	5.85	Coal+Electricity
Lime	1 kg	5.63	Coal/Wood
Lime+Fly Ash	1 kg	2.33	Coal/Wood
Steel	1 kg	42.0	Coal+Electricity
Aluminium	1 kg	236.8	Electricity
Glass	1 kg	25.83	-
Sand (Bangalore)	1 cu.m	206	Diesel
Marble (Rajasthan to Bangalore)	1 sq.m	200	Diesel
Polyester	1 litre	220	Petroleum+Electricity
GFRP	1 kg	100	Petroleum+Electricity
Mangalore Tile	1 tile	5.0-15.0	Firewood/Coal

- Energy in brick is usually calculated by determining the amount of firewood or coal used for brick burning.
- In south India, one brick needs 0.25 to 0.3 kg of wood for energy. Assuming an energy value of wood of 15MJ per kg, we get an energy content in the range of 3.75-4.5MJ.

ENERGY IN BUILDING BLOCKS

- Building blocks used for wall construction constitute a significant component of embodied energy in a building.
- Walls represent the largest volume component in a building.

Table-2: List of The Energy in Various Building Blocks

Sl. No.	Type of Block	Typical Size, Block mm	Energy per Block MJ	Energy per Brick Equivalent, MJ	Block Energy
					Brick Energy %
1	Size Stone	180x180x180	0	0	0
2	Burnt Brick	230x105x70	4.25	4.25	100
3	Stabilized Mud Block	230x190x100	2.60	1.00	23.5
4	Hollow Concrete Block	400x200x200	12.30	1.32	31.2
5	Steam Cured Block	230x190x100	6.7	2.58	60.6

- Stabilized mud block (SMB) is produced by pressing a mixture of soil, sand and cement in a machine (6% cement is used for stabilization).
- Hallow concrete block had 7% cement in the mixture.
- The steam cured block is made by pressing lime, soil and fly ash mixture and curing in a steam chamber. Lime percentage is 10% of soil and fly ash.

ENERGY IN BUILDINGS

- The total embodied energy in a building depends on the type of technologies used.
- The below table provides a comparison of four different building technologies and the total embodied energy in the building.

Table – 3: Total Embodied Energy in a Building

Type of Building	No of Storeys	Total Embodied Energy per 100m2 GJ	Equivalent Coal for 100m2, T
RC framed Construction with Brick in fill walls	8	421	21
Load Bearing Brick Walls, RC Roof, mosaic Floor	2	292	15
SMB wall, Filler Slab, roof/floor, terracotta floor	2	161	8
SMB walls, Reinforced tile, work roof, cement floor	1	93	4.7

The results presented above are based on calculation, per 100 m^2 of plinth area of the building.

ENVIRONMENTAL ISSUES RELATED TO BUILDING MATERIALS

The production of building materials leads to two types of environmental/ health related problems

1) Firstly, building material can lead to a local environmental impact either in the form of pollution/health hazard or in the depletion of natural resources.
2) Secondly, building materials production using fossil fuel energies can cause global environmental problems like global warming.

There is a need to mitigate these two kinds of environmental problems. Some Typical problem are discussed below.

1) STONE

- Especially granite is extensively used in building construction.
- Size stones are used for foundations and walls.
- Crushed stone aggregate is widely used for concrete manufacture.
- Considerable amount of fine granite dust is generated at the site of stone crushing.
- The stone workers inhale the fine dust and succumb to silicosis or tuberculosis
- The entrepreneurs involved in stone processing seem to be have no concern for the health of the workers involved in such activities.
- There is a need to educate the workers about the dangers of stone dust and develop suitable filters such that inhalation of the fine dust can be avoided.

2) TOP SOIL FOR BRICK

- The top soil is used for brick making.
- It is well known that the top soil is a rich source of nutrients for trees and crops and this nutrient base is depleted by large scale brick manufacturer.
- The landscape is also destroyed by unorganized creation of pits which can render the land useless for agriculture or other non – agriculture uses.
- Retaining the top soil while taking out the soil in the lower zones or by creating natural water bodies, can largely mitigate this problem.
- In south India, the problem is less acute since there are a large number of irrigation tanks which contains enormous of silt.

3) POLLUTION OF MARBLE DUST

The marble processing industry in Rajasthan produces large quantities of fine marble dust which can affect the usability of agricultural land.

The marble dust can be used as a resource in number of ways

a) Additive to cement to make masonry cement.
b) Source of calcium carbonate for lime / cement industry.
c) Building products like SMB, marble dust+ resin for wash basin.

4) MANGALORE TILES:

- The extensive use of firewood for making Mangalore tiles in coastal India has led to deforestation in the coastal regions.
- It is possible to use natural gas or coal for tile burning.
- Use of imported fossil fuel is the only way to save the forest.
- Development of other alternatives to tiles is also desirable to avoid deforestation as well as fossil fuel burning.

5) THE QUESTION OF TIMBER:

- In India, good quality timber is in short supply.
- Timber is imported from Malaysia and Australia.
- Some organization like CPWD, PWD have a tendency to ban the use of timber, because to avoid massive deforestation.
- Attempts are made to replace timber by concrete and Ferro-cement.
- This is a good short-term strategy.
- In the long run, this approach can be counterproductive.
- It is necessary to recognize that the timber is a material which is totally based on solar energy while cement based materials depend on fossil fuels.
- Cement based materials cause depletion of fossil fuels and excessive carbon missions leading to global warming.
- Use of timber also alleviates global warming since the carbon in timber is sorted for a long period.
- Thus, the timber is a very environmental friendly material, provided it can be procured without disturbing natural forests.

- The question before the civil engineer is to examine the possibility of growing timber in non-forest lands in an ecologically sound manner.
- There is a need to **avoid 'PLANTATION** 'type of concepts wherein a single species is planted.
- There is also a tendency to think only in terms of teak wood.
- There is a need for concerted efforts by foresters and civil engineers to grow all the available timber species.

.

GLOBAL WARMING

- The utilization of fossils fuels like coal and petroleum has been increasing steadily for more than 200 years after the invention of steam engine and I C engine.
- The carbon –di-oxide in the atmosphere which was bout 280ppm at the beginning of the industrial revolution, has now reached levels like 354 ppm.
- There has been an explosive growth of research on global warming due to carbon-di-oxide emissions and other gases released by the industry.
- Many scientists believe that global warming has arrived due to excessive burning of fossil fuels and the removal of carbon sinks by deforestation.

- Several countries across the globe agreed to reduce consumption of fossils fuels over the coming decades.
- Efforts in this direction are halting, especially since the biggest consumers like the USA is unwilling to reduce its contribution to carbon emission.
- Populus countries like India and china are also emerging as major consumers of fossils fuels although their capita energy consumption is below the levels in western countries.
- Industrialisation of these countries will certainly add to the Global warming unless new low energy strategies are developed.
- In the European Union 40% of the total energy consumption is accounted for buildings sector.
- The buildings also contribute 30% of the total CO_2 emission in European Union.
- This shows that development is invariably associated with high impact on global environment.

Hence essential to explore **'Energy Efficiency Building Alternatives'**

Two categories of energy efficiency need to be recognized.

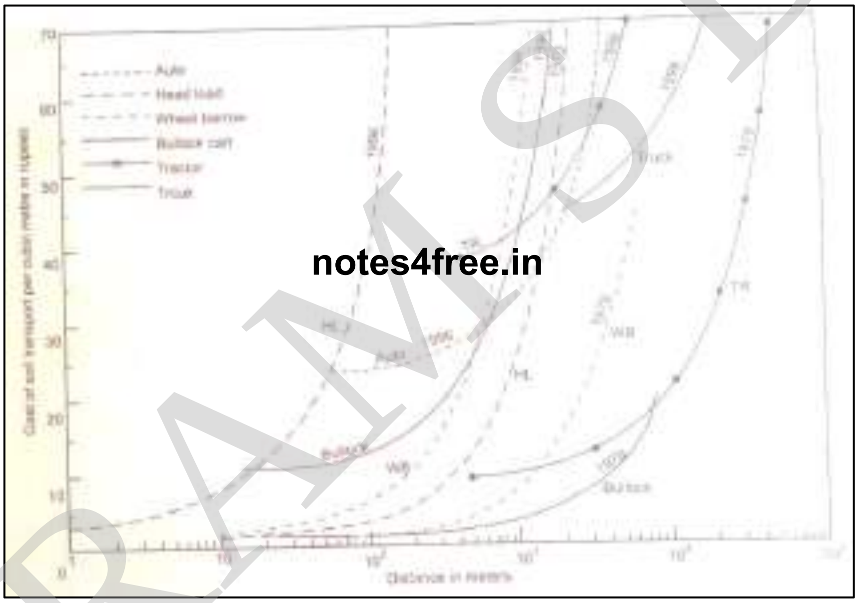
1) Firstly, the embodied energy in a building needs to reduced
2) Secondly, the energy used during the operational life of building should also be reduced.

- In UK 10% of the industrial energy consumption goes to building materials production.
- 56% of the energy is used in the maintenance of the building.
- This shows that buildings consume far more energy during its life time than what is spent during its construction.
- In UK, the energy used by a low rise flat over 25 years is about 12 GJ/m ^{2}, while the energy content of the building is only 4 GJ/m ^{2}
- In the Indian context, a 2 storeyed brick and RC building consumed 2.65 GJ/m^2 during its construction, while it consumed 5.83GJ/m^2 over a 25-year period.
- India has not reached the levels of developed country like UK in energy consumption.
- Recent trends in air conditions buildings in India can exacerbate the situation since most of buildings are poorly insulated.
- Use of solar passive cooling concepts and improved thermal insulation are needed to mitigate these problems.
- Brick vaulted building with simple solar passive cooling concepts was built which was showed significant improvements in indoor climate with marginal cost inputs.

ENVIRONMENTAL FRIENDLY AND COST-EFFECTIVE BUILDING TECHNOLOGIES

ROLE OF TRANSPORTATION IN BUILDINGS:

- Transportation of building materials to the construction site contributes to the cost and embodied energy of a building.
- Greater the distance of transportation, greater is the consumption of energy and money.
- A variety of transportation vehicles are now available in India, often tempting the users to procure materials from greater distance.
- The below fig Shows the influence of distance and mode of transport on the cost of transporting 1 cum of soil.



- Traditional transport mode like the bullock cart is becoming obsolete in recent times as it cannot compete with fossils fuel based transportation.
- The fig.1.1 also point out that procuring building material at short distances (local materials) becomes important for saving energy and costs.
- In case particular material is not available at short distance, it is useful to explore alternative techniques to perform similar task.
- Example, one can explore the issue of sand for building mortars.
- Bangalore has exhausted nearby sources of sand and it has to be imported from distances of more than 100 km.

- Extraction of sand from remote villages is also leading to rapid deterioration of roads and erosion of river banks due to loss of protective sand cover.
- In this context, if sandy soil is available locally, stabilization of the soil by lime and cement can easily produce a mortar with a short-term strength of 2.0 MPa.
- Such a mortar will acquire strength of the order 3.0MPa after about one year's time.
- This could then be local, cost and energy efficient alternative to sand based mortars.
- Alternatively, local sandy soil can be washed to produces sand provided a water resources is available (water can be recycled)

EFFICIENT FOUNDATIONS AND WALLS

- Use of stones (size stone or random rubble) is quite common in south India for foundation of walls.
- The modern practices of using cement mortar makes the foundation rather expensive traditionally, two storeyed buildings have been built on stone-in mud mortar foundation.
- The stress level in the foundation is generally so low that even mud mortars should suffice.
- Use of soil - cement as mortar or soil-lime-cement as mortars should prove to be a cost-effective alternative.
- Use of arched foundations is also a cost-effective alternative.
- Wall construction can be cost effective, if the finish of the masonry unit is so good as to eliminate plastering.
- Good quality SMB or hallow concrete block can lead to such walling solutions.
- Use of cement- soil-sand mortars is also cost effective compared to cement mortar without sacrificing masonry strength or durability.
- There is often a tendency to reduce the thickness of the wall, especially in framed structures, to achieve cost reduction.
- It must be noted that a wall thickness which is less than 225mm can lead to penetration of heat, especially from East and West facing walls.
- The marginal reduction in cost is then accompanied by a significant thermal discomfort in the interior.
- Increased use of fans and coolers will also lead to greater energy consumption throughout the life of the building.

COST AND ENERGY EFFICIENT ROOFING SYSTEM

- A number of efficient roofing alternatives can be considered.
- Use of partial or complete prefabrication can lead to efficient use of materials.
- This will also permit combination of two or three different materials for cost and energy economy.
- For instance, in jack arch roofing, expensive concrete is partially replaced by brick masonry.
- Use of filler slabs, where in tension zone concrete in partially replaced by SMB or bricks is also cost and energy efficient.
- Use of brick domes and vaults can lead to roofing systems which reduce penetration of solar heat into the building.
- Openings at the crown will facilitate air movement; reduction in the steel used facilitates reduction in the embodied energy as well.

BUILDINGS IN DIFFERENT CLIMATIC REGIONS

The Indian subcontinent has widely varied climatic conditions.

Some of the major categories of climatic may be listed as:

a) Hot summer and cold winter
b) Hot summer and moderate winter
c) Hot and humid
d) Moderate summer and cold winter
e) Cool summer and very cold winter

- The choice of building technologies/ materials depends on the climatic context.
- For instance, category (A) occurs in most of north India and the buildings should use cooling techniques in summer while retaining the heat in winter. Well insulated buildings are needed here.
- In the case of hot and humid environment, air circulation becomes important to eliminate the discomfort due to humidity.
- In situations like (e) where the winter is very cod (like Ladakh and sub- Himalayan regions), use of winter heating using solar energy becomes important.
- Concepts like 'Trombe walls' which use double glazing on the southern Walls to capture solar heat are useful.

GREEN CONCEPT IN BUILDINGS

Due to the development at a very rapid pace, we are loading our atmosphere with thousands of tonnes of CO_2 every year. To offset this CO_2, more trees need to be planted and only planting of trees are not enough. Research and studies show that the Buildings have significant amount of contribution in polluting the environment. The verge at which we have brought Mother Nature in our blind run of development is extremely critical and needs a complete green solution, which is **'Green Building'**.

We can define Green Buildings as structures that ensure efficient use of natural resources like building materials, water, energy and other resources with minimal generation of non-degradable waste. Technologies like efficient cooling systems have sensors that can sense the heat generated from human body and automatically adjust the room temperature, saving energy. It applies to lighting systems too. Green buildings have a smarter lighting system that automatically switches off when no one is present inside the rooms. Simple technologies like air based flushing system in toilets that avoids water use by 100%, Use of energy efficient LED's and CFL's instead of conventional incandescent lamp, new generation appliances that consume less energy, and many other options helps in making the buildings green and make them different from conventional ones.

Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

There are a number of reasons to build green such as

- Potential Environmental,
- Economic and Social Benefits.

Green Building refers to the incorporation of environment friendly and resource efficient processes at each stage of construction, right from site selection and designing to construction, operation followed by maintenance, renovation or even demolition. The endeavour is to seek minimum possible impact on environment.

The methods by which the concept in green buildings can achieved are as follows

a) Sustainable Site Selection:

- There should be easy availability of public transport and conveniences so as to cut down energy consumption for transportation.
- Also, rehabilitation of sites damaged by environmental contamination is a better option than any new piece of land where large amount of energy and resource is needed to make the land worthy of building on.
- Already existing landscape, soil and natural features should be protected. For this reason, hard paving on the site should be avoided to preserve top soil and ease rain water harvesting. There should be minimum storm water runoff.

b) Material and Resources

- Sustainable construction material is chosen keeping in mind various characteristics like zero or low toxicity, high recyclability, zero or low off gassing of harmful air emissions, durability, reused and recycled content, sustainably harvested material.
- Dimensional planning and other material efficiency strategies are used to reduce the construction costs. Construction and demolition material can be reused and recycled.
- Use of materials that are available locally is preferred over materials that need to be brought from distant places. It saves transportation costs.

c) Water Efficiency

- Installation of water efficient or low flow equipment's in kitchens and bathrooms to reduce water consumption and Incorporating waste water management technologies like dual plumbing for using recycled water in toilets
- Use of Micro irrigation techniques at sites instead of high pressure sprayers. Recirculation system for centralized hot water distribution.
- For landscaping purpose, local plants and trees are used as they consume less water and provisions for reusing and recycling water are made to ensure efficient water management and Using treated waste water, non-potable water for site irrigation.
- Raw sewage can be recycled using aquatic plants like duckweed and water hyacinth to produce clean water suitable for re-use in irrigation and industry.
- Integrating Rain water harvesting system in building design to ensure maximum possible utilization of rain water.

GREEN BUILDING RATING SYSTEM

Green building rating brings together a host of sustainable practices and solutions to reduce the environmental impacts. Green building design provides an integrated approach considering life cycle impacts of the resources used.

There are three primary Rating systems in India.

1) GRIHA
2) IGBC
3) BEE

1) Green Rating for Integrated Habitat Assessment (GRIHA)

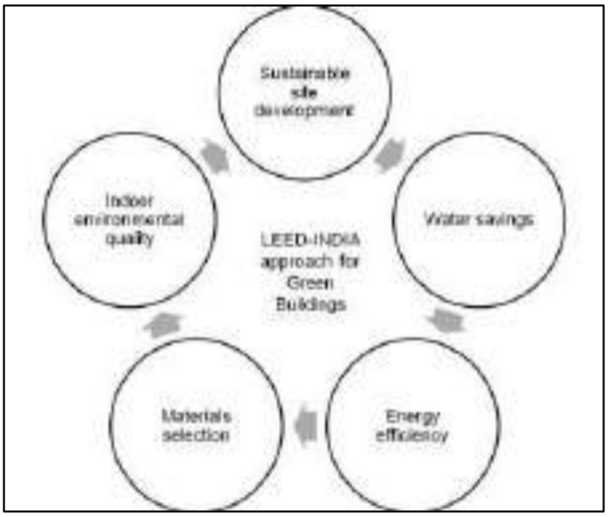
Green Rating for Integrated Habitat Assessment (GRIHA) is India's own rating system jointly developed by TERI (The Energy Resource Institute) and the Ministry of New and Renewable Energy, Government of India. It is a green building design evaluation system where buildings are rated in a three-tier process. The process initiates with the online submission of documents as per the prescribed criteria followed by on site visit and evaluation of the building by a team of professionals and experts from GRIHA Secretariat. GRIHA rating system consists of 34 criteria categorised in four different sections. Some of them are

1) Site selection and site planning
2) Conservation and efficient utilization of resources
3) Building operation and maintenance
4) Innovation.

Commonwealth Games Village, New Delhi, Fortis Hospital, New Delhi, CESE (Centre for Environmental Sciences & Engineering) Bldg, IIT Kanpur, Suzlon One Earth, Pune and many other buildings has received GRIHA rating

2) Indian Green Building Council (IGBC)

The Leadership in Energy & Environmental Design (LEED) is the rating system developed for certifying Green Buildings. LEED is developed by the U.S. Green Building Council (USGBC), the organization promoting sustainability through Green Buildings. LEED is a framework for assessing building performance against set criteria and standard points of references. The benchmarks for the LEED Green Building Rating System were developed in year 2000 and are currently available for new and existing constructions.



Confederation of Indian Industry (CII) formed the **Indian Green Building Council (IGBC)** in year **2001**. The vision of the council is, **"To enable a sustainable built environment for all and facilitate India to be one of the global leaders in the sustainable built environment by 2025".** IGBC is the non-profit research institution having its offices in CII-Sohrabji Godrej Green Business Centre, which is itself a LEED certified Green building. Indian Green Building Council (IGBC) has licensed the LEED Green Building Standard from the USGBC.

IGBC facilitates Indian green structures to become one of the green buildings.

a) The council offers a wide array of services which include developing new green building rating programmes, certification services and green building training programmes. The council also organises Green Building Congress, its annual flagship event on green buildings.
b) The council is committee-based, member-driven and consensus-focused. All the stakeholders of construction industry comprising of architects, developers, product manufacturers, corporate, Government, academia and nodal agencies participate in the council activities through local chapters. The council also closely works with several State Governments, Central Government, World Green Building Council, bilateral multi-lateral agencies in promoting green building concepts in the country.
c) All the IGBC rating systems are voluntary, consensus based, market-driven building programmes.
d) The rating systems are based on the five elements of the nature (Panchabhutas) and are a perfect blend of ancient architectural practices and modern technological innovations.
e) The ratings systems are applicable to all five climatic zones of the country. IGBC rating programmes have become National by Choice and Global in Performance.

Project teams interested in IGBC Project certification must first register with IGBC. Registration is the initial step which helps establish contact with IGBC and provides access to the required documents, templates, important communications and other necessary information. Once the project is registered, the project team can start preparing for documentation & calculations to satisfy mandatory requirements and credit submittal requirements.

The following Green Building rating systems are available under IGBC.

1. LEED India for New Construction
2. LEED India for Core and Shell
3. IGBC Green Homes
4. IGBC Green Factory Building
5. IGBC Green SEZ
6. IGBC Green Townships

Some examples of LEED rated building in India

Sl. No	Green Buildings	Rating Received
1	ABN Amro Bank N.V., Ahmedabad	LEED 'Platinum' rated
2	American Embassy School, Delhi	LEED 'Gold' rated
3	Anna Centenary Library Building, Chennai	LEED 'Gold' rated
4	Biodiversity Conservation India Ltd (BCIL) – Bangalore	LEED 'Platinum' rated
5	Birla International School, Jaipur	LEED 'Gold' rated
6	CII – Sohrabji Godrej Green Business Centre	LEED 'Platinum' rated
7	ITC Green Centre – Gurgaon	LEED 'Platinum' rated
8	Olympia Technology Park – Chennai	LEED 'Gold' rated
9	Rajiv Gandhi International Airport – Hyderabad	LEED 'Silver' rated
10	Suzlon Energy Limited – global headquarter in Pune	LEED 'Platinum' rated

Certification

To achieve the IGBC rating, the project must satisfy all the mandatory requirements and the minimum number of credit points. The project team is expected to provide supporting documents at preliminary and final stage of submission, for all the mandatory requirements and the credits attempted.

The project needs to submit the following

- Filled-in Template
- Narratives and supporting documentation such as drawings, calculations declarations, contract documents, purchase invoices, manufacturer cut-sheets, letters, material test reports, etc., for each mandatory requirement/ credit.

The project documentation is submitted in two phases preliminary submittal and final submittal:

Preliminary Phase: It involves submission of all documents, which shall include mandatory requirements and the minimum number of credits. After the preliminary submission, review is done by third party assessors and review comments would be provided within 30 working days.

Final Phase: It involves submission of clarifications to preliminary review queries and final submittal. This review will also be provided within 30 working days, after which the rating is awarded.

Leadership in Energy and Environmental Design (LEED)

It is one of the most popular green building certification programs used worldwide. Developed by the non-profit U.S. Green Building Council (USGBC) it includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighbourhoods that aims to help building owners and operators be environmentally responsible and use resources efficiently.

- Development of LEED began in 1993, headed by Natural Resources Defence Council (NRDC) led by senior scientist Robert K. Watson he brought together non-profit organizations, government agencies, architects, engineers, developers, builders, product manufacturers and other industry leaders.
- LEED grew from one standard for new construction to a comprehensive system of interrelated standards covering aspects from the design and construction to the maintenance and operation of buildings.
- LEED standards have been applied to approximately 83,452 registered and certified LEED projects worldwide, covering around 1.28 billion square meters.
- Proposals to modify the LEED standards are offered and publicly reviewed by USGBC's member organizations.

Rating systems

LEED has evolved since 1998 to more accurately represent and incorporate emerging green building technologies.

1) The Pilot Version
2) LEED New Construction (NC) v1.0
3) LEED NCv2.0
4) LEED NCv2.2 in 2005
5) LEED 2009 (previously named LEED v3)
6) LEED v4 was introduced in November, 2013. (Until October 31, 2016, new projects may choose between LEED 2009 and LEED v4. New projects registering after October 31, 2016 must use LEED v4).

LEED 2009 encompasses **Ten** rating systems for the design, construction and operation of buildings, homes and neighbourhoods. Five overarching categories correspond to the specialties available under the LEED professional program. That suite currently consists of the following

a) **Green Building Design & Construction**
   LEED for New Construction, Core & Shell, Schools, New Construction and Major Renovations and Healthcare
b) **Green Interior Design & Construction**
   LEED for Commercial Interiors.
c) **Green Building Operations & Maintenance**
   LEED for Existing Buildings: Operations & Maintenance
d) **Green Neighbourhood Development**
   LEED for Neighbourhood Development
e) **Green Home Design and Construction**
   LEED for Homes (The LEED for Homes rating system is different from LEED v3, with different point categories and thresholds that reward efficient residential design).

Under LEED 2009, there are 100 possible base points distributed across six credit categories:

1) Sustainable Sites
2) Water Efficiency
3) Energy and Atmosphere
4) Materials and Resources
5) Indoor Environmental Quality
6) Innovation in Design

Up to 10 additional points may be earned: four additional points may be received for Regional Priority Credits, and six additional points for Innovation in Design

Certification level

Buildings can qualify for four levels of certification:

- **Certified:** 40–49 points
- **Silver:** 50-59 points
- **Gold:** 60-79 points
- **Platinum:** 80 points and above

Goal of the credit system

The LEED 2009 performance credit system aims to allocate points **"Based on The Potential Environmental Impacts and Human Benefits of Each Credit"**. These are weighed using the environmental impact categories of the United States Environmental

Protection Agency's **Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)** and the environmental-impact weighting scheme developed by the **National Institute of Standards and Technology (NIST)**.

Prerequisites

To participate in LEED 2009, a building must comply with environmental laws and regulations, occupancy scenarios, building permanence and pre-rating completion, site boundaries and area-to-site ratios. Its owner must share data on the building's energy and water use for five years after occupancy (for new construction) or date of certification (for existing buildings). Each of the performance categories also have mandatory measures in each category, which receive no points.

Credit weighting process

The weighting process has three steps

1) A collection of reference buildings is used to estimate the environmental impacts of any building seeking LEED certification in a designated rating scheme.
2) NIST weightings are used to judge the relative importance of these impacts in each category.

3) Data regarding actual impacts on environmental and human health are used to assign points to individual categories and measures.

This system results in a weighted average for each rating scheme based upon actual impacts and the relative importance of those impacts to human health and environmental quality. The LEED council also appears to have assigned credit and measure weighting based upon the market implications of point allocation.

3) Bureau of Energy Efficiency (BEE)

BEE developed its own rating system for the buildings based on a 1 to 5-star scale. More stars mean more energy efficiency. BEE has developed the Energy Performance Index (EPI). The unit of Kilo watt hours per square meter per year is considered for rating the building and especially targets air conditioned and non-air-conditioned office buildings. The Reserve Bank of India’s buildings in Delhi and Bhubaneshwar, the CII Sohrabji Godrej Green Business Centre and many other buildings have received BEE 5 star ratings.

Rainwater Harvesting

Rainwater harvesting is one of the simplest and oldest methods of self-supply of water for households usually financed by the user. It is the accumulation and storage of rainwater for reuse on-site, rather than allowing it to run off. Rainwater can be collected from roofs, and in many places, the water collected is redirected to a deep pit (well, shaft, or borehole), a reservoir with percolation, or collected from dew or fog with nets or other tools. Its uses include water for gardens, livestock, irrigation, domestic use with proper treatment, indoor heating for houses, etc. The harvested water can also be used as drinking water, longer-term storage, and for other purposes such as groundwater recharge.

Advantages

a) Rainwater harvesting provides an independent water supply during regional water restrictions, and in developed countries, is often used to supplement the main supply.
b) It provides water when a drought occurs, can help mitigate flooding of low-lying areas, and reduces demand on wells which may enable groundwater levels to be sustained.
c) It also helps in the availability of potable water, as rainwater is substantially free of salinity and other salts.
d) Application of rainwater harvesting in urban water system provides a substantial benefit for both water supply and waste water sub systems by reducing the need for clean water in water distribution system, less generated storm water in sewer system, and a reduction in storm water runoff polluting freshwater bodies.

More development and knowledge is required to understand the benefits of rainwater harvesting that can provide to agriculture. Many countries, especially those with arid environments, use rainwater harvesting as a cheap and reliable source of clean water. To enhance irrigation in arid environments, ridges of soil are constructed to trap and prevent rainwater from running down hills and slopes. Even in periods of low rainfall, enough water is collected for crops to grow. Water can be collected from roofs, and dams and ponds can be constructed to hold large quantities of rainwater so that even on days when little to no rainfall occurs, enough is available to irrigate crops.

Quality

- The concentration of contaminants is reduced significantly by diverting the initial flow of run-off water to waste. Improved water quality can also be obtained by using a floating draw-off mechanism by using a series of tanks, withdraw from the last in series.
- Prefiltration is a common practice used in the industry to ensure that the water entering the tank is free of large sediment. Prefiltration is important to keep the system healthy.
- Supplying rainwater that has gone through preliminary filtration measures for non-portable water uses, such as toilet flushing, irrigation and laundry, may be a significant part of a sustainable water management strategy.

System setup

- Rainwater harvesting systems can range in complexity, from systems that can be installed with minimal skills, to automated systems that require advanced setup and installation.
- The basic rainwater harvesting system is more of a plumbing job than a technical job, as all the outlets from the building terrace are connected through a pipe to an underground tank that stores water.

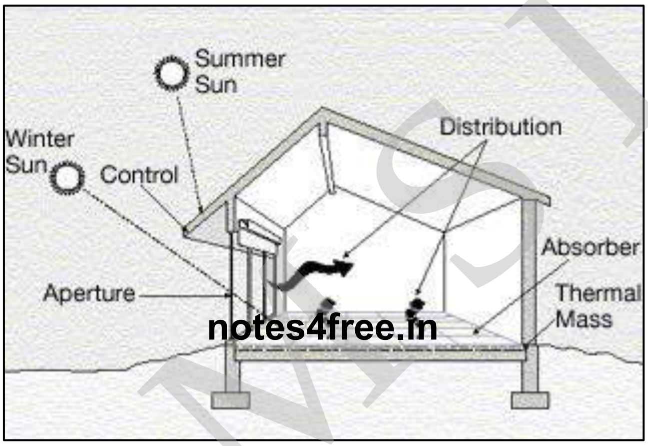
- Systems are ideally sized to meet the water demand throughout the dry season, since it must be big enough to support daily water consumption. Specifically, the rainfall capturing area such as a building roof must be large enough to maintain adequate flow of water. The water storage tank size should be large enough to contain the captured water.
- For low-tech systems, many low-tech methods are used to capture rainwater: rooftop systems, surface water capture, and pumping the rainwater that has already soaked into the ground or captured in reservoirs and storing it in tanks (cisterns).
- Before a rainwater harvesting system is built, use of digital tools is useful. For instance, to detect if a region has a high rainwater harvesting potential, rainwater-harvesting GIS maps can be made using an online interactive tool.

Passive Solar Building Design

In **Passive Solar Building Design**, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design because, unlike active solar heating systems, it does not involve the use of mechanical and electrical devices.

The key to design a passive solar building is to best take advantage of the local climate performing an accurate site analysis. Elements to be considered include window placement and size, and glazing type, thermal insulation, thermal mass, and shading. Passive solar design techniques can be applied most easily to new buildings, but existing buildings can be adapted or "retrofitted".

Passive Energy Gain

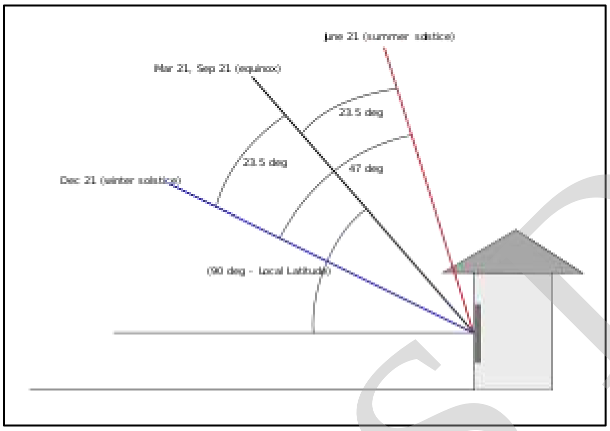


Elements of passive solar design, shown in a direct gain application

- Passive solar technologies use sunlight without active mechanical systems. Such technologies convert sunlight into usable heat, cause air-movement for ventilating, or future use, with little use of other energy sources. Passive cooling is the use of the same design principles to reduce summer cooling requirements.
- Some passive systems use a small amount of conventional energy to control dampers, shutters, night insulation, and other devices that enhance solar energy collection, storage, and use, and reduce undesirable heat transfer.
- Passive solar technologies include direct and indirect solar gain for space heating, solar water heating systems based on the thermosiphon, use of thermal mass and phase-change materials for slowing indoor air temperature swings, solar cookers, the solar chimney for enhancing natural ventilation, and earth sheltering.

- More widely, passive solar technologies include the solar furnace, but this typically requires some external energy for aligning their concentrating mirrors or receivers, and historically have not proven to be practical or cost effective for widespread use. 'Low-grade' energy needs, such as space and water heating, have proven over time to be better applications for passive use of solar energy.

The Solar Path in Passive Design



The ability to achieve these goals simultaneously is fundamentally dependent on the seasonal variations in the sun's path throughout the day. This occurs as a result of the inclination of the Earth's axis of rotation in relation to its orbit. The sun path is unique for any given latitude.

In Northern Hemisphere, non-tropical latitudes farther than 23.5 degrees from the equator:

- The sun will reach its highest point toward the south (in the direction of the equator).
- As winter solstice approaches, the angle at which the sun rises and sets progressively moves further toward the South and the daylight hours will become shorter
- The opposite is noted in summer where the sun will rise and set further toward the North and the daylight hours will lengthen.

The converse is observed in the Southern Hemisphere, but the sun rises to the east and sets toward the west regardless of which hemisphere you are in.

In equatorial regions at less than 23.5 degrees, the position of the sun at solar noon will oscillate from north to south and back again during the year.

In regions closer than 23.5 degrees from either north-or-south pole, during summer the sun will trace a complete circle in the sky without setting whilst it will never appear above the horizon six months later, during the height of winter.

The 47-degree difference in the altitude of the sun at solar noon between winter and summer forms the basis of passive solar design. This information is combined with local climatic data (degree day) heating and cooling requirements to determine at what time of the year solar gain will be beneficial for thermal comfort, and when it should be blocked with shading. By strategic placement of items such as glazing and shading devices, the percent of solar gain entering a building can be controlled throughout the year.

One passive solar sun path design problem is that although the sun is in the same relative position six weeks before, and six weeks after, the solstice, due to **"Thermal Lag"** from the thermal mass of the Earth, the temperature and solar gain requirements are quite different before and after the summer or winter solstice. Movable shutters, shades, shade screens, or window quilts can accommodate day-to-day and hour-to-hour solar gain and insulation requirements.

Key Passive Solar Building Configurations

There are three primary passive solar energy configurations

a) Direct Solar System
b) Indirect Solar System
c) Isolated Solar System

a) Direct Solar System

- In a **direct-gain passive solar system**, the indoor space acts as a solar collector, heat absorber, and distribution system.
- South-facing glass in the northern hemisphere (north-facing in the southern hemisphere) admits solar energy into the building interior where it directly heats (radiant energy absorption) or indirectly heats (through convection) thermal mass in the building such as concrete or masonry floors and walls.
- The floors and walls acting as thermal mass are incorporated as functional parts of the building and temper the intensity of heating during the day. At night, the heated thermal mass radiates heat into the indoor space.

b) Indirect Solar System

- In an **indirect-gain passive solar system**, the thermal mass (concrete, masonry, or water) is located directly behind the south-facing glass and in front of the heated indoor space and so there is no direct heating.
- The position of the mass prevents sunlight from entering the indoor space and can also obstruct the view through the glass.

There are two types of indirect gain systems

1) **Thermal Storage Wall Systems**
2) **Roof Pond Systems.**

1) Thermal Storage (Trombe) Walls

- This wall system was first envisioned and patented in 1881 by its inventor, Edward Morse Felix Trombe, for whom this system is sometimes named, was a French engineer who built several homes using this design in the French Pyrenees in the 1960s.
- In a **Thermal Storage Wall** system, often called a **Trombe Wall**, a massive wall is located directly behind south-facing glass, which absorbs solar energy and releases it selectively towards the building interior at night.

- The wall can be constructed of cast-in-place concrete, brick, adobe, stone, or solid (or filled) concrete masonry units. Sunlight enters through the glass and is immediately absorbed at the surface of the mass wall and either stored or conducted through the material mass to the inside space.
- Temperatures of the air in this space can easily exceed 49 °C. This hot air can be introduced into interior spaces behind the wall by incorporating heat-distributing vents at the top of the wall.
- A thermal storage wall typically consists of 100 to 400 mm thick masonry wall coated with a dark, heat-absorbing finish (or a selective surface) and covered with a single or double layer of high transmissivity glass.
- The glass is typically placed from ¾ inch to 2 inches from the wall to create a small airspace. In some designs, the mass is located 1 to 2 ft. (0.6 m) away from the glass, but the space is still not usable.
- The surface of the thermal mass absorbs the solar radiation that strikes it and stores it for night time use.

2) Roof Pond System

- A **Roof Pond Passive Solar System**, sometimes called a **Solar Roof**, uses water stored on the roof to temper hot and cold internal temperatures, usually in desert environments.
- It typically is constructed of containers holding 150 to 300 mm of water on a flat roof. Water is stored in large plastic bags or fiberglass containers to maximize radiant emissions and minimize evaporation.
- It can be left unglazed or can be covered by glazing. Solar radiation heats the water, which acts as a thermal storage medium. At night or during cloudy weather, the containers can be covered with insulating panels. The indoor space below the roof pond is heated by thermal energy emitted by the roof pond storage above.
- Roof pond systems perform better for cooling in hot, low humidity climates. Not many solar roofs have been built, and there is limited information on the design, cost, performance, and construction details of thermal storage roofs.

c) Isolated solar system

- In an **isolated gain passive solar system**, the components (e.g., collector and thermal storage) are isolated from the indoor area of the building.

- An **attached sunspace**, also sometimes called a **Solar room** or **Solarium**, is a type of isolated gain solar system with a glazed interior space or room that is part of or attached to a building but which can be completely closed off from the main occupied areas.
- In cold climates, double glazing should be used to reduce conductive losses through the glass to the outside. Night-time heat loss, although significant during winter months, is not as essential in the sunspace as with direct gain systems since the sunspace can be closed off from the rest of the building.
- In temperate and cold climates, thermally isolating the sunspace from the building at night is important.
- The internal surfaces of the thermal mass should be dark in colour. Movable insulation (e.g., window coverings, shades, shutters) can be used help trap the warm air in the sunspace both after the sun has set and during cloudy weather. When closed during extremely hot days, window coverings can help keep the sunspace from overheating.
- To maximize comfort and efficiency, the non-glass sunspace walls, ceiling and foundation should be well insulated. The perimeter of the foundation wall or slab should be insulated to the frost line or around the slab perimeter.

MODULE – 2

ELEMENTS OF STRUCTURAL MASONRY

Introduction

A large proportion of masonry buildings for residential and other purposes is satisfactorily designed and built in accordance with empirical rules and practices without the need for special structural consideration. However, the limits of this approach cannot be extended much beyond the scale of two-storey houses of very conventional construction without having to use very thick walls, which in turn result in waste of materials and other disadvantages.

Indeed, for a considerable time this led to the eclipse of masonry as a structural material for larger buildings, and it is only since the 1950s that the application of structural engineering principles to the design of masonry has resulted in the re adoption of this material for certain classes of multi-storey buildings, and to its use in situations which would have been precluded by reliance on rule-of-thumb procedures.

The economic success of masonry construction has been achieved not only by the rationalisation of structural design, but also because it is possible for the walls which comprise a building structure to perform several functions which in a framed structure have to be provided-for separately.

Thus, masonry walls simultaneously provide structure, subdivision of space, thermal and acoustic insulation, as well as fire and weather protection. The material is relatively cheap and durable, can provide infinite flexibility in plan form and can offer an attractive external appearance. Furthermore, masonry buildings can be constructed without heavy capital expenditure on the part of the builder.

To make the best use of these inherent advantages in multi-storey buildings it is necessary to use masonry construction in cases where the accommodation gives rise to moderate or small floor spans and where it is possible to continue the loadbearing walls uninterrupted from foundations to roof.

In some buildings where there has been a need for large spans on the first and second floors (for example, in hotels), these floors have been built in framed construction with loadbearing walls above this level.

Masonry Materials

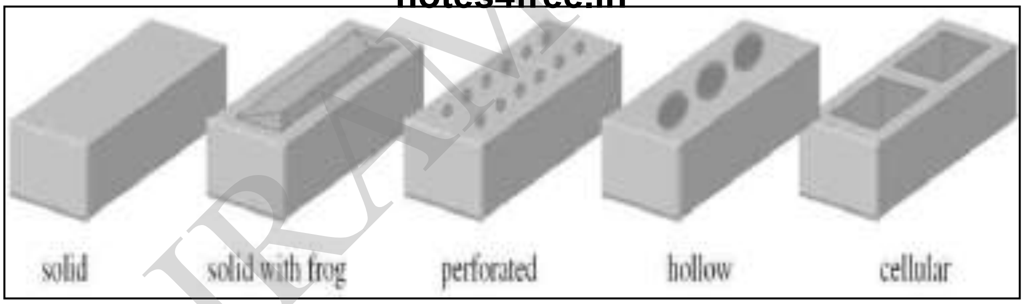
Masonry can be regarded as an assemblage of structural units, which are bonded together in a particular pattern by mortar or grout.

Structural Units

There are seven types of structural unit referred to in IS: 1905 – 1987, they are as follows

1) Burnt Clay Building Bricks
2) Stones (in regular sized units)
3) Sand Lime Bricks
4) Concrete Block
5) Lime Based Blocks
6) Burnt Clay Hollow Blocks
7) Gypsum Partition Blocks
8) Autoclaved Cellular Concrete Blocks

The selection of a particular type of unit for any given structure is dependent on a number of criteria, e.g. strength, durability, adhesion, fire resistance, thermal properties, acoustic properties and aesthetics. The structural units may be solid, solid with frogs, perforated, hollow or cellular, as indicated in Figure



Mortar

Mortar is the medium which binds together the individual structural units to create a continuous structural form, e.g. brickwork, stonework, etc.

- Mortar serves a number of functions in masonry construction as follows
- Bind together the individual units
- Distribute the pressures evenly throughout the individual units.
- Infill the joints between the units and hence increase the resistance to moisture penetration
- Maintain the sound and thermal characteristics of wall.

Present-day mortars are specifically manufactured to suit the type of construction involved. In most cases they are mixtures of sand, cement and water. The workability is often improved by the inclusion of lime or a mortar plasticiser. Lime is used in mortar for several reasons

- To create a consistency which enables the mortar to cling and spread
- To help retain the moisture and prevent the mortar from setting too quickly
- To improve the ability of the mortar to accommodate local movement.

CHARACTERISTICS OF BUILDING BLOCKS

BURNT BRICKS

Three types of burnt bricks may be mentioned in today's Indian context namely

1) Country Bricks
2) Table Mould Bricks
3) Wire Cut Bricks

Country Bricks

- Country bricks are made using a simple four sided mould.
- These bricks are moulded by the 'Soft Mud' process whose soil has a high moisture content facilitating easier pressing.
- The moulding is done on level ground and the wet brick is left on the ground to dry.
- After drying the bricks are stacked in a clamp and burnt using fire wood or paddy husk.

Table Moulded Bricks

- Five sided mould is used to shape a relatively stiffer mud in to brick
- The use of lesser moisture at the time of moulding leads to an improved shape and strength for the brick.
- The wet brick is released by turning the mould upside down on a level platform.
- These bricks generally have frog on one of the bedding faces.
- These bricks are then dried in shade and then burnt in a continuous kiln known as the Bull's Trench Kiln.
- New simpler kiln has been developed in recent years, this may be called as a clamp kiln
- The table mould brick is generally much stronger than the country brick. Strength ranges from 3.5MPa to 7.0 MPa is quite common for such bricks.
- Recently, a new type of mould was developed at ASTRA. For the table mould brick. This mould has four sides with a removable plate in the position of the 5th side.

- The plate sits at the bottom of the mould but cannot be taken out through the bottom because of stopper in the corners.
- After moulding the brick, the mould may be turned upside down on a platform and it may be taken out while pressing on the removable plates.
- The plates remain on the wet bricks to be taken out subsequently. This mould has been tested recently and lead to bricks of strength of bricks of strength 4.5 MPa.

Wire Cut Brick

- The wire cut brick is produced by a more mechanised operation.
- The selected soil is pugged adequately and then extruded into a continuous slab of clay
- This slab is then sliced by a wire frame into a number of bricks.
- After drying, the bricks are burnt in a Hoffman's kiln.
- A good wire cut brick retains a good shape and often has strengths in the range of 10.0 MPa to 20.0 MPa
- It is a very expensive brick.
- It must be pointed out that a wire cut brick of 10.0MPa strength can be conveniently used for load bearing masonry going up to 5 storeys without using RC frames.
- This may be quite cost effective compared to framed construction.

Stones and Laterite Blocks

Three types of stones are available for construction of wall such as Igneous rock- ex: Granite and Basalt, Sedimentary rock – ex: Limestone and Sand stone and Metamorphic cock – ex: Gneiss and Marble

1) All stones have a good compressive strength which is often more than adequate for wall construction.
2) Granite shows the highest strength and it is also known for its durability.
3) Fine grained stones are stronger than coarse grained stones.
4) Sandstone and Basalt are less durable although they do not deteriorate in time spans of the order a couple of centuries.
5) Sand stone temples built in Aihole and Pattadakal in 6^{th} and 8^{th} centuries show sign of erosion
6) Basalt used in Gol Gumbaz and Ibrahim Rouza in Bijapur in the 16^{th} century is showing considerable deterioration.
7) However, these stones may be considered alright for normal buildings where a life span of 200years.

Laterite

- Laterite, which is found in the coastal district of Karnataka, is an interesting building material. It is soft when excavated but hardness, on drying and the hardening is irreversible. It has been used for centuries
- Bidar district, which has pockets of laterite, Laterite is quite durable, since it has been used extensively in Bidar fort.
- Laterite, is not a very strong material. An early study showed that Khozikode laterite gave an average strength of 1.7 MPa. Recent study gave a compressive strength in the range of 1.04 to 3.47 MPa.
- Out of 13 locations studied, 11 locations showed strength below 2.5MPa.
- Laterite blocks from Calicut, tested, gave an average compressive strength of 3.8 MPa.
- These studies show that Laterite strength can be sometimes much lower than what is specified by BIS Code of practice which says that the average strength must be 3.5MPa.
- When Laterite blocks of thickness of morethan, 190mm is ued, it is possible to use blocks of strength 2.0-2.5 MPa. It is desirable to avoid blocks of strength much lower than 2.0MPa.

Concrete Block: Hallow/Solid

The concrete block has been in use in India for nearly 3 decades. Concrete offers a flexibility in production which is not there in brick manufacture. Brick manufacture is stopped in monsoon while concrete blocks making can be carried out throughout the year. The investment needed by the way if land and capital is much less for concrete block manufacture compared to brick making.

Ambalavannan carried out tests in 1992 and had obtained a strength of 2.8 to 5.4 MPa for blocks of size 390x200x190mm but the commercially available blocks in the market have shown less strength than the study. This may be due to the use of excess amount of quarry dust which contains more amount of silt like fines. The BIS prescribes a minimum of 2.0MPa for concrete block. The hollow can be deceptive by looks but can have low strengths.

It must also be mentioned that there are good manufacturers who produce good quality of block having a strength of 7.4MPa. Such blocks can be cost effective and since hollow block is having lower densities it is having advantage in construction of 3 to 4 storeys.

The use of solid concrete block is also common. The Rajasthan Avas Vikas Sansthan has come up with a simple machine to make solid concrete blocks. It is relatively easy to achieve desirable strength like 4.0MPa to 5.0MPa with a solid block. However, the density of such block will be high and may not be suites for more than 2 storeyed construction.

Burnt Clay Hallow Block

- Burnt clay hallow block made by a process of extrusion. The thickness of a hallow block is as low as 1.5 to 2.0 cms, they came with various sizes.
- These blocks give a relatively high strength when tested with load parallel to the holes, when the blocks are laid with holes aligned horizontally the strength is subsequently less.
- These blocks have a rather favourable weight/ strength ratio, they can be quite useful in planning a building with several storeys since the dead load weight can be kept low.
- They also offer possibilities of improved thermal comfort when the wall thickness is 200 mm or more and then external walls are painted white or some light colours.
- The only restriction to their use is their high cost.
- Prove to useful at places close to the factories manufacturing them.

FaL- G Bricks

- FaL-G is the name of the product named after its ingredients, Fly ash, Lime and Gypsum.
- FaL-G brick is a building material, specifically masonry units, containing class C or class F fly ash and water. Compressed at 28 MPa and cured for 24 hours in a 66 °C steam bath, then toughened with an air entrainment agent, the bricks last for more than 100 freeze-thaw cycles.
- Owing to the high concentration of calcium oxide in class C fly ash, the brick is described as "Self-Cementing". The manufacturing method saves energy, reduces mercury pollution, and costs 20% less than traditional clay brick manufacturing.
- Ever since FaL-G (Fly Ash-Lime-Gypsum) process is introduced in 1991, fly ash brick activity has been revolutionised in India. FaL-G technology developed and patented by Dr Bhanumathidas and Kalidas has simplified the process by adding gypsum to fly ash + lime/cement, converting the calcium aluminates into calcium alumino-sulphates resulting in to achieve high early strengths. Thus FaL-G brick does not need any pressure and gets cured at ambient temperature of 20-40 °C.

- By avoiding both press and heating chamber, FaL-G process has brought down the multi-million plant cost to a few lakhs, within the reach of micro units.

The raw materials for Fly Ash Bricks are:

Material	Mass
Fly ash	60%
Sand/Stone dust	30%
Ordinary Portland Cement/(Lime+Gypsum)	10%
Total formula of material	100%

The strength of fly ash brick manufactured with the above compositions is normally of the order of 7.5 N/mm2 to 10 N/mm2. Fly ash bricks are lighter and stronger than clay bricks. Main ingredients include fly ash, water, quicklime or lime sludge, cement, aluminium powder and gypsum.

The block hardness is being achieved by cement strength, and instant curing mechanism by autoclaving. Gypsum acts as a long-term strength gainer. The chemical reaction due to the aluminium paste provides the bricks its distinct porous structure, lightness, and insulation properties, completely different compared to other lightweight concrete materials. The finished product is a lighter Block - less than 40% the weight of conventional Bricks, while providing the similar strengths. The specific gravity stays around 0.6 to 0.65, hence by using these blocks in structural buildings, the builder saves around 30 to 35% of structural steel, and concrete, as these blocks reduce the dead load on the building significantly.

FaL-G process is practiced in two ways

Lime Route: The composition is fly ash (60%) slaked lime (30%) and anhydrite gypsum (10%) to which 3 to 4 times of stone dust, sand or any inert filler material can be added.

Cement Route: The composition is fly ash (76%), OPC (20%) and anhydrite (4%) to which 3 to 4 times of filler material can be added.

Advantages

1) It reduces dead load on structures due to light weight (2.6 kg, dimension: 230 mm X 110 mm X 70 mm).
2) Same number of bricks will cover more area than clay bricks
3) High fire Insulation
4) Due to high strength, practically no breakage during transport and use.
5) Due to uniform size of bricks mortar required for joints and plaster reduces almost by 50%.
6) Due to lower water penetration seepage of water through bricks is considerably reduced.
7) Gypsum plaster can be directly applied on these bricks without a backing coat of lime plaster.
8) These bricks do not require soaking in water for 24 hours. Sprinkling of water before use is enough.

Disadvantages

1) Mechanical strength is low, but this can be rectified by adding marble waste or mortar between blocks.
2) Limitation of size. Only modular size can be produced. Large size will have more breakages.
3) It is only good for the places like subtropical area or area where climate is warm because it doesn't absorb heat. But during cold it is not helpful.

STABILIZED MUD BLOCKS (SMB)

The technology of stabilized soils for wall construction has been known in India for more than 5 decades. Dept. of Civil Engineering & ASTRA (Application of Science and Technology for Rural Areas) at IISC Bangalore, since 1975 has led to a maturing of SMB technology. Today probably more than 15000 buildings in 8 states of India using the SMB technology

CONCEPT

1) When the Soils are compressed using external energy, the density of the soil reaches a value of a moisture content known as the optimum moisture content (OMC)
2) The value of OMC and the maximum density depends on the energy input during compaction.
3) The process of mechanical compression can lead to densification and strengthening of the soil.
4) If soil also stabilized against loss of strength during saturation, we can think of a stabilized mud (soil) block where the stabilization is achieved by a combination of densification and mixing of a stabilizing additive.
5) A variety of materials can be used for the stabilization namely: cement, lime and bitumen.

RAW MATERIALS

The raw materials required are

1) Gravel 0-10% (20mm to 2mm)
2) Sand 40-70% (2mm to 0.02mm)
3) Silt 15-25% (0.02mm to 0.002mm)
4) Clay 8-25% (0.002mm to 0.0000 mm)

Soil consisting of clay, silt and sand is the basic raw materials. It is preferable that the clay should be non-expansive, although expansive clays can also be stabilized using a somewhat more complex procedure. In general soil containing 10 to 15% clay and 65.0 to 70.0% sand are satisfactory for making cement stabilized mud blocks. Cement may be added to the tune of 6.0 to 8.0% by the weight of the appropriate soil.

In case the soil has high clay content, sand or a sandy additive like quarry dust may be added to correct the grading of the soil. A combination of cement and lime can be used for non-expansive soil and with clay content around 15% a cement proportion of 5% and lime proportion 2% can added for stabilization. Lime has the advantage of combining with clay in the soil and enhancing the long-term durability

THE PROCESS:

1) Sieve the soil in a 4mm sieve to remove the stones and lumps of clay and Mix sand or quarry dust to correct the clay-sand percentage in the soil, Add cement or cement and lime in appropriate proportion.
2) Sprinkle moisture onto the mixture and further mix thoroughly till the mixture is homogeneous and Test for optimum moisture content by trying to make a ball of soil in the hand. If a ball can be made without the soil sticking to the hand the moisture content is right.
3) Weight the correct amount of moist soil such that a fresh block density of 2.05 gm/cc can be achieved. The weight depends on the volume of the finished block. In case the soil contains the much sand and silt a density of 2.05gm/cc may not be feasible. Densities like 2.0gm/cc or 1.95gm/cc may be attempted.
4) The weighed soil is now poured into a soil compaction press like the Mardini. The block is now pressed by operating the toggle lever, after closing the lid, the ejected block is then stacked in a five or six block high stack for curing.
5) Sprinkling the moisture may be pursued up to 21 days to complete the block making process.

TYPICAL BLOCK SIZES

- The block size larger than the size of brick to achieve economy in the production of the materials. Usual sizes are 230x190x100mm or 305x143x100mm
- Block thickness less than 100mm can be easily made, by introducing thicker plates inside the plates. A half block size of 230x108x100mm is also sometimes useful for corner joint, door and windows jambs, partition walls and so on.

INFLUENCE OF DENSITY AND CEMENT CONTENT ON BLOCK STRENGTH

- Density and the proportion of cement added are two important parameters, which control the strength and durability of SMB.
- The fig shows the wet compressive strength of SMB as a function of its dry density and that the strength is very sensitive to the dry density.
- As the dry density increases from 1.75 to 1.9gm/cc the strength increases from 1.0 MPa to 2.0MPa. Thus 9% of increase in dry density leads to a doubling of the compressive strength.
- In practice, it is desirable to achieve a dry density of at least 1.85gm/cc.
- The below Table shows the influence of cement on the strength of SMB cubes of size 76mm.
- The soil had a sand content of 65% and a clay content of 17%. As the cement percentage is increased from 5% to 7.5% the wet compressive strength increases by about 60%
- A cement content of 6.0 to 7.0%is normally advisable for building two storied houses.

STRENGTH OF BLOCKS

- THE SMB technology is well suited to produce a range of block strengths at the site.
- As a rule a minimum wet compressive strength of 3.0MPa is desirable for two storeyed house constructions.
- A cement percentage of 6 to 7% and a sand content of 65% and a clay content of 15% is usually sufficient to achieve a minimum strength of 3.0MPa
- Using higher percentage of cement, wet compressive strength in the range of 4.0 to 7.0MPa can easily achieved.
- A block with 7.0MPa strength can be easily comfortably recommended for four storeyed load bearing masonry.

THE DISSEMINATION OF SMB TECHNOLOGY

This technology is now well demonstrated in several states of India, namely: Karnataka, Tamilnadu, Gujarat, Orissa, Meghalaya, Himachal Pradesh and Andra Pradesh.

STONE MASONRY BLOCK

1) The central building research institute, Roorkee, developed this technology in the seventies, The BIS specification IS: 12440 gives details of the technique.
2) The precast stone block masonry is an improvement over the traditional stone masonry.
3) Considering the ease in handling and other requirements the nominal length and height of the block are kept 30cm and 15cm, respectively, with three widths 20cm,15cm, and 10cm, the actual dimensions are short by 1cm to accommodate mortar joint, These blocks weigh from 9 to 18kg.
4) The blocks are cast either in individual steel moulds of fixed type or split type of gang moulds of six blocks. These moulds are made of 4mm thick M S sheet and are welded from outside.
5) A smooth level and hard surface is required for casting the block and the stone masonry blocks are made of large size stone pieces bonded together with lean- cement –concrete mix of 1:5:8 (cement: sand: stone aggregate 10mm and lees).
6) The stone pieces used are as large as can be accommodated in the mould, these can from 5to 26cm in size and obtained either from quarry or breaking the river boulders.
7) These blocks are used both load bearing as well as non-load bearing walls, the thickness of the wall depends upon the load coming over it.

8) Thus, construction system provides an economy of the order of 15 to 20 % in the walling cost against the conventional method of construction.
9) This technology has been implemented in a large number of locations in India, where stone is readily available.

STEAM CURED BLOCKS

1) Steam curing is a process for hardening concrete, cement, and mortar that involves exposure to warm steam. Materials subjected to this hardening technique tend to cure more uniformly and also much more quickly than those hardened via other processes.
2) There are some disadvantages to this process that must be considered before deciding to use it for curing, and there may be certain applications where this method is not appropriate.
3) In steam curing, objects to be cured are placed inside a chamber or room. Using a control panel, an operator can set the temperature and humidity level. Variations in pressure may also be possible, depending on the device. The heat and moisture penetrate the materials quickly to fully hydrate and harden them.

4) Steam curing requires a fraction of the time involved with traditional curing and quickly strengthens the products so they can be used immediately. The alternative to steam curing is allowing products to cure naturally at ambient temperatures and humidity levels.
5) Timing is important when using concrete, cement, and mortar, since cool, moist weather tends to provide the best cure. Dry, hot weather will cause weakness and cracking that may compromise the finished product and in some cases, the damage can be extensive enough that the product cannot be used.
6) This is an especially important consideration when working outdoors, where controlling temperatures and humidity levels is not possible. The problem with steam cured cement is that in the long term, the cement may be weaker.
7) Steam cured cement, concrete, and mortar products are stronger at the outset than traditionally cured products, but they are more likely to fracture, crumble, and develop other problems later in their useful lives. This may not be a concern in all situations, but it can become a serious issue in others.
8) Variations in the temperature and humidity levels used during curing that change the length of time required will also vary the long-term strength of the product.

- Steam cured stabilized mud blocks
- Steam cured concrete blocks
- Steam cured auto clave aerated concrete
- Steam cured sand-lime fly ash brick

SELECTION OF BUILDING BLOCKS

The selection of a suitable block in any location will depend on the following requirements.

a) Local availability of the building material.
b) Strength and performance requirements for the building in question.
c) Cost considerations.

As much as possible procure the building materials at the shortest distance as procurement of building blocks from longest distance leads to expensive wall construction. Procure the building blocks with in 30km radius to reduce transport cost.

Stone also a feasible wall element, Bricks or SMB which depend on soil as a resource will generally be feasible in most locations since soils are more abundant than stones in nature.

MODULE – 3

ALTENATIVE BUILDING MATERIALS

LIME-POZZOLANA CEMENTS

INTRODUCTION

Engineers and the general public often have the impression that use of lime in building construction is a retrograde step and that it can never compete with a modern material like Portland. This impression is perhaps correct, as long as one is thinking of concretes with strengths in excess of 15.0MPa. However, it must be observed that nearly half the cement in a building is used for low strength applications like plasters and mortars where the strength requirement if often as low as 3.0MPa. Portland cement is certainly not the best material if one looks at the requirements of a mortar that it should be preferably slow setting and have high level of plasticity and flow.

Although BIS includes mixing of cement and lime in mortars, it is never used in practice due to the inherent prejudices against lime. It is necessary here to emphasize that addition of lime to cement mortars, slows down the initial setting of cement. Such mortars can be used effectively over a much longer time after addition of water. Cement between brick and the bonding of brick and mortar are very much improved by addition of lime. It is hence necessary to recognize the inherent value of lime in the preparation of building mortars.

RAW MATERIALS

LIME STONE

One of the raw materials for all lime based mortars is lime stone. Lime stone is essentially calcium carbonate in nature. Calcium being one of the fairly abundant metals on earth. Natural lime stone is one of the purer forms of calcium carbonate occurring in nature. Calcium carbonate is mildly soluble in water and sometimes be leached out by water and ultimately deposited with clay as an impurity in the form of **'Kankar'** lime stone.

There is also an organic source of lime stone in the form of shell lime which is usually available in coastal areas. All the three sources of lime stone are used for building purposes. The 'Kankar' variety of lime stone usually displays hydraulic properties after burning.

The requirements for the use of lime for building purposes may be obtained by codes/specifications

IS:712-1973 : Specifications for Building Limes

IS:1514-1959 : Methods of sampling and test for quick lime and hydrated lime.

IS:6932-1973 : Methods of tests for building limes.

Two types of mortars can be prepared by using lime namely:

1) Lime Mortar
2) Lime-Pozzolona Mortar

Lime mortars are of two kinds

1) **Fat lime mortar**

   When the lime stone is of high level of purity the resulting lime is fat lime and fat lime when mixed the sand leads to fat lime mortar. This type of mortar does not need moisture for setting; it sets by absorbing CO_2 from the atmosphere.

2) **Hydraulic lime mortar**

   When the lime stone has clay impurities, the burning process leads to hydraulic lime which is actually a mixture of calcium oxide and burnt clay. This type of lime sets in the presence of moisture and the calcium hydroxide reacts with the amorphous silica and alumina present in burnt clay. In this case, the lime-sand mixture has to be cured by keeping in moist for at least 28 days. In general, hydraulic lime mortars have better strength than fat lime mortars.

The following chemical reactions take place in the processing of lime stone for mortars.

1. Burning of lime stone

$$CaCO_3 \rightarrow CaO + CO_2 \uparrow$$

2. Slacking of quick lime

$$CaO + H_2O \rightarrow Ca(OH)_2 + Heat$$

3. Setting of fat lime

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

The burning of limestone to produce quicklime (CaO) is generally carried out in vertical shaft kilns using either firewood or coal as fuel at a Temperature of the order of 900-1000^{0}C are needed to release CO_2 from lime stone. Thus, a ton of lime stone, when burnt will give 740kg of $Ca(OH)_2$, if there are no impurities.

Fig. Shows lime kiln design for small rural application

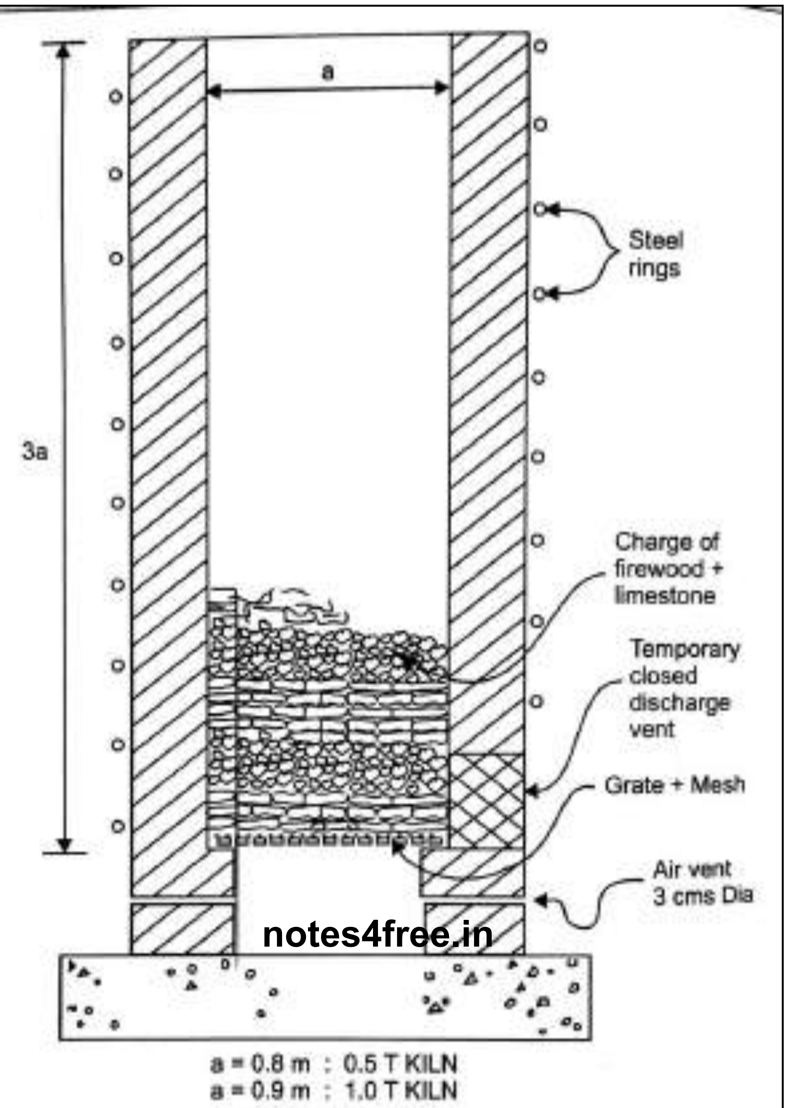


Fig. 3.1: Lime Kiln

POZZOLANA

Pozzolana is a material which consists essentially of amorphous silica or a mixture of amorphous silica and alumina. This is not cementitious by itself, but forms cementitious compounds when it combines with calcium hydroxide at ambient temperature in the presence of moisture. A mixture of finely ground calcium hydroxide and pozzolana is hence known as lime- pozzolana cement.

There are many ways in which pozzolana can be produced. The following sources of pozzolana are commonly used.

1. Powdered burnt clay (commonly known as ‘Surkhi’ in India)
2. Fly ash.
3. Rice husk ash

POWDERED BURNT CLAY

- It is made either by artificially burning clay in a kiln or by selecting wastes of burnt clay materials like bricks, tiles, and pottery.
- When clay is burnt in a kiln for the purpose of making pozzolona, it is desirable to select a soil with high proportion of clay. If the clay occurs along with large amounts of sand, the sand may be removed by sieving to obtain high clay soil.
- This is necessary since sand is a diluent and does not react with lime in the manner in which pozzolona does.
- The high clay soil may now be made into thin briquettes. The wet clay may be spread on level ground to a thickness of 2.5cms and then sliced into thin cakes of sizes 10cms x 10cms x 2.5cms.
- These cakes may now be dried and then charged into the kiln with alternate layers of firewood. Usually the firewood used could be around 10% of the weight of the clay, With the amount of firewood, a temperature of about 700°C can be expected.
- The burnt clay may now be pulverized to about 90μ size particles. Ball mills are usually used for the purpose. This pozzolona can store in bags indefinitely without any loss of its reactivity.

Fly Ash

Fly ash as pozzolona is ultimately obtained from thermal power plant which used pulverized coal in the fuel.

- The fine particles of coal, which are collected in electrostatic precipitators, are known as fly ash. They contain significant amount of amorphous silica and alumina.
- Thermal power plants also produce significant amounts of coal ash in the form of pond ash and bottom ash. These types of ashes are generally not good as pozzolona.
- Fly ash is a waste product and may be considered as a zero-thermal energy material, unlike burnt clay which needs specific energy inputs.

Rice Husk Ash

Rice husk ash is a natural source of silica. Normally rice husk contains about 20% silica and the rest of it is combustible material. This silica is amorphous and if the husk is burnt under controlled conditions a highly pozzolonic ash can be produced. The below figures show two typical arrangements for burning rice husk.

Honeycomb Kiln

It is an annular honey comb brick structure is erected and a closely spaced mesh is placed at a height of 20cms above the ground.

- Alternate layers of rice husk and clay are placed in the kiln such that the husk is about 30 to 40% by weight of the clay.
- The width of the clay layers should about 15cms less than the width of husk to permit easy air movement through the bed of husk.
- The stack is now set fire to from below and the entire mass burns out over one or two days.
- The end product is a mixture of burnt clay and rice husk, this may be ground in a ball mill to obtain fine pozzolona.
- Combination pozzolona, is obtained from this process, which is a mixture of burnt clay and rice husk ash, and This technique has the advantage of producing a relatively large quantity of pozzolona.
- It must be noted that the national availability of rice husk ash is around 2.0 million tonnes of combination pozzolona can be generated to the country.

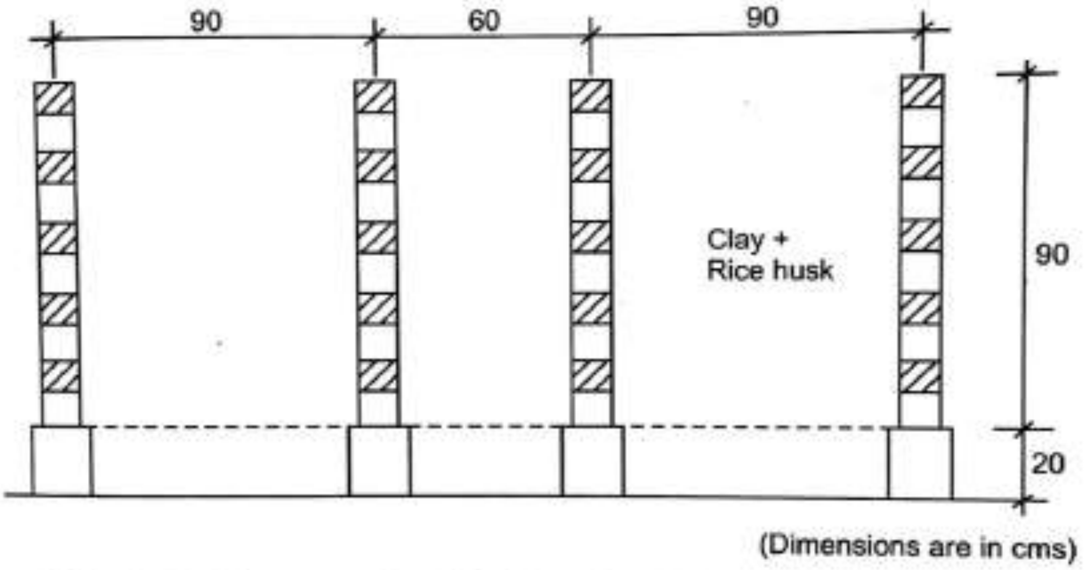


Fig. 3.2: Honeycomb Kiln for Combination Pozzolana

Rice Husk Burner

It is known as the tube in basket burner and It has an annular mesh enclosure in which rice husk is stacked and set fire from bottom. The entire mass burns over several hours with central opening acting as a chimney.

- Copper tube carrying water may be inserted in the bed of husk to generate hot water from the burning husk. This technique also leads to good quality pozzolona

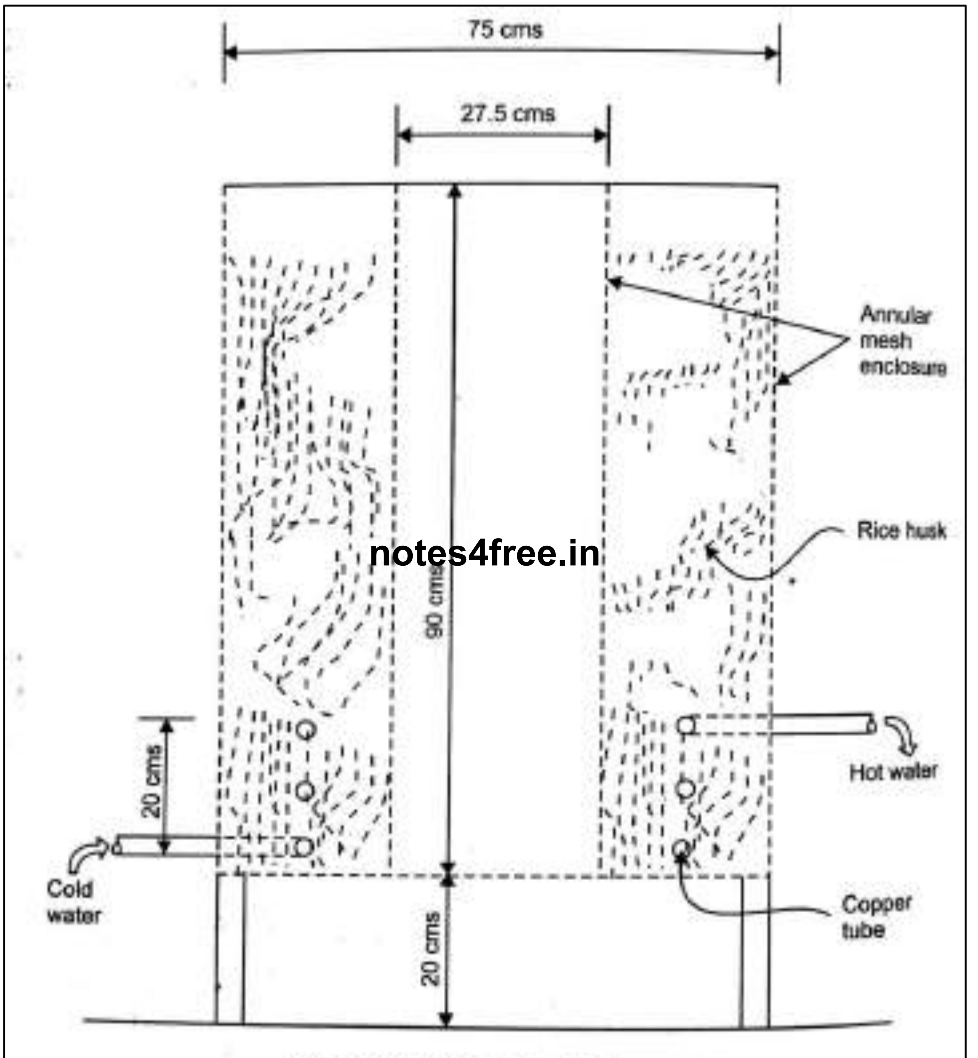


Fig. 3.3: Rice Husk Burner

THE PROCESS

LIME - POZZOLONA CEMENT

It is an intimate mixture of lime and pozzolona will set in the presence of water, forming calcium silicate and calcium aluminates compounds.

- In the traditional lime Surkhi mortar, slaked lime and brick powder is mixed and ground in the presence of moisture in bullock driven mortar mills and the ground moist mixture is then directly used in construction.
- In the modern context, power-driven pan mills are used to grind the mortar.
- Unlike Portland cement, which is already a complete cementitious product, lime pozzolona cement needs an additional step of mixing lime pozzolona. The efficiency of the lime pozzolona cements depends on the intimacy of the mixing of lime and pozzolona.
- The traditional process of lime Surkhi mortar involved wet grinding of lime and Surkhi mixture. According to the studies made in KERS Dam site, it was found that the mortar strength reaches a maximum when the duration of grinding in 35 minutes. Grinding for longer or shorter durations leads to lower strengths.
- However, in the context of modern construction wet grinding may be considered to be an inconvenient procedure, since this needs deployment of diesel engine or electric energy at the site for mortar mixing. It would be ideal if wet grinding can be avoided.

Two alternative techniques have been explored at Dept. of Civil Engineering IISc Bengaluru

a) Dry blending of lime and pozzolona
b) Wet blending of lime and pozzolona

Dry Blending of Lime and Pozzolona

In this technique, the slaked lime and pozzolona should be separately processed as dry powders. The pozzolona may be dry ground in fineness of 90μ. The two powders may now be blended in a ball mill for duration of about 1 hr.

- In this technique, the size reduction of lime and pozzolona is carried out first and mixing the two is carried subsequently.
- This mixture is then added to sand and after thorough dry mixing. Water is added to complete the preparation of mortars.
- This procedure also means that the dry mixture of lime and pozzolona may have to be stored in bags.

- This also leads to the question of shelf life of lime pozzolona mixture. It was found that lime pozzolona mixture will lose strength rapidly on storage.
- Stored in gunny bags or LDPE bags, the day's strength shows a 60%reduction after 21days of storage.
- Important to note that the blended dry mixture of lime and pozzolona should not be stored for more than 14 days if the strength reduction is to be less than 10%.
- The poor shelf life of pozzolona mixture is probably one reason why this approach alternative cement has not succeeded.

Wet Blending of Lime and Pozzolona

- In this approach, the pozzolona has to be produced and ground to 90µ fineness and stored in gunny bags or woven LDPE bags.
- The pozzolona can be stored indefinitely.
- Slaked lime may be freshly produced by slaking quick lime at the site.
- The slaked lime and the well ground pozzolona may now be mixed in a simple drum or hand mixing concrete mixture in the presence of water.
- After blending the two for about 20 minutes, the lime pozzolona slurry now be poured over sand and mixed thoroughly to get the lime pozzolona mortars.

PROPERTIES AND USES

Strength of Mortars with Burnt Clay and Combination Pozzolona

Number of studies was carried out to determine the typical strengths of lime-pozzolona mortars using burnt clay and combination pozzolona. Typical results of burnt clay pozzolona based mortars are shown in table below

Table 3.1 Strength of Lime-Burnt Clay Pozzolana Mortars

Type of Resource	Particle size of pozzolana microns	Duration of inter-grinding Lime & Pozzolana minutes	Mortar Proportion Lime:Pozz: Sand by weight	Average Compressive Strength, MPa		
				7d	28d	180d
Red Soil 1	< 90	0	1:2:9	3.2	5.4	–
Red Soil 2	< 90	30	1:2:9	4.3	6.1	9.3
Black Soil 1	< 90	30	1:2:9	2.4	5.1	8.75
Tile Powder	< 90	30	1:2:9	3.95	7.7	–
Brick Powder	< 600	0	1:4:10	0.55	1.8	3.15

- The listed proportions indicate proportion by weight. It can be seen that the 28 days strengths of most of the mortars are above the BIS codal requirement of 3.0 MPa.

- It must be noted that bulk density of lime–burnt clay mixture is quite low and hence the mortar proportions by volume are quite rich when compared to the usual cement mortar proportions
- This means that greater proportion of lime-pozzolona cement has to be used to achieve satisfactory mortar strengths.
- It is seen that when the burnt clay and rice husk are separately produced adequate rice husk ash can be added to provide good strength.
- When rice husk is used to burn the clay, the process become more economical but the strengths are moderate. It must be noted that 6 months strengths are substantially high.
- A clay rice-husk ratio of 1:0:6 is ideal from the point of view of strength and economy.

Fly Ash as Pozzolona

Fly ash is collected from electrostatic precipitator in thermal power stations which use pulverized coal as the fuel. When exceedingly fine coal particles are burnt, the residence times are low and the ash containing silica and alumina is quite amorphous.

This ash, which is very fine in terms of particle size, is hence quite reactive and is an excellent pozzolona. There are also types of fly ash which are coarse and not very reactive. The grain size distributions of two samples of fly ash from Raichur and Neyveli are shown in figure below

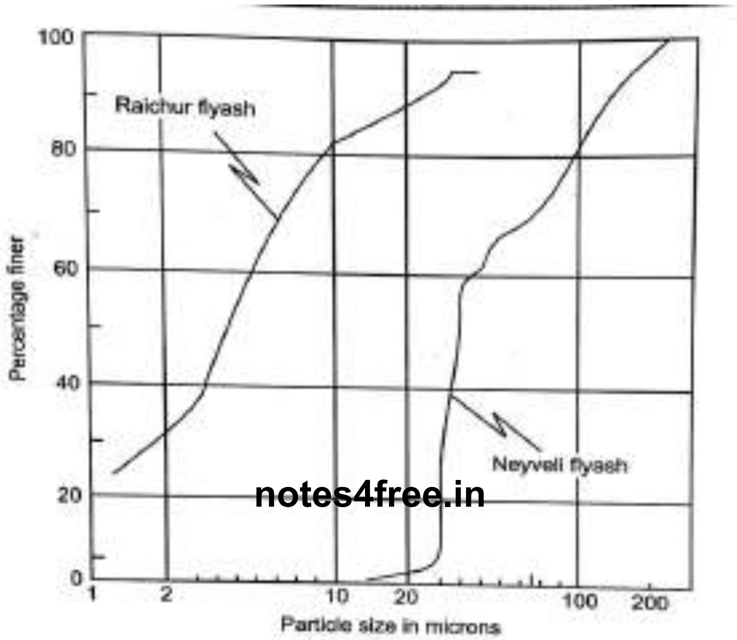


Fig. 3.4: Grain Size Distribution of Fly Ash

- It can be seen that the Raichur fly ash is very fine and 30% of the particles are finer than 2µ. The Neyveli ash is rather coarse and most of the particles are coarser than 25µ.
- The characteristics of fly ash as pozzolona were studied using these two samples and making lime pozzolona mortar cube of 5cm size.
- The lime fly ash mixtures were ground in a ball mill and Accelerating additive like plaster of Paris, gypsum was sometimes added.
- The tests show that lime-fly-ash mortars are eminently suitable for construction with the 180 day strengths in excess of 10.0MPa. Leaner mortars could be used because of high strength of 1:3 cement-sand proportions.
- The Raichur fly ash, with its fine particulars is exceedingly good as pozzolona while Neyveli fly ash is very much inferior.

FIBRE REINFORCED CEMENT COMPOSITES

Cement concrete can be cast to any desired shape, it also possesses many desirable properties like high compressive strength and stiffness and low thermal and electrical conductivity. But two of its characteristics Viz. Weak in tension and brittleness at failure have limited its use for various applications. These limitations are overcome by adding materials strong in tension to concrete resulting in a composite material. One of the ways this has been achieved is by placing steel bars in concrete, in regions where concrete is subjected to tension leading to what is called as RCC. Even though the concept of RCC has eliminated one of the major weaknesses of concrete. (Inability to resist tensile forces), it still falls short of many more desirable properties like toughness, ductility, controlling of cracking and energy absorption. This is basically because the reinforcement component in RCC is present in certain pockets of the cross-section of the structural member. In order to achieve all the above- mentioned properties it is essential to distribute the reinforcement uniformly throughout the c/s. Such a way of reinforcing the brittle concrete matrix is possible by adding to the constituents of the concrete mix, short fibres of small diameter that are either metallic or non-metallic. This new material with improved mechanical properties is called **"FIBRE REINFORCED CEMENT COMPOSITE" (FRC)**.

- The concept of reinforcing a brittle matrix with discrete fibres is an age-old practice. For example: fibres made of straw or horse hair were used to improve the properties of bricks for thousands of years.
- The modern day use of fibres in concrete started in early 1960's. In the initial years only straight steel fibres were used and improvements in fractures toughness and ductility were reported.
- Some of the major problems encountered during the early periods were difficulty in mixing and workability particularly when longer fibres were used at higher volume.
- Use of longer fibres resulted in segregation of the constituents of the mix and also lumping of fibres in certain regions and bridging between aggregates causing voids. This is called as balling in the fibre reinforced concrete.
- With the advent of deformed fibres and water reducing admixtures like super plasticisers some of the above-mentioned problems were overcome.
- The performance of a composite material depends on the properties of matrix and the fibres and the strength of the bond between the two.

MATERIALS

Fibre reinforced cement composite is a two-phase material consisting of matrix which is reinforced with randomly oriented small fibres to improve the mechanical properties of the matrix

Matrix Material

The matrix generally consists of Portland cement, aggregate and admixtures and can be any of the following.

a) Plain Portland cement
b) Cement with additive such as soil, fly ash or condensed silica fume.
c) Mortar containing cement and fine aggregate
d) Concrete containing cement, fine and coarse aggregate.

Water is added to the concrete mix for hydration of cement and for moulding of the concrete to the desired shape. It is very well established that the compressive strength of the concrete depends up on the water cement ratio in the mix.

- W/c ratio of 0.28 is sufficient for the hydration process, to obtain a plastic workable mixture, a minimum w/c ratio of 0.6 is needed. Addition of fibres to the concrete reduces the workability. In order to keep the w/c ratio within reasonable limits of not affecting the compressive strength but to still achieve workability, water reducing admixtures have become an integral part of fibre reinforced composites.
- In addition to water reducing admixtures, mineral admixtures like fly-ash and silica fume are also added to the matrix.
- Fly ash is used to improve workability, reduce the heat of hydration, economy and to enhance permeability characteristics of the matrix.
- Silica fume is added mainly to achieve high strength matrix.

Reinforcing Material

The reinforcement is in the form of short fibres of small diameter distributed throughout the matrix.

The fibres can be broadly classified as:

1. Metallic fibres
2. Polymeric fibres
3. Mineral fibres
4. Natural fibres

By its very definition reinforcement is supposed to induce an increase in strength in the reinforced material (i.e. matrix).

In order to be effective in concrete matrix, the fibres must have the following properties.

a. Tensile strength significantly higher than that of concrete
b. Bond strength with concrete matrix preferably of same order as or higher than the tensile strength of matrix.
c. The elastic modulus in tension to be significantly higher than that of concrete.
d. The poison's ratio and the coefficient of thermal expansion preferably be of the same order as that of matrix.

Metallic Fibres

Metallic fibres are either made out of carbon steel or stainless steel. The tensile strength ranges from 345MPa to 1380MPa. The modulus of elasticity is about 200GPa.

- The fibres c/s may be circular, rectangular, crescent shaped or irregular. Most common steel fibres are round in c/s with dia ranging from 0.4mm to 0.8mm and a a length ranging from 25mm to 60mm.
- Their aspect ratio is generally less than 100 with common range of 40 to 80.
- The below figure shows some of the fibres types of different shapes used in practice.

a) Round and straight steel fibres
b) In order to the bond strength, the fibres have been indented.
c) Crimped
d) Hooked at the ends
e) Enlarged at the ends
f) Fibres are produced from wires that have been shaved down in the steel wool making process and such fibres have a crescent shaped c/s.
g) Fibres have irregular surface with crescent shaped c/s.

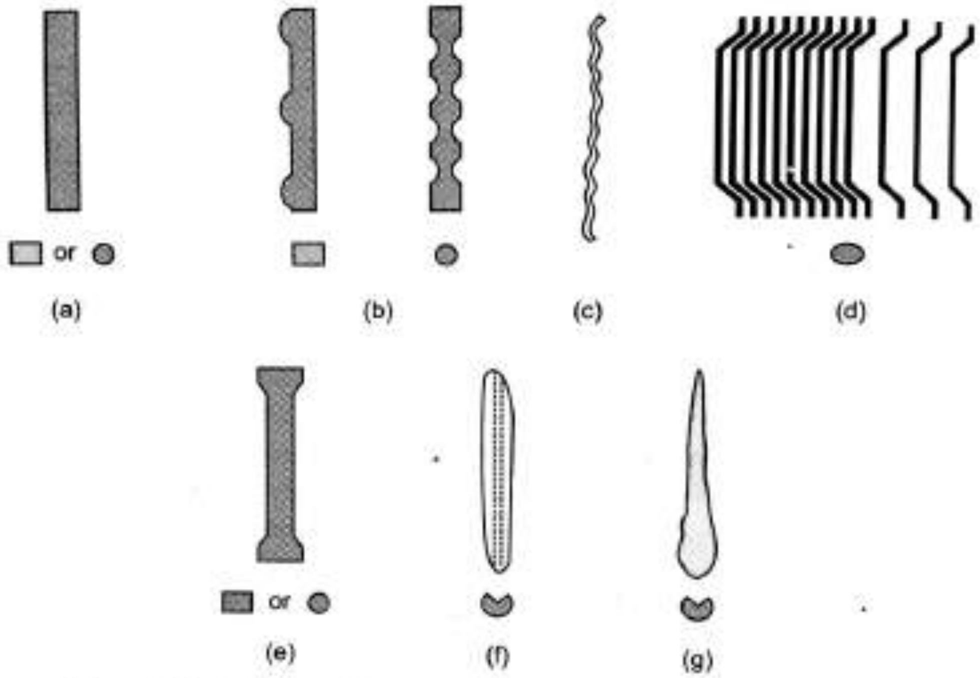


Fig. 4.1: Various shapes of steel fibres used in fibre reinforced concrete.

Polymeric Fibres

Polymeric fibres are by products of petrochemical and textile industries. The fibres types have been explored for use in cement based matrices are Acrylic, Aramid, Nylon, Polyester, Polyethylene and Polypropylene. Even though these fibres have reasonably high tensile strength, the modulus of elasticity of most of them is quite low (except aramid).

- Fibres that contain at least 85% by weight of Acrylonitrile are classified as acrylic fibres.
- Nylon was one of the first of the polymer fibres to be included in cement based matrices.
- When used in small volumes (<1% volume fraction of composite) it has been found to reduce the flexural strength of the composite.
- Compared with other polymeric fibres, Aramid fibres have higher tensile strength and modulus of elasticity and hence they can enhance the mechanical properties like tensile and bending strength of the composite.
- The primary limitation for their use in concrete is high cost compared to other fibres.

Mineral Fibres

Glass fibres are the predominately used mineral fibre. Glass fibre is silica based glass compounds that contain several metals oxides which can be tailored to manufacture different types of glass

- These fibres relatively high tensile strength and modulus of elasticity compared to polymeric fibres.
- Furthermore, they are quite economical and hence are the most commonly used fibres for structural applications.
- In the initial stages borosilicate glass fibres (E- glass) and soda-lime-silica glass fibres (A-glass) were employed to reinforce cement-based composites.
- Since both E-glass and A-glass fibres were found to lose their strength property in the alkaline environment of cement based composites (pH ≥12.5), the need for alkali resistant fibres resulted in the development of alkali resistant glass (AR glass)

Natural Fibres

Since in many parts of world manmade fibres like steel or polymer fibres are not available, attempts have been made to incorporate naturally occurring fibres extracted from plants in cement based composites.

- A unique aspect of these fibres is the low energy needed for their extraction. A major problem in the use of these fibres in cement/concrete matrix is that they disintegrate in the alkaline environment and hence durability of the composite is a matter of concern.
- Since these fibres are economical, attempts have made to overcome the problem of durability either by use of admixtures in concrete to reduce its alkalinity or by protecting fibres by some special treatment.
- Some of the natural fibres used in Portland cement composite are akwara, bamboo, coconut (coir), jute, sisal, sugarcane bagasse, wood and elephant gross. Even though these fibres are sufficiently strong in tension, their modulus of elasticity is quite low.
- Akwara fibre is extracted from a vegetable plant stem, which is grown in large quantities in Nigeria. They are found to be durable in the alkaline environment and dimensionally stable under alternate wetting and drying conditions.
- Bamboo fibres have tendency to absorb water, which adversely affects the bonding between fibre and the matrix during the curing stage.

- Fibres extracted from the coconut are called as coir. Coir fibres are short in length and are found to be sensitive to moisture change.
- Sisal fibres are extracted from the leaves of Agave sisalana and it primarily consists of hemicellulose, lignin and pectin. Sisal fibres even though relatively strong, are not durable in alkaline environment.
- Elephant grass fibres are extracted from elephant grass stems, which grows up to a height of 3m. The stems are packed with tough sharp fibres bonded together with lignin. Extraction of elephant grass fibres is difficult but they are stable under varying moisture conditions and alkali resistant.
- Wood fibres constitute a major portion of natural fibres used in concrete. These fibres have high tensile strength and young's modulus and process of extraction is very well developed. The process of extracting fibres from wood is called pulping and the process can be mechanical, chemical or semi-chemical.

Carbon Fibres

Carbon fibres are the most expensive of all the fibres discussed till now.This is due to the increased cost of their manufacturing process as well as the increased cost of raw materials required for their manufacture. Carbon fibres have high strength and modulus comparable to that of steel fibres. They are relatively inert to alkaline environment and their specific gravity is about 1.9. Hence they are used to make special products requiring high tensile and flexure strengths and light in weight.

- Current manufacturing technologies use polyacrylonitrile (PAN), rayon (regenerated cellulose) and pitch as starting materials, PAN based carbon fibres have good properties but are high in cost.
- Pitch based carbon fibres are more economical but their mechanical properties are poorer than PAN based carbon fibres but still higher than polymeric and neutral fibres.
- PAN based carbon fibres have a modulus and tensile strength of 300GPa and 5200MPa respectively; whereas pitch based carbon fibres have a modulus and strength of 160GPa and 1400GPa respectively.

FIBRE REINFORCED (PLASTICS) POLYMER COMPOSITES

INTRODUCTION

Human endeavour towards continuous improvement in quality of life resulted in a host of new materials and technologies. In fact, the 'various stages in the progress of mankind is characterized according to dominant material of the period viz. stone age, bronze age, iron age etc.

It May be appropriate to call the present era as the plastic age. The concept of combining two different materials having different properties to obtain a material possessing far superior properties than the individual materials is not new. The need for materials that are strong, lightweight, corrosion and chemical resistant and permeable to electromagnetic radiations has led to the advent of fibre reinforced polymer (FRP) composites.

In the initial years, FRP composites were predominantly used in aerospace applications, but in the last two decades civil/structural engineers and architects have realized the potential of FRP composites in building industry.

In the previous topic, we have discussed the concept of reinforcing the brittle cement based matrix with small diameter fibres. In cement based composites only limited amount (volume) of reinforcing fibres (up to 5% volume fraction) can be used. This is basically due to limitations in the flow characteristics of cement-based matrices, which is essential to completely wet and impregnate all the fibres in the matrix.

In view of good flow characteristics of the polymers, its use as matrix enables incorporation of large volume (up to 70%) of reinforcing fibres in the composite. This has resulted in the development of a large number of products using FRP composites. In this portion various materials used in the production of FRP composites and their properties, manufacturing techniques and applications are discussed.

MATERIALS

The fibre-reinforced polymer composite is a two-phase material consisting of polymer matrix reinforced with small diameter fibres which are either continuous or discontinuous and oriented uni-directionally or randomly

MATRIX MATERIALS

The matrix in a composite performs the following functions;

a) It glues the bundles of fibres together and helps in distributing the external load to all the fibres,
b) It protects the fibres from adverse environmental effects and prevents the buckling of fibres under compressive forces, and
c) It protects the fibres from mechanical abrasion.

Polymers, also called as Resins are employed as matrix material in FRP composites.

The polymers are classified into two types.

1) Thermo-set polymers
2) Thermoplastic polymers

Polymers (in Greek: poly+meros meaning many parts) are large organic compounds formed by the joining together of many small molecules to form a large molecule by a process called as polymerization. The simple compounds from which polymers are made are called as monomers.

Both thermo-set and thermoplastic polymers are long chained molecules. The polymers in which their long molecular chains are interconnected with chemical bonds or cross links forming a rigid three-dimensional structures are called as thermo-set polymers.

- In the case of thermoplastic polymers their long molecular chains are not chemically interconnected and are held in place by weak secondary bonds like Vander Walls bonds.
- Thermo-sets are generally liquid resins, which are heat activated (or cured) to achieve cross-linking of the molecular chains.
- Thermoplastics are solids, which have to be melted by heating, moulded to the desired shape and cooled. Because of their differing chemical structure, the thermo-sets and thermoplastics have unique properties.
- Thermo-sets are more rigid than thermoplastics due to their cross linked chemical structure and cannot be re melted by heating, whereas thermoplastics can be re melted by heating.
- Thermo-set polymers have good thermal stability and chemical resistance. They also exhibit reduced creep and stress relaxation compared to thermoplastics. Thermo-sets have short shelf life after mixing with curing agents (catalysts) and low strain to failure and impact strength.

- Thermoplastic polymers on the other hand have high impact strength, fracture resistance and strain to failure.
- The below figure shows the schematic representation of thermoplastic and thermosetting polymers.

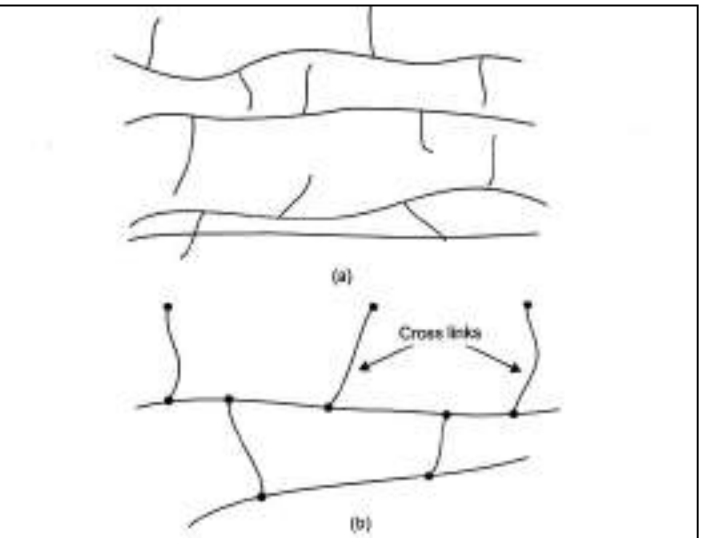


Fig. 5.1: Schematic representation of (*a*) thermoplastic and (*b*) thermosetting polymers

- Typical examples of thermoplastic resins are polycarbonates, nylon, polyethylene, polypropylenes and polystyrenes.

The most commonly used thermo-set polymers are

1) Polyester Resins
2) Vinyl Ester Resins
3) Epoxy Resins

POLYESTER RESINS

These are formed by condensation polymerization of a diacid with dialcohol. By the elimination of water between the acids and alcohols, ester linkages are formed. The resulting molecular chain of alternate acid and alcohol molecules is collectively called polyester resin. The cross-linking occurs by the addition polymerization reaction. A molecule that readily produces free radicals initiates the cross-linking reaction. Polyester resins are the cheapest resins suitable for making FRP composites for civil engineering applications.

- Styrene (reactive diluents) is added to the resulting polymeric liquids to reduce its viscosity.
- The Orthophthalic resins have low thermal stability and chemical resistance,

whereas the Isophthalic resins have better chemical and thermal resistance.

- The properties of polyester resins depend strongly on the cross-link density like for example increasing the density of cross-links, improve the elastic modulus, glass transition temperature and thermal stability but reduces the strain at failure and impact energy.

VINYL ESTER RESINS

- These resins are derived from the reaction of Bisphenol A diglycidyl ether with acrylic or methacrylic acid.
- Vinyl esters are classified separately from polyesters due to their enhanced mechanical properties.
- They offer excellent physical strength and in general, posses much better impact and thermal shock resistance than polyester resins.
- A unique characteristic of vinyl ester is that it contains a number of OH (hydroxyl) groups along its length, which can form physical bonds with similar groups on glass fibre surface resulting in excellent wet-out and good adhesion with glass fibres.

EPOXY RESINS

These resins are generally manufactured by reacting epichlorohydrin with bisphenol A. Varying the proportions of the two reactants forms different resins. Epoxies possess many desirable properties like excellent adhesion, strength, low shrinkage, corrosion protection and processing versatility. These resins are expensive compared to polyesters.

FILLERS AND OTHER ADDITIVES

Fillers are added to thermo-set polymeric matrices for one or more of the following reasons:

1. Reduce cost
2. Increase stiffness (modulus)
3. Reduce mold shrinkage
4. Control viscosity
5. Produce smoother surface

- The most common filler for polyester and vinyl ester resins is calcium carbonate, which is used to reduce cost as well as mold shrinkage.

- Other materials employed as fillers are clay, mica and glass micro-spheres.
- Even though fillers increase modulus they reduce strength and impact resistance of the cured resin.
- In addition to fillers, colorants, flame-retardants and ultra violet absorbers are also added to the resins.

REINFORCING FIBRES

Reinforcements in the form of fibres, particles or whiskers are used with resin systems to improve the mechanical properties of the resins and to produce usable products. By far the most important fibre used with polyester and epoxy resins is glass fibre which is available in a variety of forms like rovings, woven rovings, cloths and random chopped fibre mats.

In recent years high strength carbon fibres and polyaramid fibres have found increasing use in the manufacture of composite materials for a variety of applications. Natural fibres such as jute and sisal have also been used to reinforce thermosetting resins.

APPLICATIONS

FRP composites have found application in various branches of engineering and technology. During the initial years it was predominantly used in aerospace structures due to its light weight and high strength where cost was not the governing factor. With the passage of time its application spread to other areas of engineering. Due to its corrosion resistant property it is used in chemical industries. It is also used in making sports equipment like tennis racket, fishing and pole-vaulting rods and baseball bats. It is also used in bio medical engineering for making prosthesis. Pultruded FRP rods have been used as reinforcement in concrete. FRP sheets have also been used for repair and retrofit of concrete structures. FRP composites will find newer applications in future in all spheres of life

BUILDING MATERIALS FROM AGRO AND INDUSTRIAL WASTES

INTRODUCTION

Traditional housing in all civilizations has depended heavily on biomass resources including Agro wastes. Typical examples of agro wastes utilization may be mentioned as use of thatch for roofing, use of wattle and daub for walls and use of cow-dung for flooring. After increasing industrialization and urbanization use of agro wastes is becoming less common. Some attempts have been made in recent times to improve their properties. Use of chemically treated thatch is one such example.

While the use of such modifications to traditional technologies may have its place even in a modern context they do not seem to have wide acceptance. Use of biomass resources like bamboo, reeds and timber, with and without treatment is however useful even now in view of their renewable nature. The management of such resources is however fraught with difficulties as there is a tendency to overexploit forest resources. Appropriate management practices to grow these resources on non-forest lands is inescapable if the use of such materials has to remain ecologically sound.

TYPICAL AGRO WASTES AND OTHER BIOMASS RESOURCES:

Some of the agro wastes which can have applications in building construction may be listed as under

1) Rice Husk
2) Rice Husk Ash
3) Bagasse
4) Sugar cane tops
5) Coir fibre
6) Sisal fibre
7) Straw
8) Coconut and Areca nut tree trunks
9) Coconut leaf

- Use of straw or sugar cane tops for thatching is well known. However, straw is not very durable and where the rainfall is high (more than 1000 mm per year) it may not last more than one year. Sugarcane tops are more durable and there are examples of it lasting 5 years.
- Coconut and Areca nut tree trunks have been used as timber substitutes. Coconut leaf is also popular as thatching.

The other agro wastes have not been used traditionally in building construction but they all have potential uses as follows

- For instance, experiments have been made by making rice husk-phenol formaldehyde boards. Such boards could be used as replacement for plywood panels. This is more environment friendly than plywood since use of plywood implies considerable deforestation.
- Rice husk ash, when rice husk is burnt under controlled conditions, results in amorphous silica with excellent pozzolona properties.
- Coir and sisal fibres have been attempted in fibre cement composites, but their durability characteristics are not well known. However, using coir and sisal fibre along with polyester resin as a matrix appears to offer a cheaper, energy efficient alternative to glass fibre reinforced polyester composites. The properties of such composites are yet to be fully explored.
- Bamboo, cane and lantana are other biomass resources with potential in building construction. Among these, use of bamboo in building construction is well known. It has been used extensively for housing is North East regions of India. Its use in wattle and daub walls is well known in Mysore and Shimoga districts.

- Use of cane for furniture is well known. The long rounded cane lengths could be considered for use as tension members in a truss. Joining details for such use need to be worked out.
- Lantana has also been attempted as a substitute for cane. Since lantana is a weed, it could be an ideal resource for construction. It appears to have termite resistant properties and this may have considerable advantage. Its termite resistance, however, needs to be conclusively proven. Woven mats of lantana can be used as reinforcement for wattle and daub walls or partition boards.

CHEMICALLY TREATED THATCH:

Treatment of thatch has been attempted in India to improve the life of thatch. Two technologies have been used for this purpose.

- The first one refers to treatment of thatch like material by dipping in copper-chrome-boric acid solution. Here the thatching material is dipped in a solution containing 1% copper sulphate, 1% potassium or sodium dichromate and 1 to 5% boric acid for a period of two hours. After removal of the thatch and drying of the surface, the material can be bundled and used for thatching.

- One such experiment was carried out at ASTRA, Indian Institute of Science in 1978, using grass thatching.
- The top surface of the thatch appeared to deteriorate in 1985 and the entire thatch was removed. It was, however, observed that the thatch in the interior was intact and had not deteriorated.
- Probably, the roof could have worked for a few more years! This was attempted in Ungra Village, Kunigal Taluk, Tumkur District. This experiment showed that chemical thatch treatment using copper-chrome-boric can work well in moderate rainfall areas (75-100 cms/year). However, this treatment may not ensure resistance to fire hazard.
- The second technique, developed in Regional Research Laboratory, Trivandrum, involves dipping coconut leaf in copper sulphate solution and subsequent coating with Cashew Nut Shell Liquid and Kerosene.
- The report by RRL claims an increase in life of coconut thatch from year to 3 years in Trivandrum. A number of NGO's in South India implemented this technique for housing with financial support from CAPART (Council for Advancement of People's Action and Rural Technology, New Delhi).

- The experience of many of these organizations has been varied. In some areas, it is claimed that life increases from years to 3 years.
- Again, in practice the thatch is dipped for 5 minutes instead of the 48 hours suggested by the R.R.L. Report. It is not clear if dipping for 5 minutes is inadequate.
- However, the technology was accepted only as long as CAPART subsidized the supply of treated thatch. The technology seems to have died a quick death after the completion of the project.
- Even today, thatch is used extensively in Tamil Nadu for temporary shelters, road side shops, shelter on the flat roof of a pucca house and so on.
- There is a need to examine this technique further and even attempt improving it by providing fire retardation as well

INDUSTRIAL WASTES:

A large number of industries produce waste materials which need to be either disposed of or utilized for some purpose. Very often, disposal of wastes could pose problems. There are instances where large chunks of land are rendered useless or unavailable due to deposition of such wastes. Fly ash and marble dust are two typical wastes which can pose serious disposal problems.

Some of the typical industrial wastes may be listed as under:

1) Fly ash from thermal power stations.
2) Blast furnace slag from steel plants.
3) Mine wastes from iron ore mines.
4) Tailings from copper mines.
5) Fine rock dust from gold mines.
6) Granite polishing wastes.
7) Marble polishing wastes.
8) Rock dust from stone crushers.
9) Red mud from Aluminium factories.
10) Brick, Mortar and Concrete wastes from demolished buildings.

USE OF INDUSTRIAL WASTES:

Fly Ash

Fly ash, which is obtained from Electrostatic Precipitators in thermal power stations, generally contains amorphous silica and alumina.

- These products have the property of combining readily with calcium hydroxide, at ambient temperatures, in the presence of moisture (pozzolonic properties). The resulting compounds are similar to what is found in hydrated Portland cement.
- Thus, fly ash can be used as pozzolona in lime-pozzolona cements. Addition of gypsum/ plaster-of-Paris in small quantities will accelerate the strength gain in such cements. Blending/intergrading of calcium hydroxide, fly ash and gypsum is important if the full strength of the mixture is to be achieved.
- However, a dry mixture of Ca(OH)2 and fly ash should be used within about 7 days of mixing since the shelf life of the mixture is low.
- Fly ash can also be an important ingredient in building blocks. Lime-fly ash-gypsum-sand mixtures or cement-fly ash-sand mixtures can be pressed into blocks

for wall construction

- A good quality, reactive fly ash will generally consist of silt like fines with clay size fractions of the order of 5 to 20%.
- There are other types of ash known as pond ash or bottom ash which are generally not very reactive. Such wastes can be used as sand replacement or for inert fillers in building blocks. They are also ideal for Road Construction projects.

Blast Furnace Slag

- The slag from blast furnace has cementitious properties.
- Portland Blast Furnace Slag Cement is made by grinding normal clinker with slag.
- This cement has sulphate resisting properties and is ideal for use in aggressive environments.

Iron Ore Tailings

- The Kudremukh Iron Ore Company of Karnataka has stored iron ore tailings to the tune of 150 million tons. This waste has sand particles to the extent of 79% and silt particles to the extent of 19%.
- This can be an ideal sand substitute for local construction activity.

Gold Mine Tailings

- Gold is often extracted from finely crushed granite. The waste granite dust after removal of gold is a fine material with no known use.
- It is often predominantly silty in nature and does not have pozzolanic properties.
- The Kolar Gold Fields of Karnataka have 35 million tons of such waste. It can be ideally used for building blocks after mixing with cement and sand.

Grabute and Narbke Polishing Fines:

- These are silt like fines obtained during the polishing of granite and marble slabs.
- They may also contain clay size fractions in the range of 10 to 20%.
- These can be used for making ‘fine concrete’ blocks mixing 20% fines with 80% sand and then stabilizing the mixture with 6 to 7% cement.
- The blocks have to be made by compaction rather than vibration due to the presence of fines. Blocks of strength approaching 10.0 MPa can be easily made.

- Marble dust can also be used for lime and Hydraulic lime manufacture. The marble dust may be converted to ball like aggregates by mixing boiled starch. Such aggregates can then be burnt in a lime kiln to produce quick lime.
- If the marble dust is mixed with clay and then made into balls, the balls can be used to make Hydraulic lime.

Demolished Building Wastes:

- Demolished buildings are a major source of land pollution in large cities. Most of these wastes can be recycled into building materials.
- Sieving out fine material below 2 mm can provide sand for plasters and mortars. This may not be suitable for strong concrete.
- Brick bats, broken concrete etc. can be used as aggregates for low strength concrete applications like foundation concrete, flooring concrete etc.

MODULE – 4

ALTENATIVE BUILDING TECHNOLOGIES

EFFICIENT FOUNDATIONS

The Use of stones (size stone or random rubble) is quite common in south India for foundation of walls. The modern practices of using cement mortar makes the foundation rather expensive traditionally, two storeyed buildings have been built on stone-in mud mortar foundation. The stress level in the foundation is generally so low that even mud mortars should suffice. Use of soil - cement as mortar or soil-lime-cement as mortars should prove to be a cost-effective alternative. Use of arched foundations is also a cost-effective alternative.

ALTERNATIVES FOR WALL CONSTRUCTION

TYPES OF WALLS

Construction of walls can be carried out in a number of ways. Different types of walls may also be recognized. In one of the simplest sub-divisions one can consider walls to be

1) Load bearing
2) Non-load bearing

- Walls built of masonry or in-situ casted walls can be either load bearing or non-load bearing.
- In load bearing construction, the weight of floors and walls of upper storeys are carried by the walls and transferred eventually to the foundation.
- In the case of non-load bearing walls, the weights of floors and upper storey walls are carried by columns and transferred to the soil through footings.
- Masonry walls make use of a variety of bricks or blocks (which may be called as the masonry unit) which are usually held together with the help of a mortar.
- Bricks and stones have been known since ancient times. In recent years, new materials like hollow or solid concrete blocks, hollow clay blocks and light weight blocks have emerged as the other alternatives.
- A new concept of interlocking masonry units has also been discussed in recent times. It is often claimed that such units can be used without mortar to build load bearing walls. However, such claims have to be examined through carefully planned tests before being use for load bearing walls. Penetration of water through gaps between blocks, inadequate elastic modulus while resisting vertical loads are some of the problems which need to be sorted out.

- It is also possible to use reinforced masonry for wall construction. The reinforcement will vastly enhance the lateral load carrying capacity of the wall. Use of reinforcement bands along the horizontal joints is a convenient way of reinforcing masonry.

Two types of in-situ walls may be mentioned:

1) Cast-in-situ RC walls.
2) Rammed Earth Walls.

The Rammed Earth could use either plain earth or stabilized earth

CONSTRUCTION TECHNIQUES:

Masonry Bonding

- A large variety of bonding techniques may be considered in masonry construction.
- In conventional brick masonry, English bond and Flemish bond are well known. English bond is the most common mode of construction in India. When blocks are not proportioned in the way in which burnt brick is, these bonds are no longer feasible.
- For instance, when hollow-concrete blocks of size 40 cms x 20 cms x 20 cms are used, the blocks have to be kept in 'Stretcher bond' leading to a wall thickness of 20 cms and a course height of 20 cms as shown in Figure below.

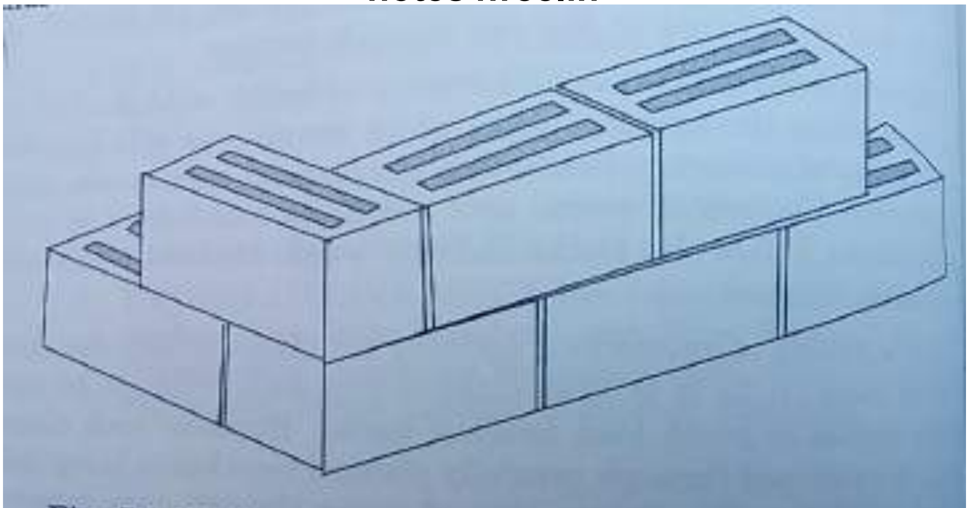


Fig. 7.1: Hollow Concrete Block Wall: Stretcher Bond

- Laterite blocks are also used in the same way.
- When stabilized mud blocks of size 23 x 19 x 10 cms are used, either a header bond with wall thickness of 23 cms or a stretcher bond of 19 cms wall thickness can be used.
- The below Figure shows a typical bond. The manner of corner bonding using a smaller block must be noted.

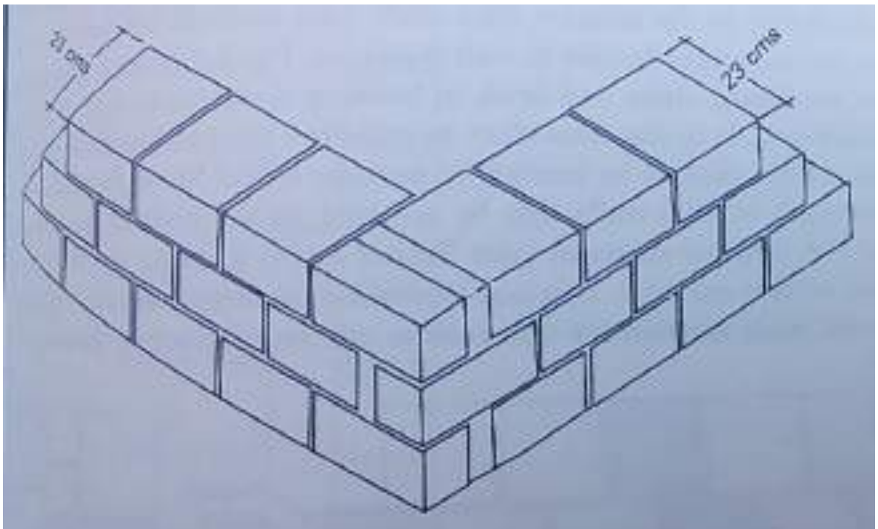
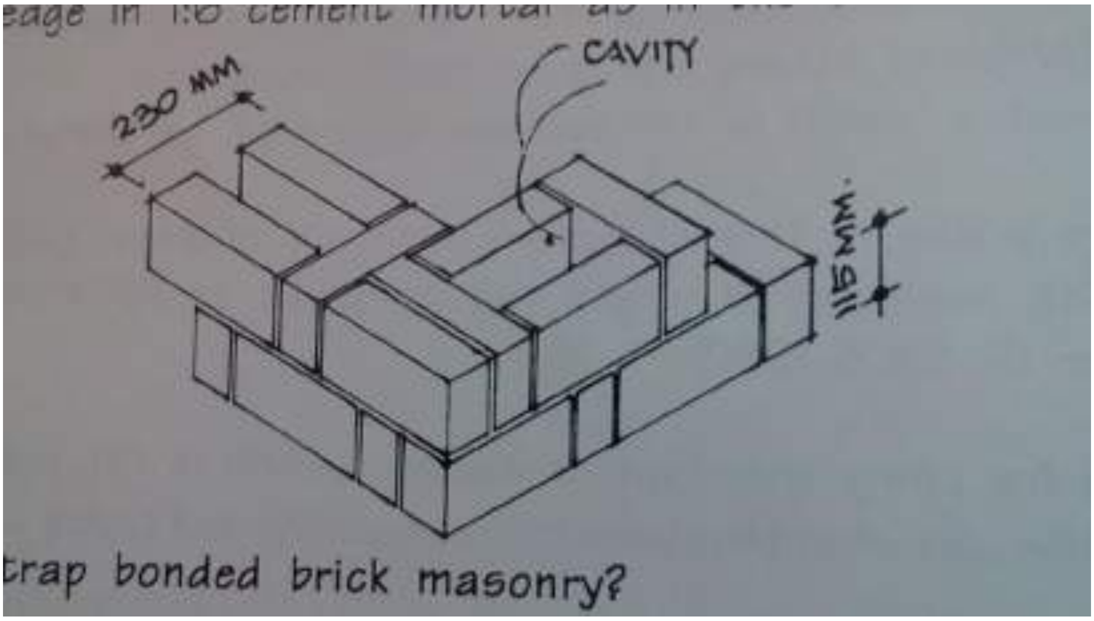


Fig. 7.2: Header Bond with Stabilized Mud Blocks

- The concept of rat-trap bond was popularized by Laurie Baker in Kerala in the seventies. This involves keeping bricks on edge creating a gap in the thickness of the wall.
- About 25% of the bricks can be saved by this process.
- Many practitioners hold the view that rat trap bonding does not lead to a loss of strength and one can build such walls of 22.5 cm thickness up to four storeys!
- At present, when 3.5MPa bricks are used, such walls can certainly be used for single storey construction.
- Figure 7.3 shows a typical view.



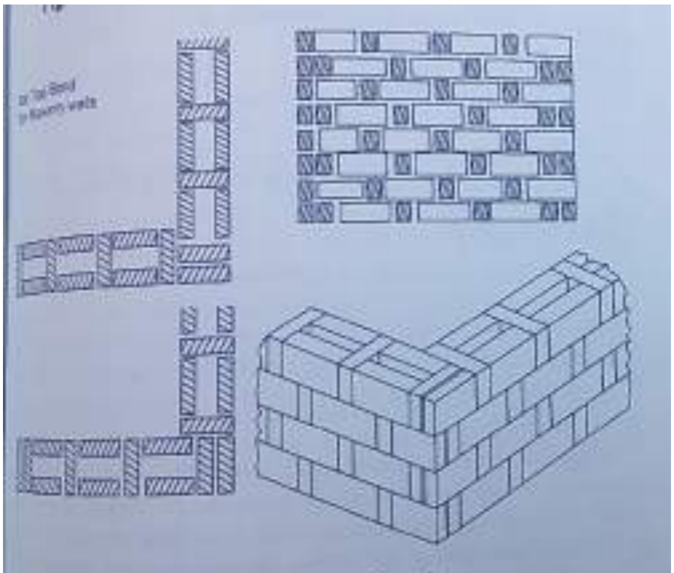


Fig. 7.3: Rat Trap Bond

Composite Masonry:

- It is sometimes useful to build walls of two different materials.
- The materials selected may be stone-cum-brick, stone-cum-SMB, burnt brick-cum-un burnt brick and so on.
- This can lead to using a very durable material on the external face and a material of moderate durability in the interior.
- Very often such methods are useful in cost reduction and reduction in wall thickness.
- Fig. 7.4 shows a typical way of combining stone and brick in building a composite wall of 29cms thickness.

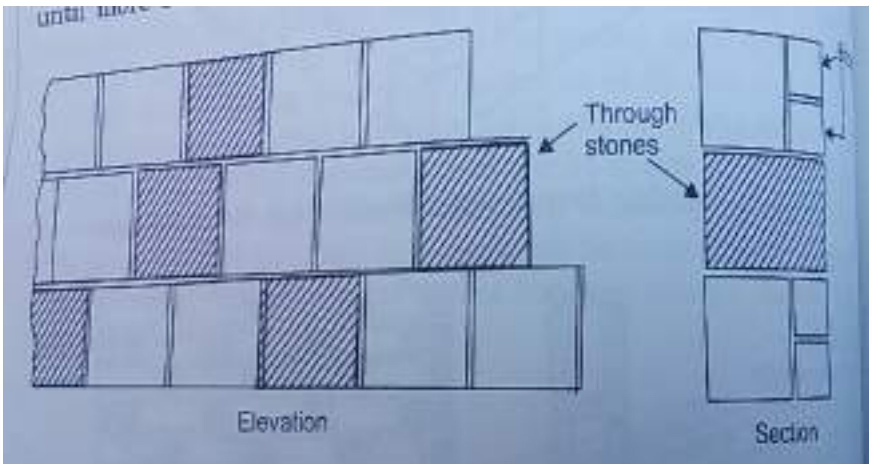


Fig. 7.4: Composite Stone and Brick Masonry

- It is also important to note that the two layers of different materials need to be bonded by periodic use of 'through stones'.
- The strength of such walls may be assessed on the basis of the strength of the stronger material (also thicker layer) ignoring the strength of the weaker material.

Cavity Walls:

- Such walls are common in Western countries to improve the thermal insulation of the walls.
- In countries like India, such concepts may be used in very hot regions to prevent penetration of solar heat through walls.
- However, it must be observed that the overall wall thickness may have to go up to more than 40cms if these techniques are to be effective.
- Fig. 7.5 shows a typical brick wall with a 7cms cavity.

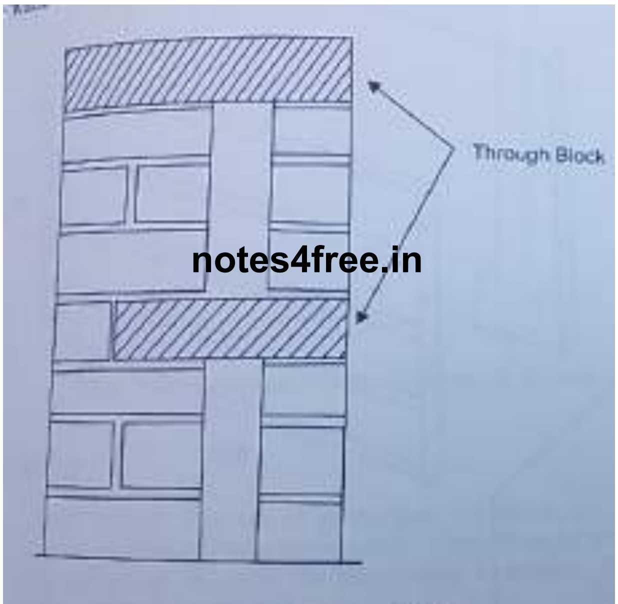


Fig. 7.5: Cavity Wall

- It is important to use bond blocks to bond the two layers. These bond blocks could be made of concrete with strength of at least 5.0 MPa to obviate separation of the veneer through shearing of bond blocks.
- The cavity can also be filled with brick bats or coal cinder to improve the insulation. It may be pointed out that walls of such higher thickness are necessary only for external walls facing East and West and all the other walls may be of 23 cms thickness

Rammed Earth

- This is a technique of in-situ wall construction wherein either plain earth or stabilized earth is compacted in layers between two plates.
- Fig. 7.6 shows typical sketch of a simple rammed earth mould.

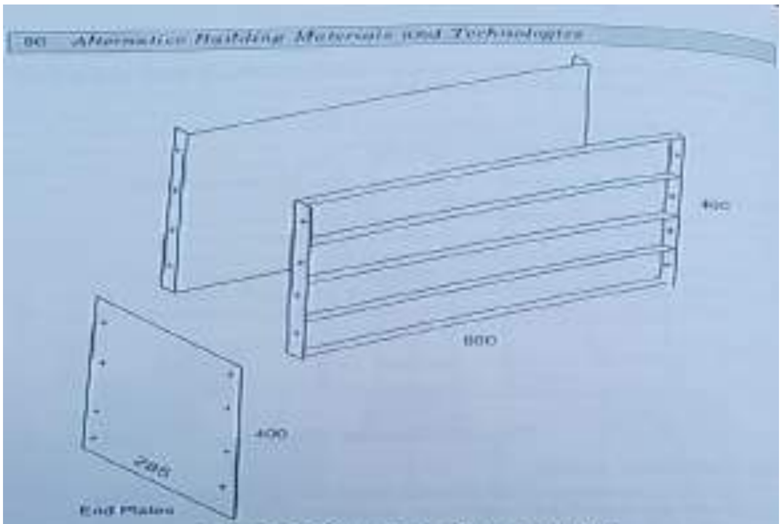


Fig. 7.6: Rammed Earth Mould

Fig. 7.7: Rammed Earth Wall Construction.

- A dry density of about 1.85 gm/cc has to be achieved for good performance of rammed earth walls.
- Figure 7.7 shows a typical wall construction in progress using the rammed earth technique.
- Typical rammers used for this purpose are shown in Figure 7.8.

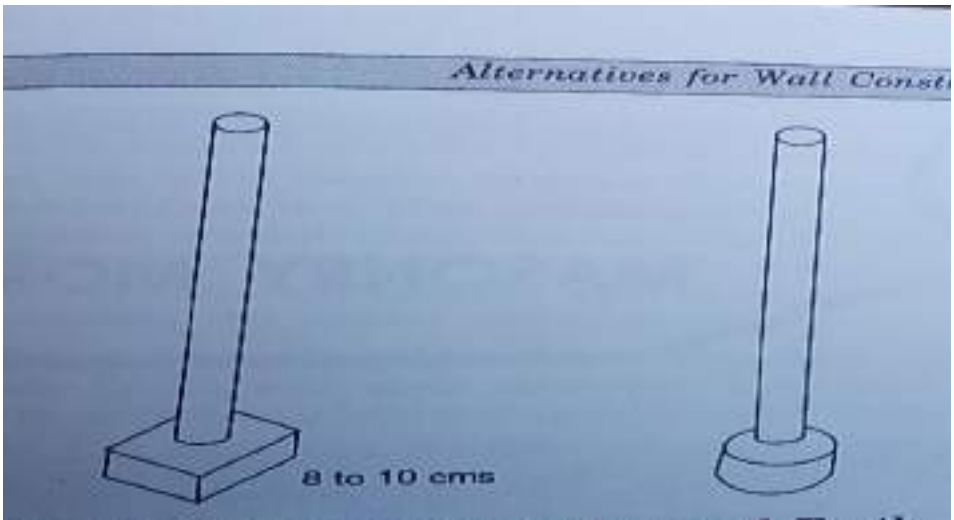


Fig. 7.8: Rammers for Rammed Earth

- It is desirable to use rammers of weight in the range of 6.0 to 9.0 kg.
- The area of ramming surface for flat rammers could be in the range of 64 to 100cm^2.
- Alternative use of flat and rounded bottom rammers have been found to be effective.
- Some of the recent experiments in the laboratory and the field have shown that achieving a dry density of 1.95 gm/cc not difficult.
- This means that use of rammed earth may offer better strengths for walls than the use of stabilized mud blocks for the same stabilizer percentage.

FERRO-CEMENT AND FERRO-CONCRETE

INTRODUCTION

- Ferro-cement is a special form of reinforced concrete. It is a composite material consisting of cement-sand mortar (matrix) reinforced with layers of small diameter wire meshes.
- It differs from conventional reinforced concrete primarily by the manner in which the reinforcement is arranged within the brittle matrix.
- Since its behaviour is quite different from that of conventional reinforced concrete in performance, strength and potential applications, it is classed as a separate material. Usually steel bars are also used in addition to wire mesh, to form a steel skeleton, which helps in retaining the required shape of the Ferro- cement components until the cement mortar hardens.
- The wire mesh reinforcement will be uniformly distributed across the thickness of the element. This helps in achieving improved mechanical properties viz. fracture, tensile and flexural strength, fatigue and impact resistance.
- In addition, it also eliminates the use of formwork particularly for complicated shapes. Ferro-cement is used in thin-walled structural components where strength and rigidity are developed through form and shape and hence they are lightweight.

- In view of this, Ferro - cement is ideally suited for prefabricated construction and in particular for housing applications in developing countries.
- The success of Ferro - cement in various terrestrial applications can be attributed to
    a) Ready availability of materials locally
    b) Need of low level technology for its production
    c) Better utilization of available human resources and
    d) Architectural flexibility.
- The history of Ferro-cement dates back to 1848, when Joseph Louis Lambot started experimenting on reinforcing mortar to make articles for which normally timber would have been used.
- Lambot had made plant tubs, water tanks and rowing boats from this material, which he called "Ferciment" and patented it in 1852.
- In early 1940's, Italian engineer-architect, Dr. Pier Luigi Nervi resurrected the original idea of Lambot and established the preliminary characteristics of Ferro- cement through a series of tests. He also pioneered the use of Ferrocement in buildings by constructing a small storehouse and covering a swimming pool with a 15 m vault.

- Ferro-cement can be considered as a material with many paradoxes. This is because it possesses a degree of toughness, ductility, strength, crack resistance and durability considerably greater than other forms of reinforced concrete. It has been possible to achieve these improved properties in structural components having a thickness of 25 mm, which dimension is unthinkable in other forms of concrete construction.
- Normally improvements in properties of materials are associated with sophistication in manufacturing processes with increased demand for quality control. But this is not so in case of Ferro-cement, which is a forgiving material as these improved properties, can be achieved with almost primitive techniques without any advanced technology.
- Furthermore, most of the advanced materials had their origin in developed countries and later took birth in developing countries. But Ferro-cement as a new material had its roots in developing countries of the world than the lands of east and west.

MATERIALS:

The materials used for Ferro-cement are

- Cement
- Sand
- Wire Mesh
- Steel Bars

In addition to the above, high tensile steel wires are also used for pre-stressed Ferro-cement.

Cement:

- Ordinary Portland cement that is commercially available in the market is satisfactory for Ferro-cement construction. However, other types of Portland cement can be used like sulphate resisting cement for Ferro-cement construction in marine environment.
- Portland pozzolana cement has also been recommended for Ferro-cement as it provides good resistance to sulphate attack and also competitive in price compared with ordinary Portland cement.
- Rice husk ash (up to 20% by weight) can be used as pozzolana and mixed with Portland cement without any deleterious effects on the mortar.

Sand

- Well-graded natural river sand with particle size less than 4.75 mm having fineness modulus between 2.5-3.0 is suited for Ferro-cement construction.
- As cover to reinforcing mesh is small and does not exceed 2-3 mm, the cement mortar covering the mesh wires has to be dense to prevent corrosion of reinforcement.
- Hence grading of sand for mortar mixes becomes very important to get workable cement mortar with low water-cement ratio.
- The water used for preparing cement-sand mortar should be potable and relatively free from organic compounds.
- The proportion of cement-sand mix generally varies from 1:1.5 to 1:3 and water-cement ratio varies from 0.35 to 0.55.

Wire Mesh:

- One of the important constituents of Ferro-cement is wire mesh reinforcement.
- These generally consist of thin wires, (galvanized or un - galvanized) either woven or welded at their intersections.
- The mechanical properties of Ferro-cement depend on the type, quantity, orientation and strength properties of the mesh reinforcement.

- Different types of mesh reinforcement are available in the market, which are suitable of Ferro cement construction. Some of them are listed below

Hexagonal wire mesh: also commonly known as chicken wire mesh is fabricated from cold drawn wires of diameter varying from 22 - 26 gauge and woven into hexagonal patterns with mesh opening varying from 10 mm to 25 mm. This is the cheapest, easiest to handle and most commonly used in Ferro-cement construction.

Woven wire mesh: is fabricated by simply weaving the galvanized wires into desired grid sizes without welding them at the intersections. The grids are generally square. The mesh wires are not perfectly straight and some amount of waviness exists.

Welded wire mesh: is fabricated in rectangular or square pattern by perpendicular intersecting wires (generally 2-3 mm diameter) made of low to medium tensile strength steel (which are much stiffer than hexagonal or woven wire mesh) and welded together at the intersections.

Expanded metal mesh, which is sometimes used in Ferro- cement construction, is formed by slitting thin gauge sheets and expanding them in a direction perpendicular to the slits to produce diamond shape openings. This mesh has inherent advantages like good mechanical bond and ease of placing.

Skeletal Steel

- As the name implies this is generally used for making framework of the structural component upon which layers of wire mesh reinforcement are laid and also serve as spacer to wire mesh.
- The steel rods are provided in both longitudinal and transverse directions.
- When they are provided for non-structural purpose, they are spaced as widely as possible and when provided for carrying external loads, their spacing is governed by design considerations.
- In general, mild steel rods or galvanized iron wires of diameters varying from 2 mm to 6 mm are used.
- Sometimes for structural purpose high yield strength deformed bars are also employed.

Admixtures

- Admixtures are additives, which are introduced in the cement sand mortar mix to modify some of the properties of the mortar in its fresh and hardened states.
- These materials may be chemical admixtures in which case they are added in quantities no larger than 5% by weight of cement or other materials in which case they are added in excess of **5%** by weight of cement and referred as additives.

- Different types of admixtures are used to improve/modify various properties and some important ones used in Ferro-cement are briefly discussed here.

Retarders

- A delay in the setting time of cement paste is achieved by the addition of a retarding admixture and thereby helping in reducing the generation of heat.
- Retarding action is exhibited by sugar, carbohydrate derivatives and some other salts.

Water reducers:

- These admixtures also called as plasticizers help to improve the plasticity of the mix in its fresh state and are mainly used to achieve higher strengths by reducing water-cement ratio or for improving workability to facilitate proper compaction of cement-mortar.
- In addition to the above admixtures, Ferro-cement may require chemical additives to reduce the reaction between matrix (alkaline environment in cement-mortar) and galvanized reinforcement, which produce hydrogen gas. As the gas is formed on the wires, they deleteriously affect the bond strength.
- Chromium trioxide added to the mixing water has been reported to be useful in reducing this problem.

- Foamed blast furnace slag has been used as a lightweight aggregate for partial or full replacement of sand, which results in reduction of density and thermal conductivity of Ferro-cement.
- Both these properties are desirable, when Ferro-cement elements are used for roofing and wall panels.
- Use of fly ash as partial replacement of cement can help in improving durability of Ferro-cement and at the same time reduce the cost.

CONSTRUCTION METHODS:

- Ferro-cement construction does not require skilled labour nor heavy capital investment on equipment to produce them.
- There are four major steps in Ferro-cement construction
    1. Placing of reinforcement
    2. Mixing of mortar
    3. Placing mortar
    4. Curing
- As the reinforcement content in Ferro-cement is very high (up to 8% by volume) and is uniformly distributed throughout the thickness of the element, the essential requirement is that the continuous mesh reinforcement has to be completely impregnated and covered with cement mortar.

- Basically to achieve this goal one may either force the cement mortar into the pre-existing skeletal steel framework or alternatively force layers of mesh reinforcement into a bed of mortar.
- A number of techniques are being used for placing the mortar into the framework of mesh. Among these are hand plastering of mortar from one side against a mould or from both sides.
- During this process care must be taken to ensure full penetration of mortar and elimination of voids within the thickness of the panel.
- Hand vibrators may be adopted when available, while casting-using mould.
- Moulds of metal, wood or masonry are made to suit the shape of the Ferro-cement component.

One-stage technique

Consists of single application of mortar from outside to inside of mesh and subsequently finishing it off to a smooth surface before initial set takes place.

Two-stage technique

- In this process mortar is plastered from one side without fully penetrating through all the mesh layers and the outer surface is finished smooth and cured. Later the remaining portion is plastered with mortar.
- To assist in bond between the old and new mortar, cement grout is applied before second stage plastering is carried out on the old mortar. This technique is adopted when more than five layers of mesh is used.

Sectional plastering

- While undertaking plastering of large Ferro-cement structures, it may be preferable to plaster in sections using one-stage technique, necessitating the need for construction joints.
- The disadvantage of this method is the difficulty in obtaining a smooth construction joint due to differential shrinkage of mortar layers of different ages.

Apart from the above mentioned manual methods for manufacture of Ferro-cement, some mechanized methods have also been developed viz.

1. Shotcreting or gunite plastering, where in mortar is applied pneumatically by spraying on to the skeletal steel frame work by means of compressed air
2. Centrifuging for casting cylindrical units
3. Vibro-pressing for compaction. All these mechanized methods; are useful for large-scale production of quality Ferro-cement components,' but require skilled technicians and considerable capital investment for machinery/equipment.

DURABILITY

- The performance of Ferro-cement structures depends to a great extent on its durability against the environment that it is exposed.
- Even though measures needed to ensure durability of conventional reinforced concrete are also applicable to Ferro cement, there are three other factors affecting its durability, which are unique to Ferro cement.
- There are three other factors affecting its durability which are unique to Ferro-cement.

1) The cover to reinforcement in Ferrocement is very low and hence it is relatively easy for corrosive liquids to reach it.
2) The surface area of reinforcement is high and so the area of contact over which reaction takes place and the resulting rate of corrosion are quite high.

- Due to the use of galvanized reinforcement, the zinc coating can react with the alkalis (calcium hydroxide) present in the fresh cement mortar leading to formation of calcium zincate and hydrogen gas.
- The release of hydrogen gas on the surface of reinforcement can deleteriously affect the bond between the cement mortar and reinforcement.
- It has been reported that addition of about 100 ppm of chromium trioxide to mixing water inhibits the formation of hydrogen.
- A more serious difficulty is the galvanic corrosion, which can take place when galvanized steel (mesh) and ordinary steel (skeletal steel) are in contact via the electrolytic solutions present in the mortar.
- The reinforcement is protected from corrosion by the mortar cover, which may get damaged by external or internal causes.
- The external causes may be physical, chemical or mechanical like weathering, abrasion and attack by natural and industrial liquids and gases.

- The extent of damage caused by these agents depends on the quality of the mortar, even though under extreme conditions any unprotected mortar is bound to deteriorate.
- The internal causes are alkali-aggregate reaction and permeability of mortar. Permeability of Ferrocement is of significance particularly with regards to water tightness of liquid retaining structures.
- Further permeability of mortar in precast units for housing like roof, floor and wall elements can cause penetration of humidity resulting in corrosion of reinforcement.
- In Ferrocement marine structures due to thin cover of mortar the danger of corrosion of reinforcement is quite high.
- To protect the reinforcement from corrosion, coatings of vinyl or epoxy types can be provided.
- The coatings should have the following characteristics:

1) Good adhesion to mortar,
2) Tolerant to alkalinity in ferrocement,
3) Good abrasion and chemical resistance,

4) Impermeable to water and chemicals and
5) Should be non-toxic and suitable for use by unskilled labour.

MECHANICAL PROPERTIES:

- Ferro-cement derives its unique properties due to the subdivision and distribution of the reinforcement which can be described with the two parameters namely volume fraction of reinforcement defined as volume of reinforcement per unit volume of Ferrocement and specific surface of reinforcement defined as surface area of reinforcement per unit volume of Ferrocement.
- Within the elastic range Ferrocement can be considered as a homogeneous material and its elastic properties can be obtained from the elastic properties and volume fractions of its constituents.

Behaviour in Tension.

Within the elastic range the total load (Pt) carried by the Ferro cement element is shared between the reinforcement carrying a

Behaviour in Flexure:

- Ferro cement elements being thin walled, they derive their strength and stiffness due to the shape and form of the element.
- The analysis of Ferro-cement elements in bending can be performed using the conventional reinforced concrete theory.
- It is assumed that the cross-sections of the element, which are plane and normal to neutral axis before bending, will remain plane and normal to the deformed neutral axis.
- If the skeletal steel is provided very close or at the centroid of the cross-section, practically it will have no contribution in bending and hence can be neglected within the elastic range.
- The cracking behaviour like number of cracks and their widths depends of the specific surface of the mesh reinforcement in the longitudinal direction.
- If skeletal steel is provided for structural purpose, they will be located close to the tension face of the element and their contribution to the flexural strength needs to be accounted.
- Typical design calculations for a Ferro cement roof element having an open cylindrical cross-section

APPLICATIONS:

Ferro-cement applications can be broadly classified into two types

1. Marine applications
2. Terrestrial applications

- The early applications of Ferro-cement have been more to the building of boats and yachts.
- In recent years Ferro-cement has received attention as a material for terrestrial uses in housing, agriculture, water and grain storage structures, irrigation, water supply, biogas digesters and as permanent forms for reinforced concrete construction.
- Ferro-cement is well suited for prefabricated housing components like wall elements, floor/roofing units, trusses, tiles, lintel and chejja.
- Roof/ floor elements of various cross-sectional shapes like trapezoidal, V-shaped, cylindrical, corrugated, channel catenary and cored slab have been developed.
- In order to use them over longer spans, they could be pre-stressed (Pre-tensioning/Post-tensioning) so that deflection can be controlled to within permissible limits,

ALTERNATIVE ROOFING SYSTEMS

CONCEPTS IN ROOFING ALTERNATIVES

Alternative roof must be based on a satisfaction of several objectives. The primary functions of a roof may be listed as follows:

1) Withstand imposed dead and live loads.
2) Prevent leakage of water during rain.
3) Provide a secure enclosure.
4) Keep costs low.
5) Provide a durable roof covering.
6) Promote thermal comfort in the interior.

Some of the currently used technologies like thatch, tiles, asbestos sheet and reinforced concrete may be examined with reference to the above functions.

- If one examines the issue of cost reduction, it is clear that reinforced concrete is not a desirable technology.
- Other options are very often not acceptable due to disadvantages like thermal discomfort, lack of security, lack of status value and so on.
- It is hence desirable to have more alternatives, which may provide a better performance on the average at moderate costs.
- It is also useful to explore alternatives, which meet the functional requirements besides promoting overall development of the community.
- we need technologies, which promote local self-reliance and reduction in energy consumption.

Types of Roofs

There are several ways in which a roof can be constructed. Accordingly, different types of classifications can be thought of. Very often a roofing system can be subdivided into roof structure and roof covering. There are also roofs, which combine the structure and the covering in a single element. Such roofs may be designated as integral roofs.

Roofing system

Structure + covering	**Integral roof**
Thatch	RC
Tiles	Ferro-cement channels
A c sheet	Brick vault
Jack arch	Composite T beam

	Light roofs		Prefab roofs
Roofs	Intermediate roofs	Roofs	Partial prefab roofs
	Heavy roofs		Cast in-situ roofs

- The choice of a roofing system will thus also mean a choice of specific type of roof and the class of technologies available under the type. There are more ways of classifying roofs based on other parameters.
- For instance, following classifications are also relevant to the design and construction environment available at a site.

The Approach to Cost Optimization

- Generally designers would like to minimize the cost for a specific performance requirement.
- It is necessary to look at the roof as a system while attempting to carry out a cost optimization.

Roof as a Static Structural System

The cost of a roof structure depends on three factors.

1) Loads acting on the roof,
2) Efficiency of the structural system
3) Material used for the structure.

- The cost and the performance may be optimized by reducing roof loads and spans.
- Improving the efficiency of the roof structure and by selecting cost-effective materials.
- All these steps can be taken simultaneously leading to significant cost reduction.
- As a typical illustration of the optimization of a roof element, Table 11.2 shows the cost of a rafter for a tiled roof building of span 3 meters.

Roof Structure + Covering

In this class of roofs, the cost reduction may be achieved by three techniques:

1) Reduce weight of covering
2) Use more efficient structure
3) Increase size of covering unit.

- A combination of all the three techniques may be used.
- For instance, one can replace the Mangalore tile by a locally produced micro-concrete tile, which could be larger in size.

- This will increase reaper spacing and reduce the number of joints.

Integral Roofing

- All the proposed alternatives need to be discussed in relation to reinforced concrete with reference to cost and performance comparisons. The reinforced concrete slab has two basic inefficiencies. Firstly, a typical 12.5 cms slab weighs 300 kgs per sq. metre. This has to be designed for a live load of 200 kg. per sq. metre. This means, for a design load of 500 kg/m2, self-weight is 60%. In other words the structural efficiency of the R.C. slab is only 40%.
- Secondly, the concrete in the tension zone hardly takes any stress although it is quite expensive. Thus, an alternative to the normal R.C. slab is a beam and slab roofing which has a reduced slab thickness. In general, this saves steel and concrete by using the materials more efficiently.
- The typical stress distribution in the R.C. slab and the beam and slab system.

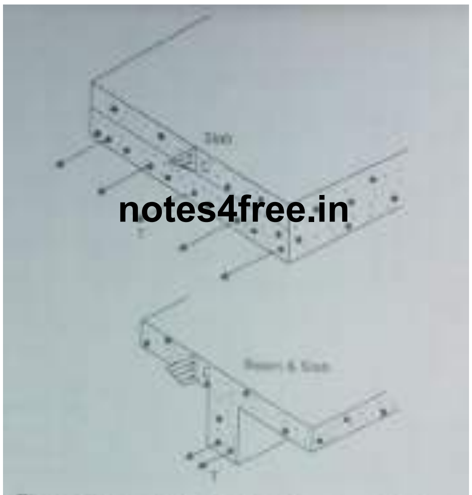


Fig. 11.1: Stresses in slab and beam and slab

- The increased efficiency of this beam and slab system, however, poses a new problem.
- The heat transfer through a thinner roof slab can increase the thermal discomfort in the space below.
- Additional features to alleviate this are needed.
- A hollow element in the slab portion with good gross thickness of more than 15cms leads to better thermal comfort.
- Sometimes it is possible to use the beam and slab concept in composite constructions using different materials for the beam and the panel.
- Such systems where the beam and the panels are structurally integrated may be known as the composite T-beam roof.

- In this case the beam may be of built-up steel or R.C. or timber while the panel may be of concrete, brick work or stone.
- A large variety of local variations of such systems can be thought of. Fig. 11.2 shows a typical example.

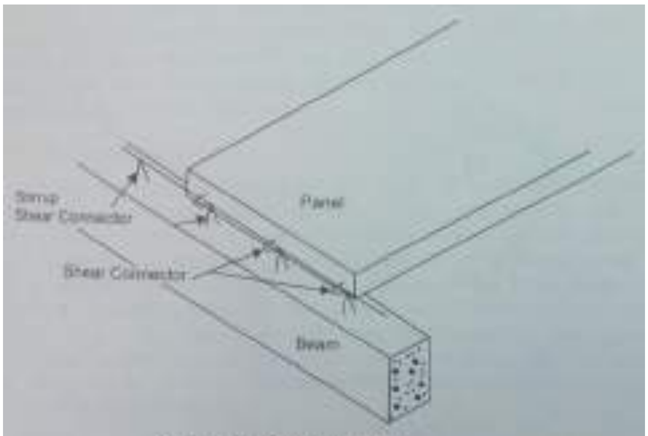
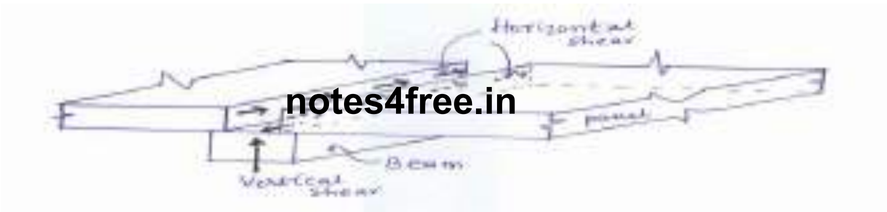
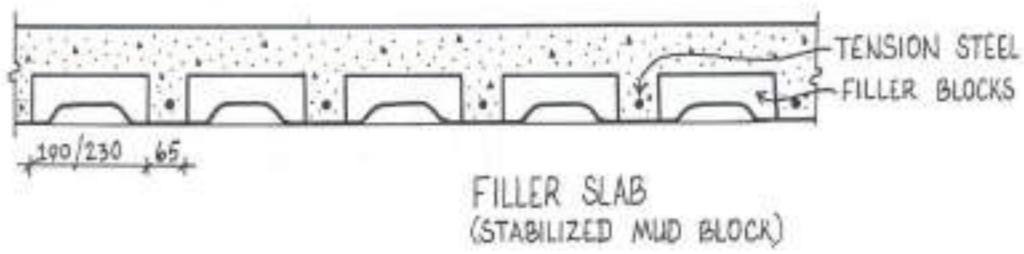


Fig. 11.2: Composite T-beam



- The filler slab is another concept, which has been in use in this country for more than 50 years.
- Here, part of the concrete in the tension zone of a R.C. slab roof is replaced by a cheaper, possibly lighter alternative.
- In a recent construction example, about 23% of the concrete could be replaced by mud blocks (the cost of mud block being one third of the cost of concrete for the same volume).

FILLER SLAB
(MANGALORE TILE)



SMB filler blocks with reinforcement

SMB Filler slab roof ceiling (prior to finish)

Ceiling – Mangalore tile filler slab

- Brick masonry vaulting is another concept of an integral roof. Such roofs require very little steel and can provide good performance over a long period of time.
- Brick vaulted roofs spanning up to 10 metres have performed well for several centuries in South India.
- It is also possible to use alternative building blocks like concrete blocks or stabilized mud blocks for such masonry. Spherical domes using brick masonry are again equally feasible where the plan area to be covered is circular or square.

Views of masonry hipped vault from inside and outside

- The hyperbolic paraboloid shell roof using thin reinforced concrete is another option for an integral roof.
- This is suited only for single storeyed buildings.

- The shape of the roof leads to a great economy in the use of cement and steel.
- This can be constructed using fairly simple formwork consisting of casuarina poles and mud cantering.
- Fig. shows a typical rectangular room with a twin “hypar” shell roof. Such thin roofs may indeed show problems of thermal comfort in the interior.

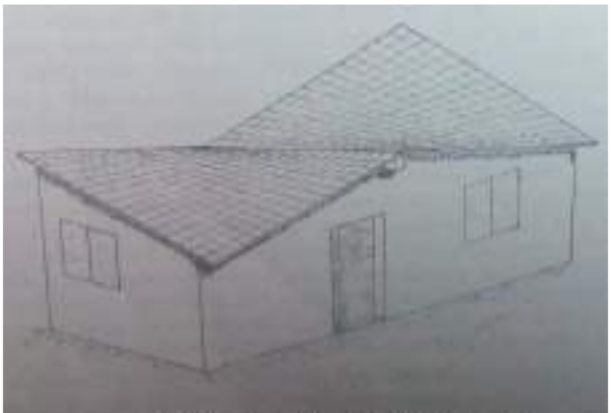


Fig. 11.4: Hyperbolic paraboloid shell roof

Cost Reduction through Construction Process Efficiency

Local Transport

- There is a tendency in the Indian construction industry to use inefficient local transport systems.
- For instance, transport of sand or bricks through head load can be very inefficient.
- Use of a wheel barrow is far more cost effective than head load transport.
- Again, using head load for moving materials from the ground to the first floor or second floor makes wasteful use of human energy.
- Use of a pulley at the upper floor for manual hauling of materials is much faster and less strenuous to the labourer.

Prefabrication

- There is a need to explore prefabrication in building components like lintels, sunshades, stairs, window frames and roofing elements.
- The time and expense involved in formwork is thus avoided.
- However, it is necessary to emphasize that the type of prefabrication.
- Complex machinery involving uses of diesel or electric power are to be avoided.
- The composite T-beam roof is ideally suited for partial prefabrication.

Use of moving formwork

- In special constructions like brick masonry vaults, use of moving, light formwork can be taken advantage of to avoid the problem of setting up a large support system.
- Such moving formwork is especially handy in brick masonry, since joining previous day’s brickwork to the current brickwork presents no problems.

FILLER SLAB ROOFS:

- Filler slab roofs are basically solid reinforced concrete slabs with partial replacement of the concrete in the tension zone by a filler material. The filler material could be cheaper or cheaper and lighter. A number of filler materials can be thought of:
    a) Brick or brick panel,
    b) Mangalore tile,
    c) Stabilized mud block,
    d) Hollow concrete block,
    e) Hollow clay tile block, etc.

- Size and shape of the filler material are governed by the factors like slab thickness, code guidelines on spacing of reinforcement bars, desired ceiling finish, etc and has to be carefully selected.
- Typical sizes of the filler materials are given in below Table

Fig. 11.5: Different types of SMB filler blocks

Table 11.3 Details of some typical filler materials

Sl. No.	Type of filler material	Sizes of filler materials (mm)		
		Length	Breadth	Thickness
1.	Mangalore tile (single tile)	410	260	30 – 35
2.	Mangalore tile (double tile)	413	260	65 – 70
3.	Stabilised mud block (single)	230 305	190 143	50 – 100 50 – 100
4.	Stabilised mud block (double)	230	380	50 – 100
5.	Burnt clay brick (double)	230	200	75
6.	Hollow concrete block	400	150 – 200	100 – 200
7.	Hollow clay tile block	300 – 400	150	75 – 150

- Quantity of concrete in the tension zone of the slab that can be replaced by a filler material depends upon the shape of the filler material available and the thickness of the solid slab.
- For example, in a solid concrete slab of 125mm thickness, a filler block of 60- 70mm thickness can be easily accommodated.
- In a typical situation by using a stabilized mud block, 25% of the concrete can be replaced by a material, which costs l/'3rd of the cost of concrete.
- This means that 15%—20% of the cost of concrete can be saved by this operation.
- In general, the SMB used as filler will have a higher percentage of cement (-8%) to ensure a high level of performance under wet conditions as well.

COMPOSITE BEAM AND PANEL ROOFS

- The cost of a roof/flooring system is significant in the total cost of a building.
- Developing an alternative roofing system which is cost effective and energy efficient is always a challenging task.
- Simple prefabrication techniques coupled with more efficient use of materials can lead to structurally efficient roofing system.
- Composite beam and panel roof is one such system wherein the beams and panels can be

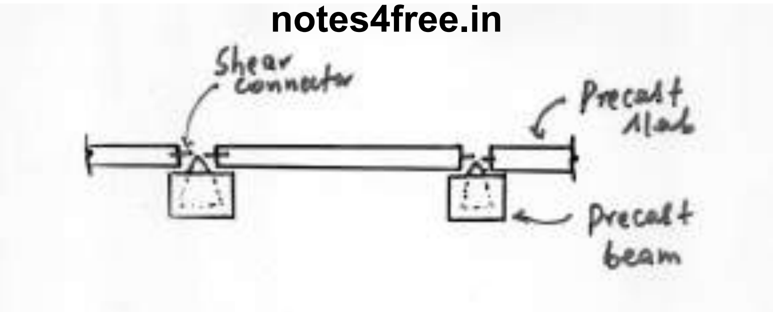
prefabricated, and assembled into a roofing system with minimal formwork without the use of heavy equipment.

- It is expected that such roofs are lighter and structurally more efficient when compared to solid reinforced concrete slab roofs/floors.

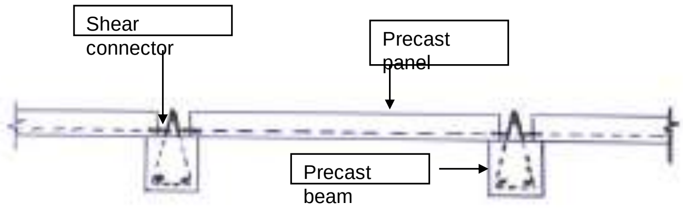
The Concept and Details of Composite Beam and Panel Roofs

- The roofing system consists of panels and beams cast separately and assembled such that the system behaves like a T-beam.
- These types of roofing systems can be broadly grouped into two categories viz.:
- Flat panel roof and
- curved panel or jack-arch roof, based on the shape/geometry of the panel.
- Below Figs show typical cross- sections of these two types of roofing configurations.

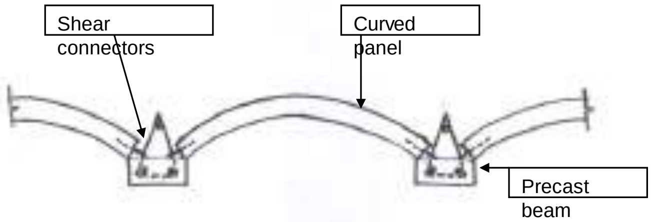
Composite beam & panel roof



•Composite action between Beam & Slab
•Achieved by shear connectors
•Partially cast beam with shear connectors



Flat panel roof



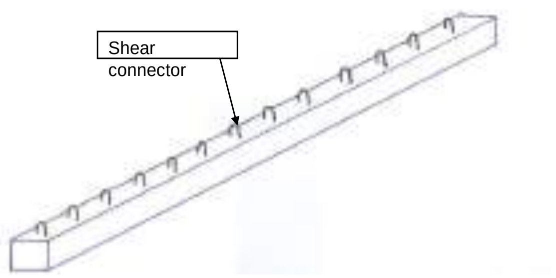
Curved panel (jack-arch) roof

- Since the panels and beams are cast separately and then assembled, there should be proper shear connection between them to achieve composite action for the system to behave as an integral structural unit.
- The flexibility of composite beam and panel roofs arises out of the fact that the materials for the beams and the panels could be of two different materials, and the composite action between them could be achieved by proper shear connectors.
- In the absence of shear connection, the panels will simply sit on the beam and the roofing system will be structurally inefficient.
- Table 11.4 gives the typical list of materials/technologies for the beams and panels.

Table 11.4 Materials/Technologies for the Beams and Panels

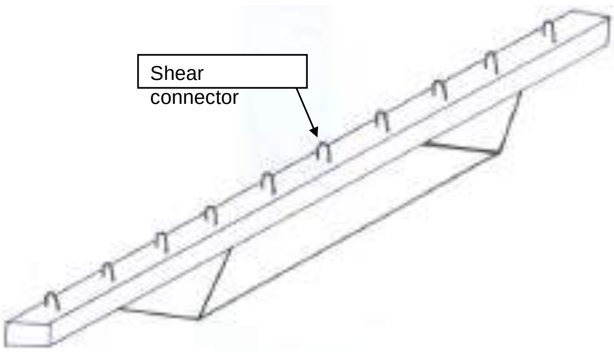
BEAM/RIB	PANEL
R.C. — CAST-IN-SITU	R.C. — CAST-IN-SITU
R.C. — PARTILLY PRECAST	R.C. — PRECAST
STEEL (ROLLED SECTION)	REINFORCED BRICKWORK/ BLOCKWORK
STEEL (TRUSSED)	REINFORCED TILEWORK
TIMBER	STONE SLABS
STEEL & R.C. COMPOSITE	HOLLOW CLAY TILE PANEL
TRUSSED TIMBER	CURVED or ARCHED BRICK TILE
TIMBER & STEEL COMPOSITE	HOLLOW R.C. PANEL

- Various combinations of beams and panels could lead to different types of composite beam and panel roofing systems.
- Figs. show sketches of some possible geometric configurations for the beams and the panels.

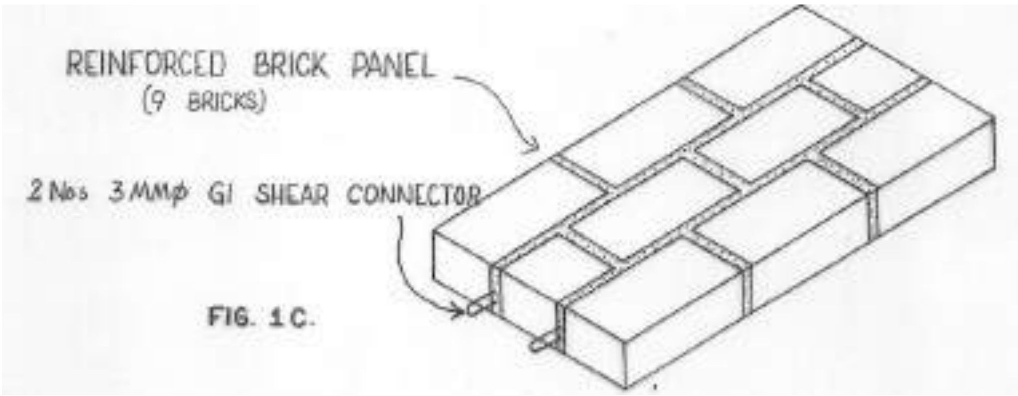


Partially cast R.C. beam with shear connectors/stirrups

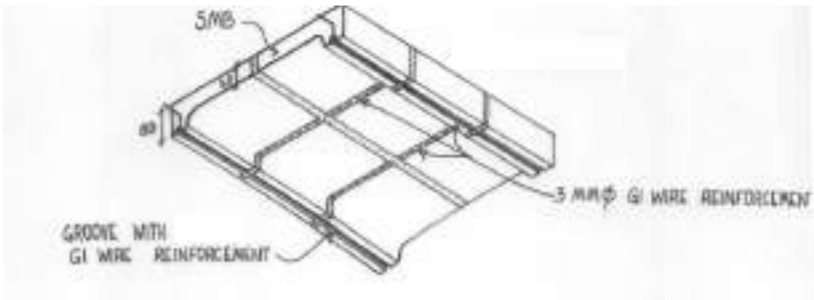
Trussed beam (6mm rods), ferrocement flange



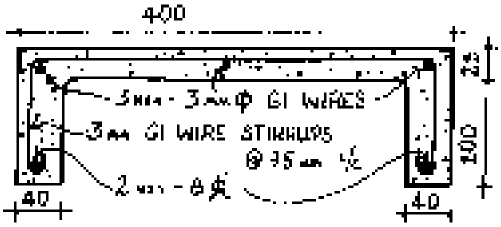
Trussed beam with R.C. beam top chord



Reinforced brickwork flat panel



Reinforced soil-cement block-work flat panel



Ferroconcrete channel floor – C/S details

Construction Details and Roof Assembly

- Composite beam and panel roof consists of partially cast beams \ over which the panels are assembled and then shear connectors are \ grouted before spreading the screed concrete on top.
- Thus the beam becomes complete after the completion of in-situ concreting/mortaring to bring in the shear connectors into action.
- Typical construction sequence involves:
  1) Casting of beams and panels and curing
  2) Positioning the beams into required spacing and providing temporary props
  3) Placing the panels on the beams and mortaring the joints between the panels
  4) Grouting the shear connectors jetting out of beams as well as panels
  5) Tying nominal shrinkage reinforcement bars and spreading screed concrete
  6) Removal of temporary props after curing and finishing
  7) Both the beams and the panels can be precast and then assembled into a roofing system.
  8) In case of precast beams, the beams are partially cast and hence they require some props while assembling the roofing system.

Props for partially cast beams while assembling the roof

- In some situations especially for larger roof spans where the beam size is large, it may be difficult to handle the beam manually while assembling the roofing system.
- In such situations one can resort to in-situ casting of the beams.
- Since the concept is aimed at optimising the sizes of beam and panel elements it is preferable to keep the panel sizes small such that the weight of each panel is within 50kg.
- This will facilitate handling of the panels manually thus avoiding need for any heavy hoisting equipment.

DETAILS OF CASTING PANELS AND BEAMS:

Panels

- Based on the geometrical shape, the panels could be of two types, curved cross-section or flat panels.
- Different types of panels and the material used for the panels

Casting of Curved Shape (Jack-arch) Panels:

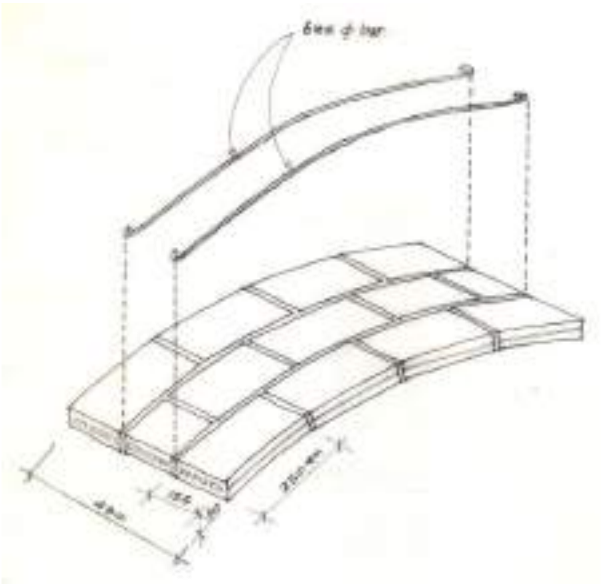
Casting of curved shaped panels requires a simple mould to get the proper curvature.

A typical mould is shown in Fig. 11.25. Casting involves keeping a wooden template (Fig. 11.25) on the mould, placing the nominal reinforcement cage, pouring the concrete and finishing the panel.

Figs. 11.26 and 11.27 show the casting and finishing details of jack-arch R.C. panels.




- Wooden template will ensure the thickness and size of the panel precisely.
- In case of brickwork or tile-work panels, the bricks/tiles are arranged as shown in Fig. 11.28, place the reinforcement in the joints and then pack the joints with mortar.



Casting of jack-arch tile-work or brickwork panel

The following mentioned precautions or measures have to be exercised while casting the panels.

a) Spread a sheet of thin paper on top of the mould and then place the wooden template over that. This will facilitate easy removal of the panel from the mould
b) In case of tile-work or brickwork panels smear the side faces of the bricks/tiles with a fresh cement slurry (1 cement: 1 water) just before placing them into the wooden template. This coating will enhance the bond between the brick/tile and the mortar grout.
c) Do not hold the shear connectors while lifting and handling the panels. This will avoid disturbing the shear connector which can impair the shear connection and the composite action
d) The panels after casting should not be disturbed far at least 24 hours. The panels after removing from the mould can be stacked on edge separately and continue curing in the stack. Concrete panels have to be cured for 4 weeks while the brickwork or tile-work panels should be cured for at least 7 days

Casting of Flat Shape Panels:

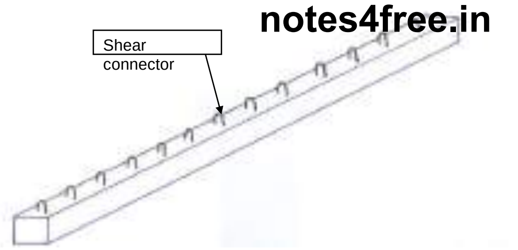
- Casting of flat panels requires only a wooden or metal template, which will control the size of the panel.
- Prepare a levelled platform on which a number of panels can be cast.
- Casting involves positioning the template, placing the reinforcement and pouring the concrete or grouting the mortar joints in case of brickwork or tile-work panels.
- The precautions/measures mentioned above for curved panel casting will apply for flat panels also.

Casting of Beams:

In a composite beam and panel roof system partially cast beams are used.

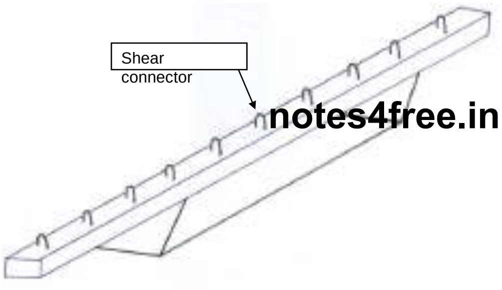
The beam will be complete after integration of the panels with the beam through shear connectors.

Different types of possible beam configurations are shown in Figs. 11.16 to 11.18.



Partially cast R.C. beam with shear connectors/stirrups

Trussed beam (6mm rods), ferrocement flange



Trussed beam with R.C. beam top chord

- The beams can be fabricated at site on a levelled platform.
- Easily dismountable formwork or mould is required.
- They could be prepared using either wood or metal sheets.
- The casting procedure involves the following steps.

a) Position the dismountable formwork/mould on the levelled platform.
b) Place the reinforcement cage into the formwork/mould. Reinforcement cage will have shear pins jetting out much above the top of the formwork/mould.
c) Pour the fresh concrete into the formwork/moulds and compact it properly such that it is in level with the top of the formwork.
d) Generally the partial cast beam height will be in the range of 100 - 200mm depending upon the roof span and the beam spacing. The formwork/mould can be dismantled after 2 hours of casting, leaving the partially cast beam on the platform.
e) The dismantled mould can be assembled again to cast another beam.

- Fig. 11.29 shows the mould and partially cast beams in a casting yard.
- Fig. 11.30 shows the assembling of composite beam and panel roofing system.
- Figs. 11.31 to 11.33 show some typical ceiling finishes and external appearance of different types of composite beam and panel roofs.

Composite panel with shear connectors

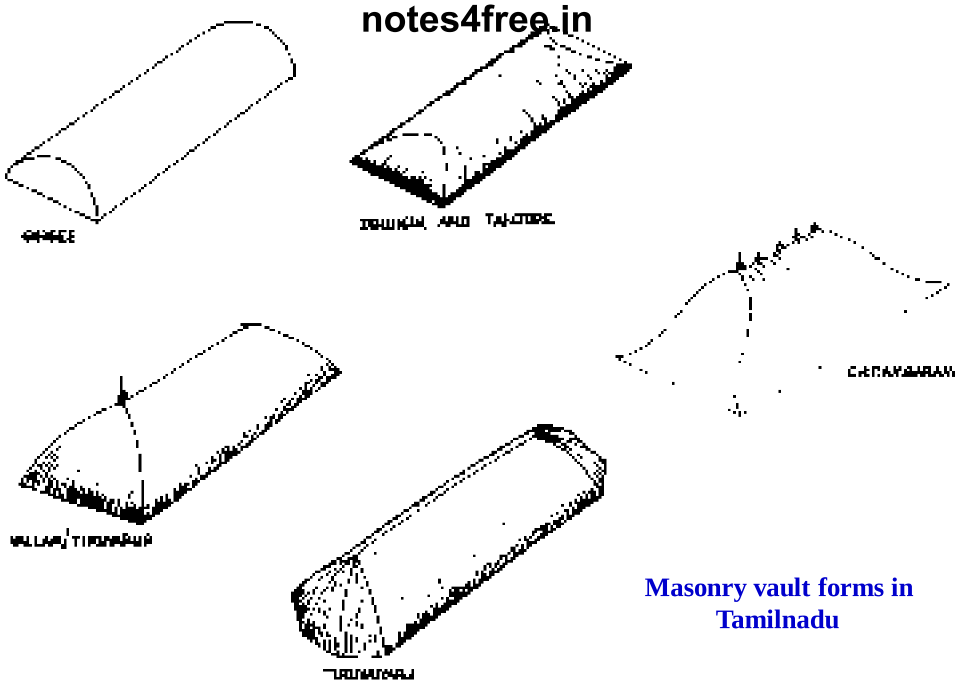
Trussed beam (plastered) tile-work panel


notes4free.in

MASONRY DOMES AND VAULTS

HISTORICAL NOTES

- The post and lintel construction is perhaps the most ancient method of covering an opening or spanning a roof.
- However, the use of arched and vaulted constructions can be traced back to the Egyptian and Mesopotamian civilizations.
- The pitched brick vault had the advantage that it could be built without centering.
- The unreinforced brick vault of 25.5 meters span built in 550 A.D. in Iraq.
- The construction of vaults and domes spread to the South at the same time due to the emergence of the Vijayanagar empire and the Bahamani Kingdoms.
- The vault construction was no longer confined to mosques in this region.
- Even the temples in Tamil Nadu started using vault constructions probably in the 17th and 18th centuries.
- A large number of these vaults are intact and there are examples of vaulted structures of the 18th or early 19th century still in use as public buildings
- Figure 12.1 shows some typical vault shapes in Tamil Nadu.



Masonry vault forms in Tamilnadu

- It looks as though the well-established technology of vaulted construction suffered a quick death with the arrival of the British in India.
- This may perhaps be explained by the fact that until the establishment of British rule, the construction industry was essentially in the hands of traditional artisans.

- The Engineering practice in England in the nineteenth century was perhaps totally unfamiliar with brick vaulting.
- The analysis of shell structures was practically unknown while the technological practice in India was nearly 150 years ahead of the European Science of shell analysis.
- The practice of vault building must have died out to lack of patronage, alternatives using wood and steel and lack of support by matching developments in Engineering Science.
- The construction of domes has always paralleled closely the developments in vaults.
- The dome had the added advantage that it could often be built without formwork.
- The dome at Bijapur is perhaps one of the finest examples of Indian dome construction.
- One could perhaps argue that the dome never died in the Indian context.
- There have always been situations where domes were needed architecturally and have been produced in British India as well as independent India.

RELEVANCE OF VAULTS AND DOMES AT PRESENT:

- Brick masonry is often cheaper than concrete, since it can be produced using lesser quantity of cement per unit volume. If a structure has predominantly compressive stresses masonry is indeed advantageous.

- A properly designed vault or dome will develop negligibly small tensile stresses. The vault and dome are also advantageous in areas of high rainfall or intense summer and winter conditions.
- Thus, the current functional and architectural interests seem to encourage a strong revival of vault and dome construction in India. A large number of such structures have been built in different parts of India over the past 10 to 15 years.
- The case for the vault and dome as a satisfactory roofing technology seems to be quite strong. There have been examples of vaulted roofing even for two storeyed buildings. It is not necessary to regard masonry to be in competition with reinforced concrete regarding domes and vaults.
- The advantages of masonry construction for these lies in the fact that formwork can be avoided for spherical domes and vaults can be constructed by using moving formwork (slip forming).
- Again, there are possibilities of combining masonry and reinforced concrete. A thin layer of nominally reinforced concrete over and above the unreinforced masonry can vastly

enhance the performance of masonry roofs.

- One of the principal disadvantages of unreinforced masonry is its inability to handle stresses due to differential settlements.
- Reinforced masonry or a masonry-RC composite can mitigate this problem to a great extent.
- Use of modern materials like glass fibre reinforced plastic as externally attached reinforcement can also provide additional flexibility and strength.

CONSTRUCTION OF MASONRY DOMES

- A masonry spherical dome can be often constructed without using any formwork.
- We need a mechanism by which the position of each brick is to be precisely determined.
- This can be done if a rod or a wire can be used to fix the brick location.
- The rod/wire is to be connected to the centre of the dome through a spherical joint and fixed to the ground

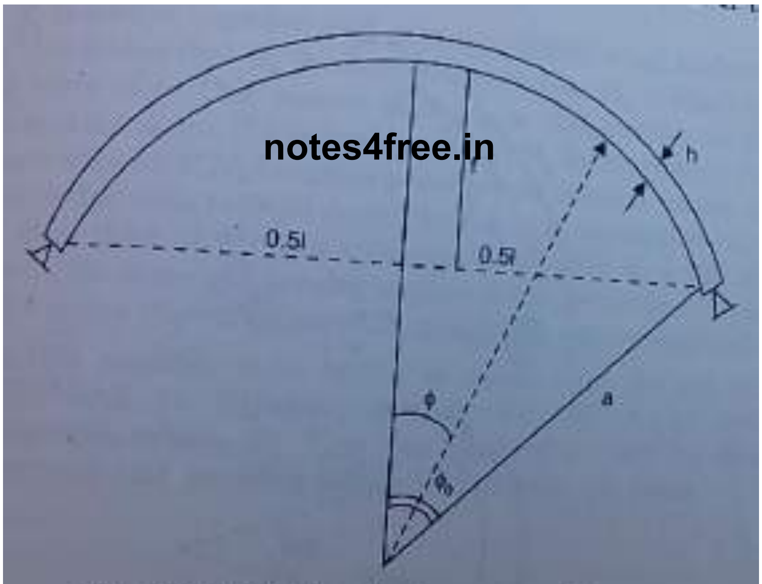


Fig. 12.2 A Spherical masonry dome

Fig. 12.8: Ring beam at dome base

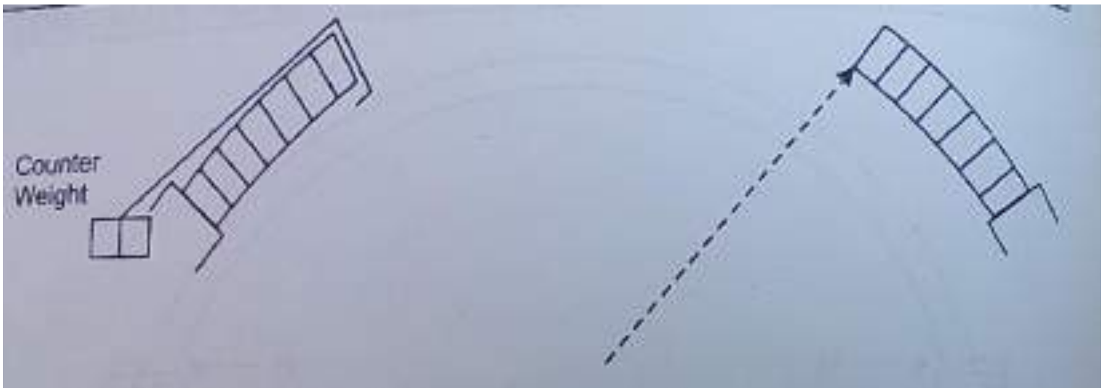


Fig. 12.9: Construction sequence for spherical dome

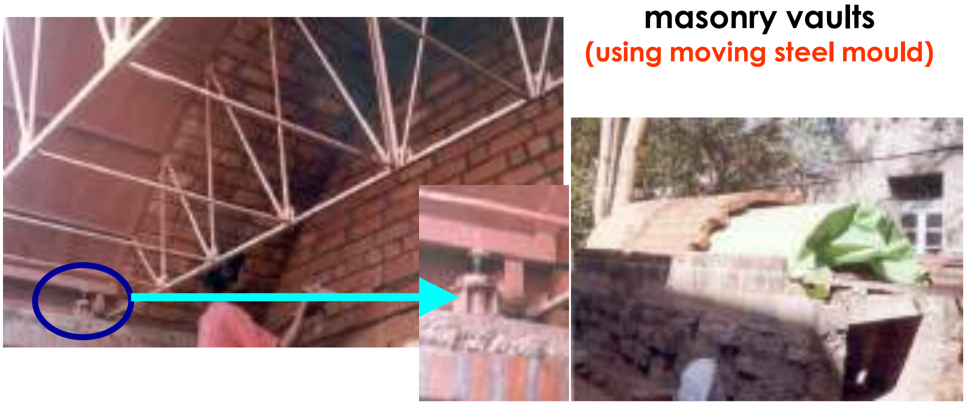
- The brick can be positioned precisely using this radial rod/wire. The brick may be secured temporarily to the mortar below by suspending weights hooked onto the brick. The brick laying can now proceed horizontally till one circle is completed. Repeating this dome can be completed.

CONSTRUCTION OF MASONRY VAULTS

- Traditionally circular vaults have been constructed using a formwork for the entire structure.
- On the other hand, the Nubian vault permits construction without any formwork.
- A mobile formwork to support the vault over a length of about 1.0m is first fabricated. Of the gable-end walls is constructed such that the top of the wall coincides with the formwork. The formwork is now placed adjacent to this wall.
- A portion of the vault is constructed to rest partly on the end wall and partly on the formwork.

- The formwork is lowered after 24 hours and moved laterally to extend the previous day's work.

Construction of masonry vaults
(using moving steel mould)



Construction of masonry vaults
(using steel templates)

- The vault construction proceeds in this manner till the other end is reached.
- A variation of the moving formwork was attempted by having two arch shaped templates kept parallel to each other with a distance of about 17cms separating the two. The template had the facility of the two ends having small hinged portions. By rotating the hinged portion, the span could be reduced and the template can be brought down.
- In this system a portion of the vault is built using the two templates as support. The inner template is then removed and placed in front of the outer template to continue the vault.
- In this construction mode the vault is always supported on a gable wall at one end on a template at other

MIVAN TECHNOLOGY

Mivan is an aluminium formwork system developed by a European construction company. In 1990, the Mivan Company Ltd. from Malaysia started manufacturing these formwork systems. Today, more than 30,000sqm of formwork from Mivan Co. Ltd. is used across the world. There are a number of buildings in Mumbai that are being constructed with the help of the Mivan system, that has proven economical as well as satisfactory for the overall Indian construction environment. One of the architectural examples is XRBIA which uses MIVAN system to achieve its dream of "A House for Every Indian"

The technology has been used extensively in Europe, Gulf Countries, Asia and other parts of the world. Mivan technology is suitable for constructing large number of houses in a short span of time using room size forms to construct walls and slabs in one continuous pour on concrete. In this system of formwork construction, cast–in–situ concrete wall and floor slabs cast monolithic provides the structural system in one continuous pour. To facilitate fast construction, early removal of forms can be achieved by hot air curing / curing compounds. Large room sized forms for walls and floor slabs are erected at site. These strong and sturdy forms are fabricated with accuracy and are easy to handle. The concrete is produced in RMC batching plants under strict quality control and convey it to site with transit mixers.

The frames for windows, doors and ducts for services are placed in the form before concreting. Staircase flights, façade panels, chajjas and jails etc. and other pre-fabricated items are also integrated into the structure. This proves to be a major advantage as compared to other modern construction techniques. High quality Mivan Formwork panels ensure consistency of dimensions. On the removal of the formwork mould a high quality concrete finish is produced to accurate tolerances and verticality. The high tolerance of the finish means that, no further plastering is required.

Uses of Mivan Formwork:

- 3S – System of Construction – Speed, Strength, Safety
- Column and beam construction are eliminated
- Walls and slabs are cast in one operation
- Specially designed, easy to handle light weight pre-engineered aluminium forms
- Fitting and erecting the portion of shuttering
- Carrying out concreting of the walls and slabs together

Advantages:

- Mivan formwork requires relatively less labour
- More seismic resistance
- Increased durability
- Lesser number of joints and reduced leakages
- Higher carpet area
- Smooth finishing of wall and slab
- Uniform quality of construction
- Negligible maintenance
- Faster completion

Limitations:

Even though there are so many advantages of Mivan formwork the limitations cannot be ignored. However the limitations do not pose any serious problems. They are as follows: –

- Because of few small sizes finishing lines are seen on the concrete surfaces
- Services after completing become slightly difficult due to the small width of components
- It requires uniform planning as well as uniform elevations to be cost effective
- The formwork requires number of spacer, wall ties etc. which are placed @ 2ft c/c; these produce problems such as seepage, leakages during monsoon
- Due to box-type construction, contraction cracks are likely to appear
- Heat of hydration is high due to shear walls
- It is rigid in design once placed, as any alteration becomes tough later

Remedial Measures:

It is possible to minimize contraction cracks by providing control strips in the structure which could be concreted with a delay of about 3-7 days after major concreting. The problem of cracking can be avoided by minimizing the heat of hydration by using flash.

TOP DOWN CONSTRUCTION PROCEDURE

Introduction

Conventionally building having basements are usually built by bottom-up method. In simple words, stage of construction is from bottom of sub-structure to top of superstructure. Gigantic civil engineering projects usually have constraints of time and working space. So we have to follow the reverse of this conventional procedure. We call it “Top Down construction method” which means we go from top to bottom.

Reason for selecting Top Down Construction?

1. Distance between boundary wall of existing building and building to be constructed is too close and possibility of soil collapse is too high.

2. This method is preferred for buildings having two or more basements.

3. If water table is too high in area where building has to be constructed.

4. This method is usually preferred for tall buildings with deep basements, underground car parks, underpasses and metro railway projects.

Advantages

1. De-watering is not required

2. This method enables above ground construction work to be carried out simultaneously with excavation of basement thus resulting in saving of time and resources.

3. It vastly improved the speed of project delivery to the client.

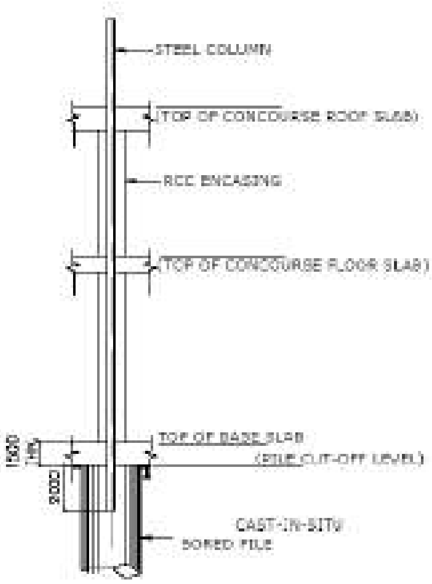
4. It offers dramatic Capital cost improvements while providing excellence of finish to the build, enhancing and reducing resource usage, improving cost and reducing pollution.

5. It eliminates the need for sheet piling.

6. Dust levels are kept to minimum.

Structural Requirements

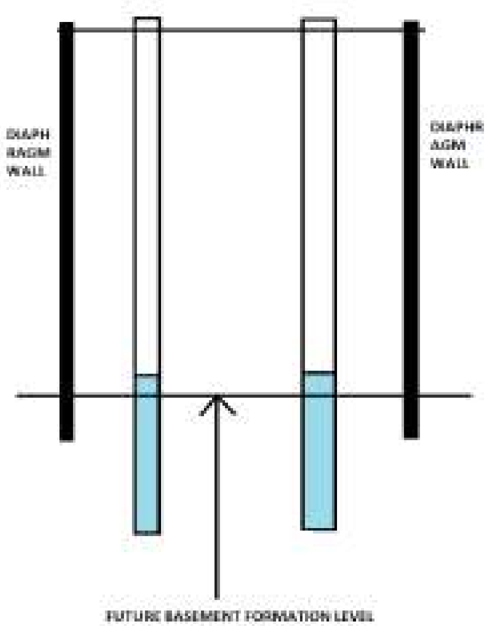
Columns with sufficient capacity has to be pre-founded in bored piles to sustain the construction load and to utilize as part of bracing system.- Pre-fabricated steel columns called Stanchions are used as these columns.



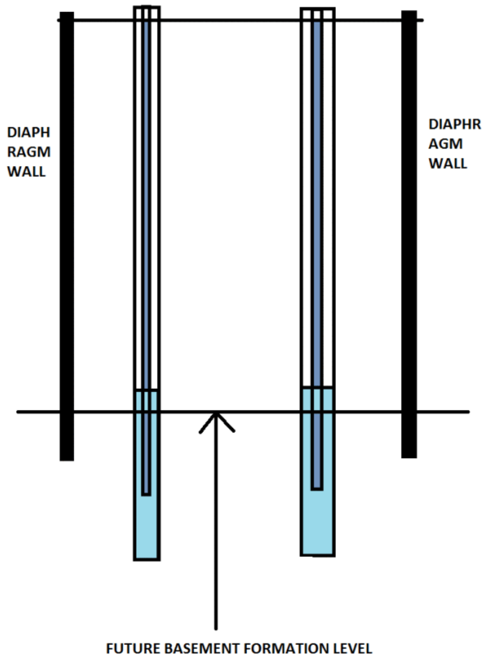
Excavation for basement must be carried out with the support of permanent retaining wall so that basement floor slabs can be utilized as lateral bracing-Diaphragm wall of 600mm to 1200mm in thickness with sufficient embedment in firm soil layers is commonly used as a retaining wall. The wall is constructed panel by panel in full depth.Panel width varies from 2.5m to about 6m. Short widths of 2.5m are selected in less stable soils, under very high surcharge or for very deep walls.

Procedure

1. Piles are drilled into the ground level to the bearing stratum using conventional drilled shaft or slurry trench techniques. Shafts made are concreted up to the lowermost basement level to form foundation piers.



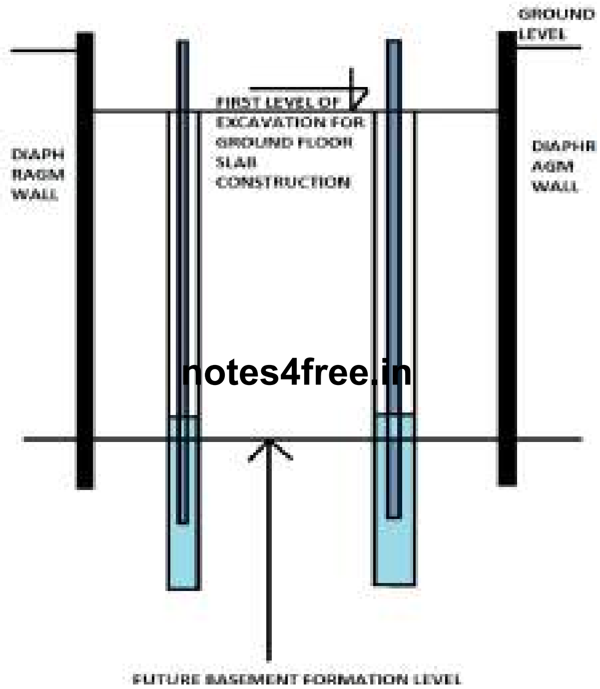
2. Structural steel columns are installed in the open shafts to rise from foundation pier to the ground floor level.



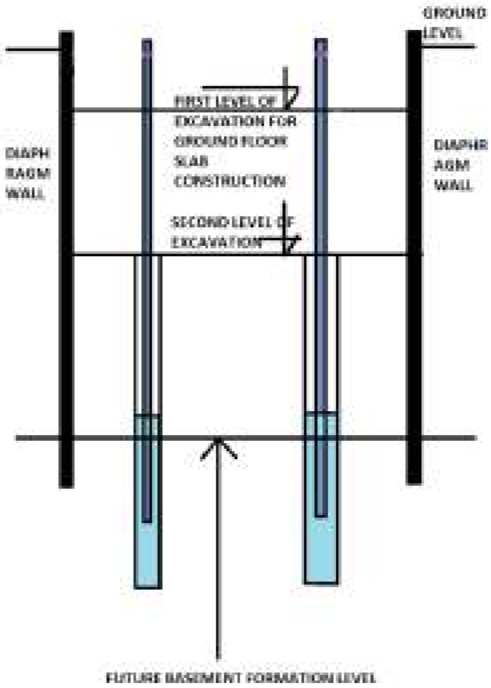
3. First level of excavation for ground floor slab is done. Ground floor slab is cast either above the unexcavated soil or on drop down form system anchored to columns if the soil is excavated. Ground floor slab is anchored with the diaphragm walls with the dowel/coupler bars which are initially left at the time of casting of diaphragm walls.

Ground floor slab is cast and cured. Ground floor acts as a lateral bracing for the perimeter walls.

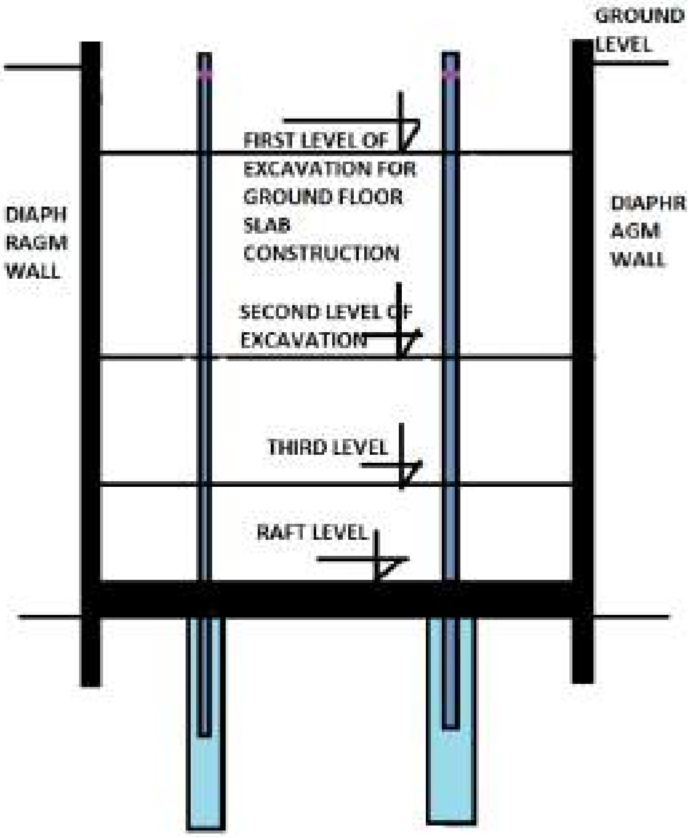
It is to be noted that access openings are left in the ground floor slab for vertical soil removal and for supply of equipment's , manpower and other construction materials required for construction.



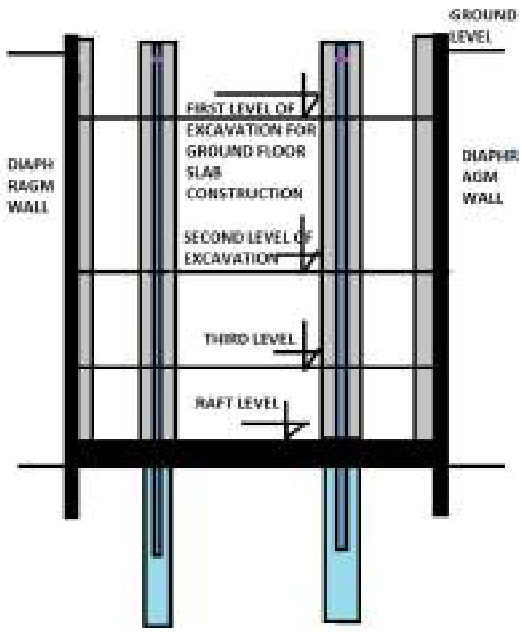
4. Next lower level basement slab is poured which acts as a subsequent lower level lateral bracing for diaphragm walls.



5. This process is repeated down up to the required levels.Each floor acts as a permanent plan bracing for perimeter walls eliminating the need for temporary bracing to retain diaphragm walls.Excavation is repeated until completion of entire basement.



6. Cast the basement wall and encase the steel stanchion to become permanent columns using form work and reinforced concrete.Basement walls and steel stanchion are encased with additional reinforcement to become permanent columns.



Advantages

1. It allows early restoration of the ground surface above the tunnel The temporary support of excavation walls are used as the permanent structural walls
2. The structural slabs will act as internal bracing for the support of excavation thus reducing the amount of tie backs required It requires somewhat less width for the construction area
3. Easier construction of roof since it can be cast on prepared grade rather than using bottom forms
4. It may result in shorter construction duration by overlapping construction activities

Disadvantages

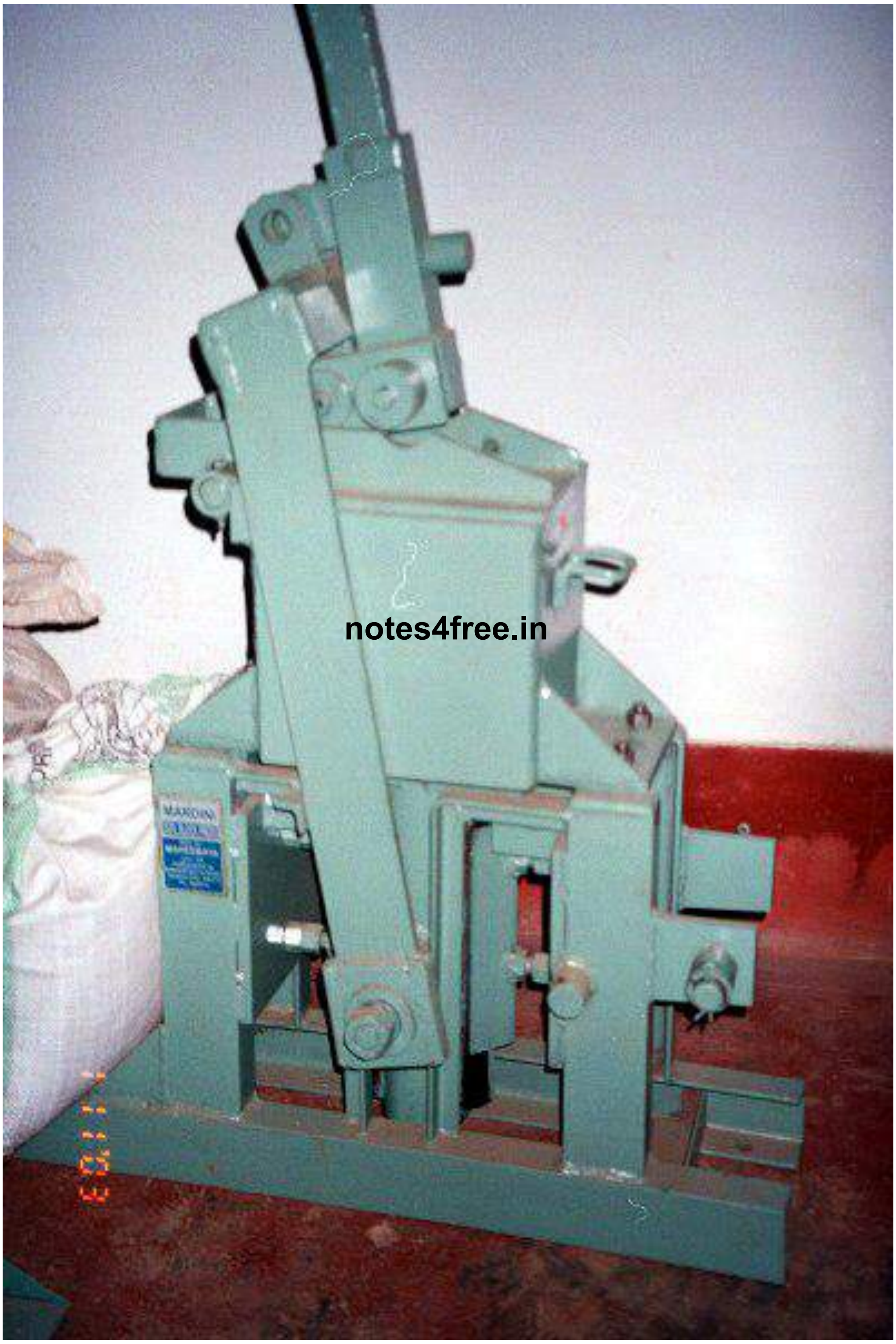
1. Inability to install external waterproofing.
2. More complicated connections for the roof, floor and base slabs.
3. Potential water leakage at the joints between the slabs and the walls
4. Risks that the exterior walls (or center columns) will exceed specified installation tolerances and extend within the neat line of the interior space.
5. Access to the excavation is limited to the portals or through shafts through the roof.
6. Limited spaces for excavation and construction of the bottom slab.

MODULE – 5

EQUIPMENT FOR PRODUCTION OF ALTERNATIVE MATERIALS

EQUIPMENT FOR PRODUCTION OF ALTERNATIVE MATERIALS

Machines for production of stabilized blocks: Mardini Machine



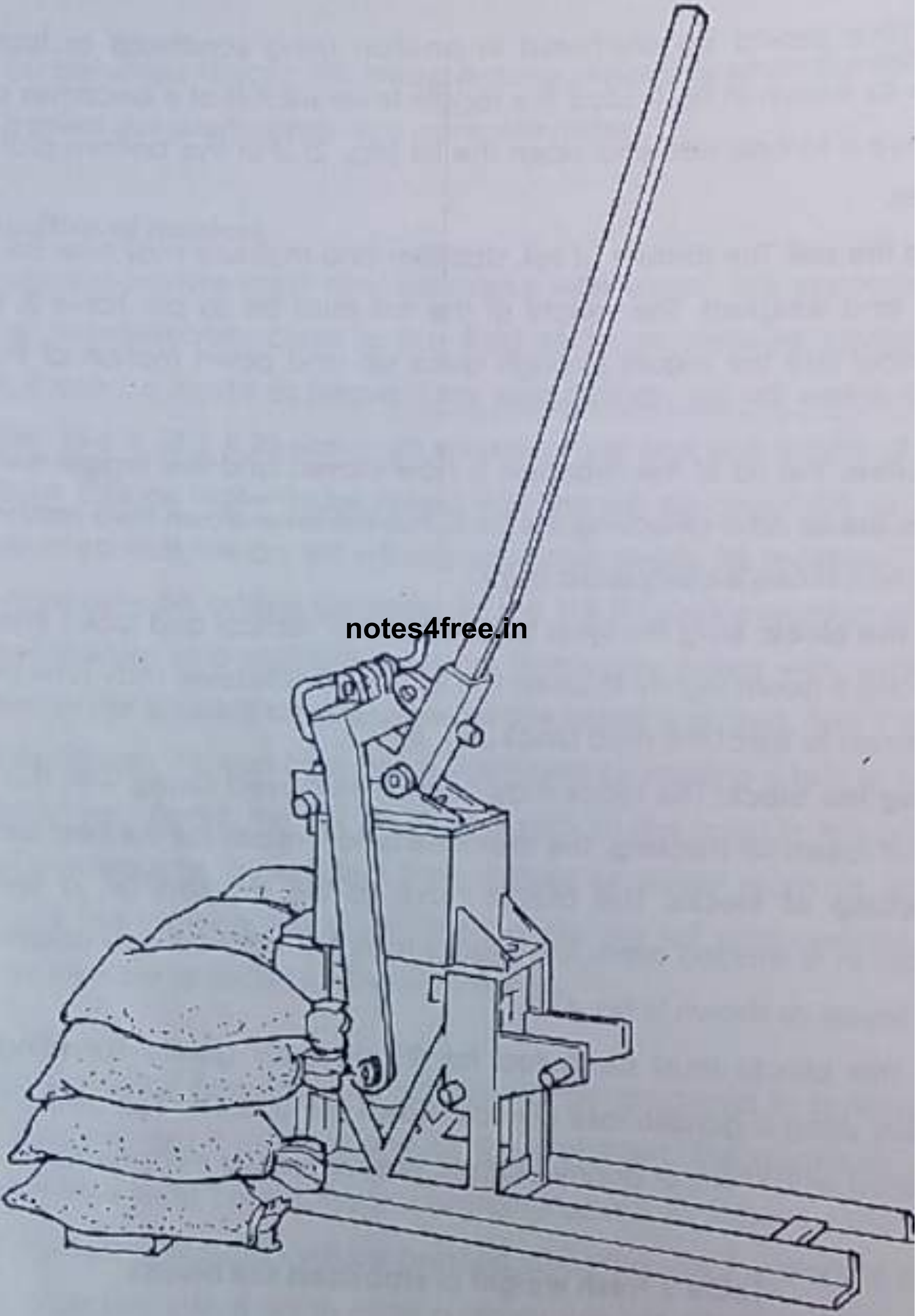


Fig. 1 - Anchoring the Mardini press using sand bags

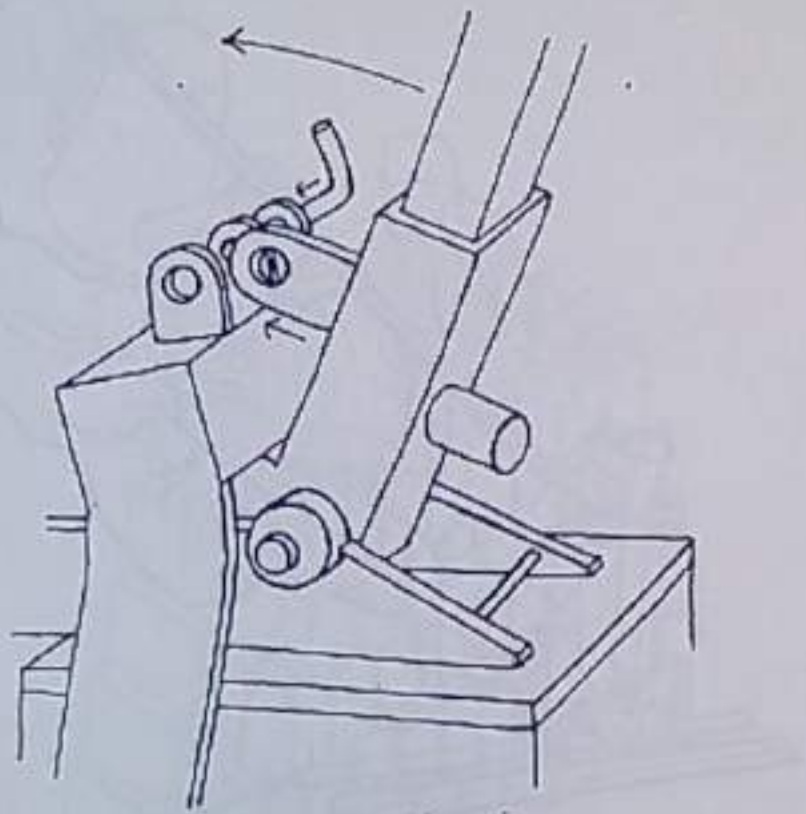


Fig. 2 – Locking the lever

Fig. 3 – Filling the mould

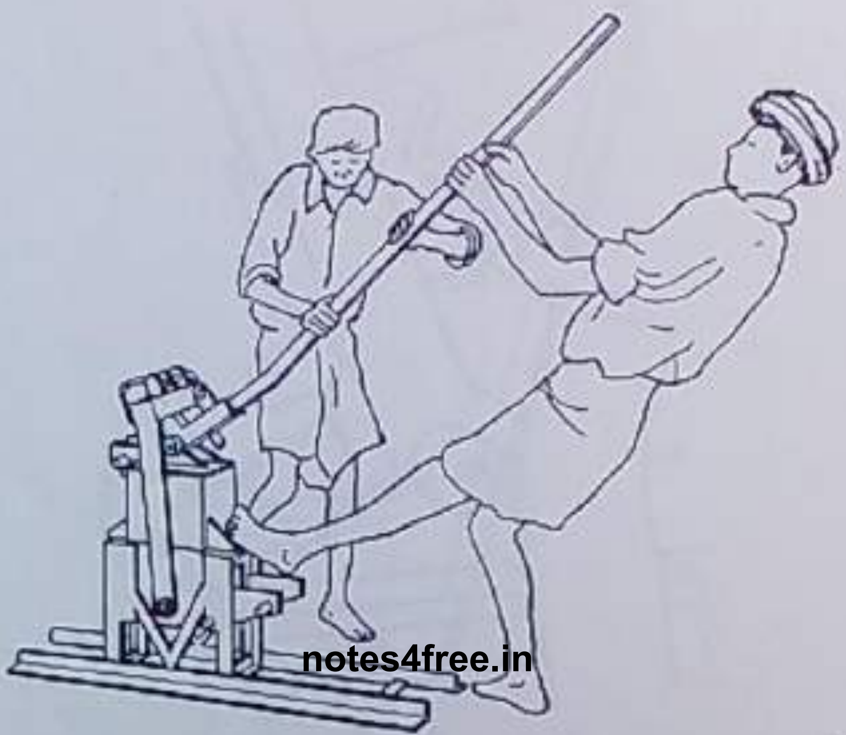
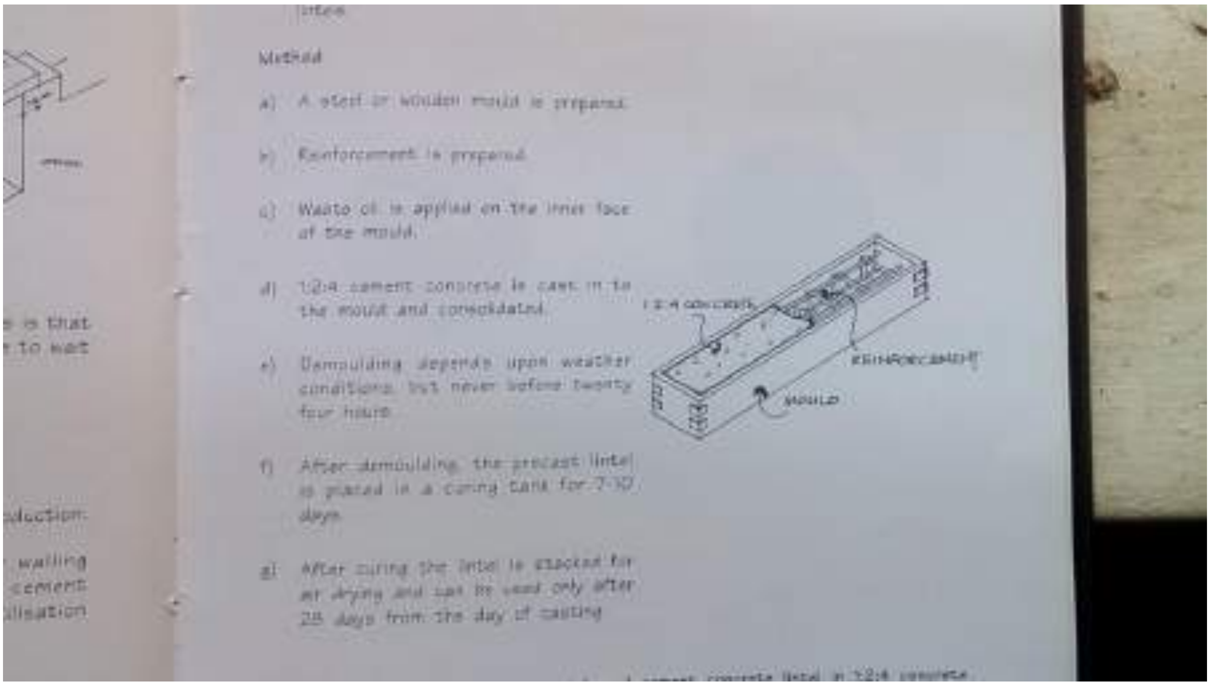


Fig. 4- Compaction

Fig. 5 - Ejection

MOULDS AND METHODS OF PRODUCTION OF PRE-CAST ELEMENTS:



Method

a) A steel or wooden mould is prepared.

b) Reinforcement is prepared.

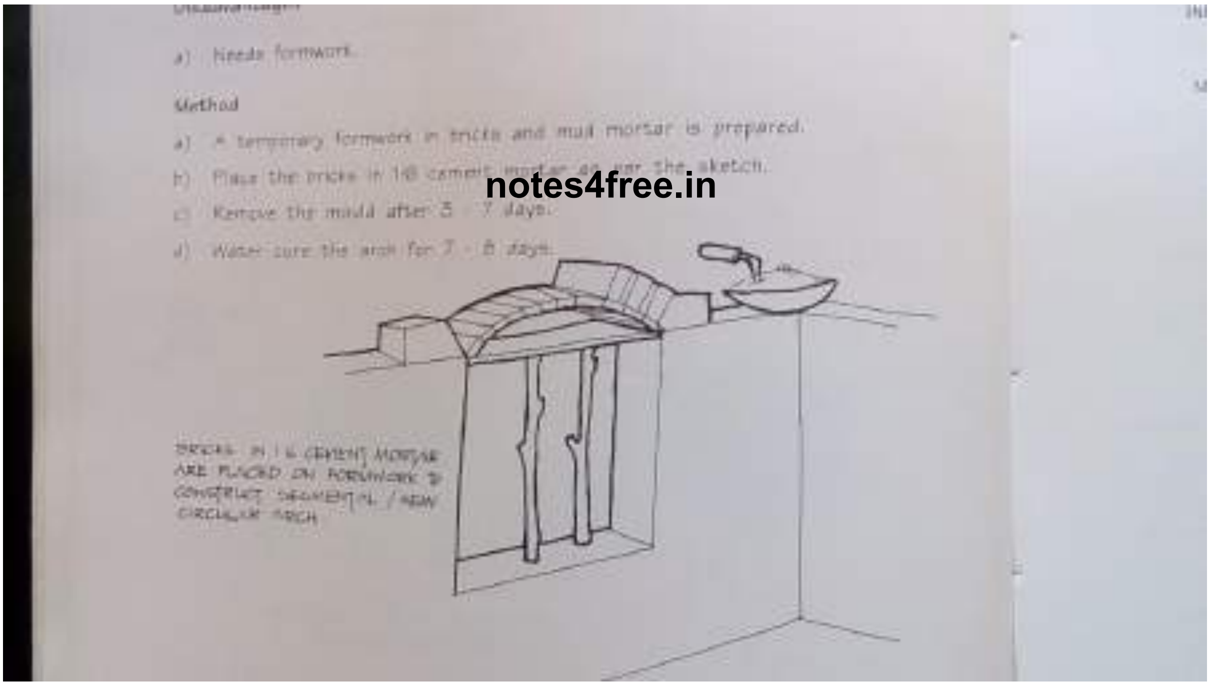
c) Waste oil is applied on the inner face of the mould.

d) 1:2:4 cement concrete is cast in to the mould and consolidated.

e) Demoulding depends upon weather conditions but never before twenty four hours.

f) After demoulding, the precast lintel is placed in a curing tank for 7-10 days.

g) After curing the lintel is stacked for air drying and can be used only after 28 days from the day of casting.



a) Needs formwork.

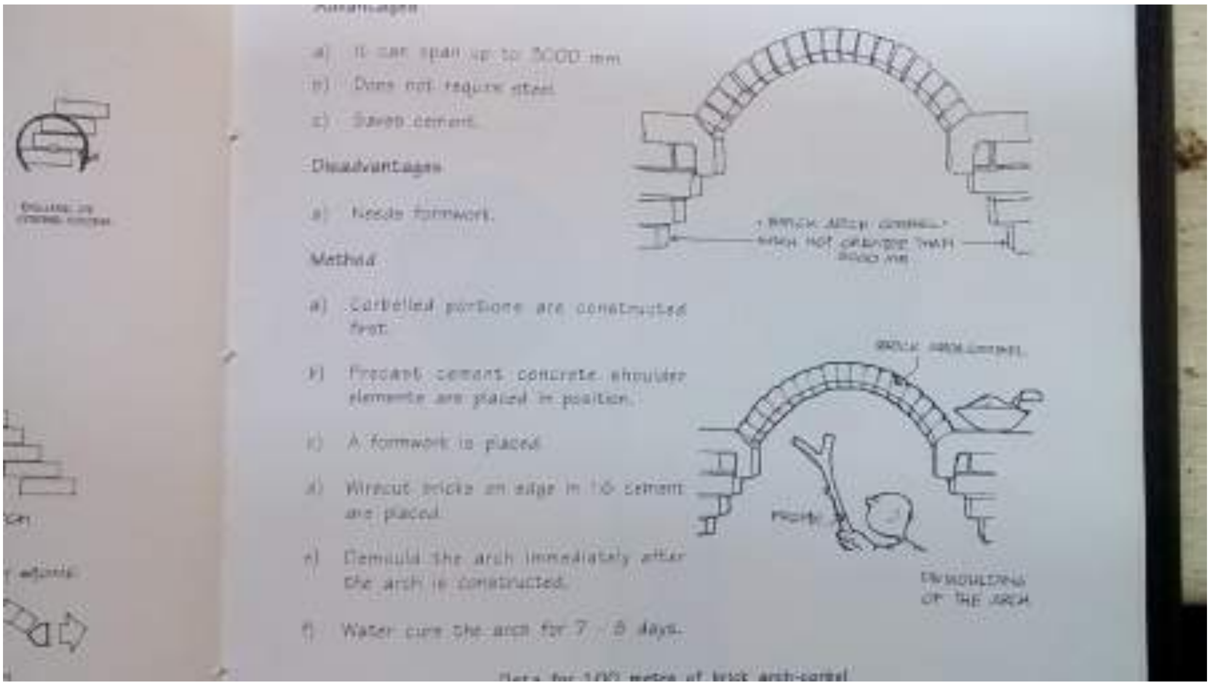
Method

a) A temporary formwork in bricks and mud mortar is prepared.

b) Place the bricks in 1:6 cement mortar as per the sketch.

c) Remove the mould after 5 - 7 days.

d) Water cure the arch for 7 - 8 days.



Advantages

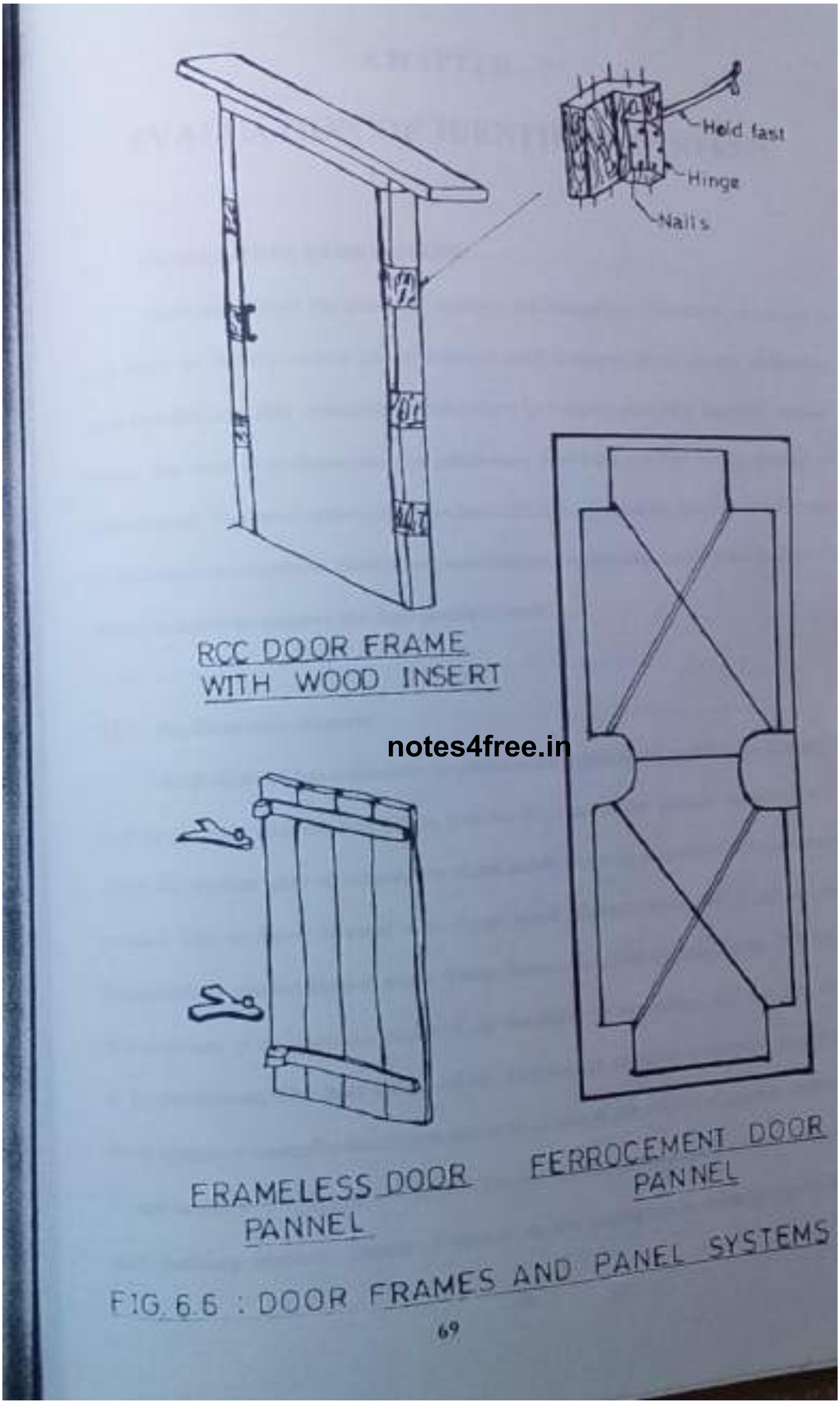
a) It can span up to 3000 mm
b) Does not require steel
c) Saves cement

Disadvantages

a) Needs formwork.

Method

a) Corbelled portions are constructed first.
b) Precast cement concrete shoulder elements are placed in position.
c) A formwork is placed.
d) Wirecut bricks on edge in 1:6 cement are placed.
e) Demould the arch immediately after the arch is constructed.
f) Water cure the arch for 7 - 8 days.


Held fast
Hinge
Nails
RCC DOOR FRAME
WITH WOOD INSERT
notes4free.in
FRAMELESS DOOR
PANNEL
FERROCEMENT DOOR
PANNEL
FIG 6.6 : DOOR FRAMES AND PANEL SYSTEMS
69

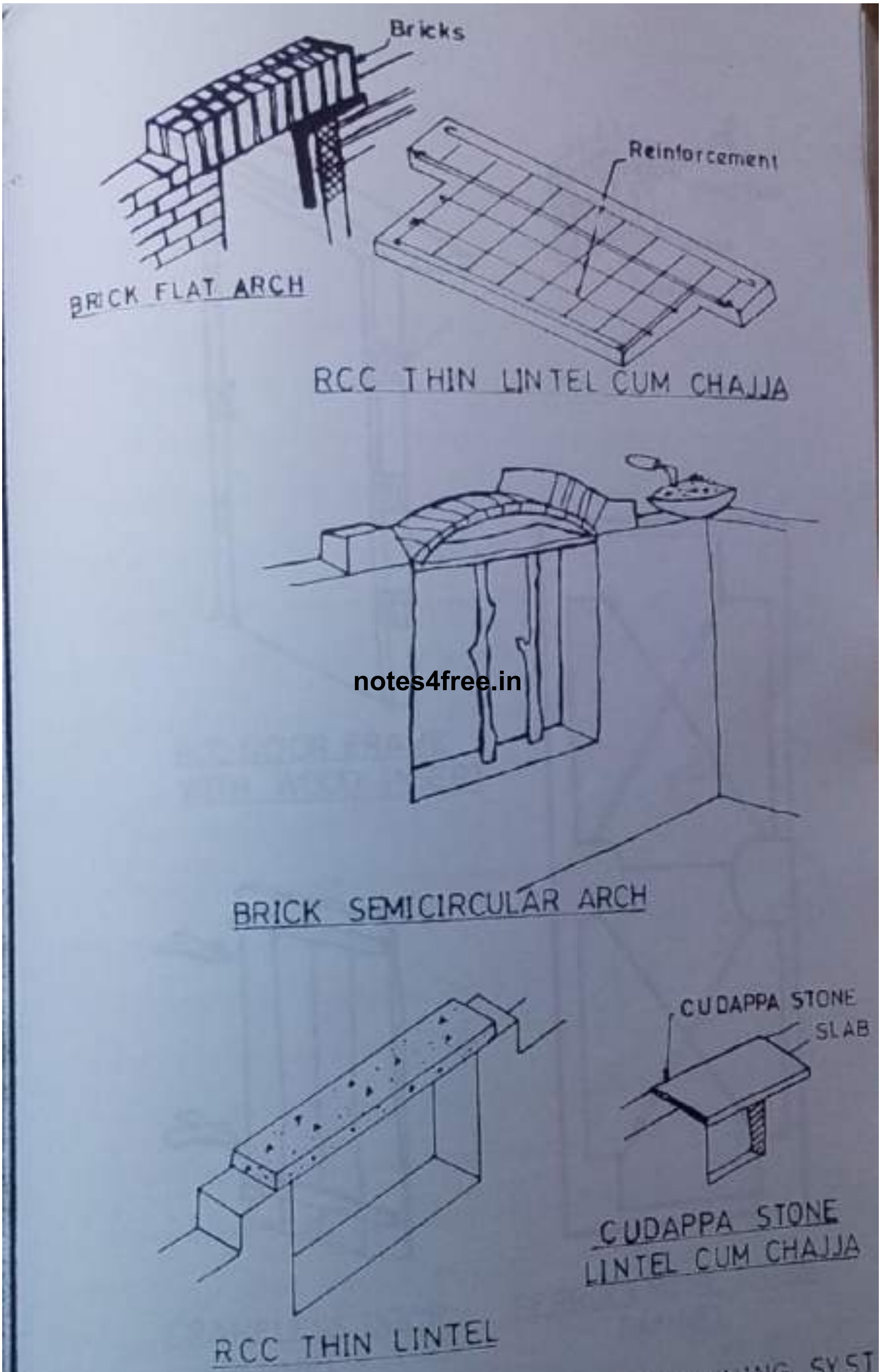


FIG. 6.5 : DIFFERENT TYPES OF OPENNING SYST

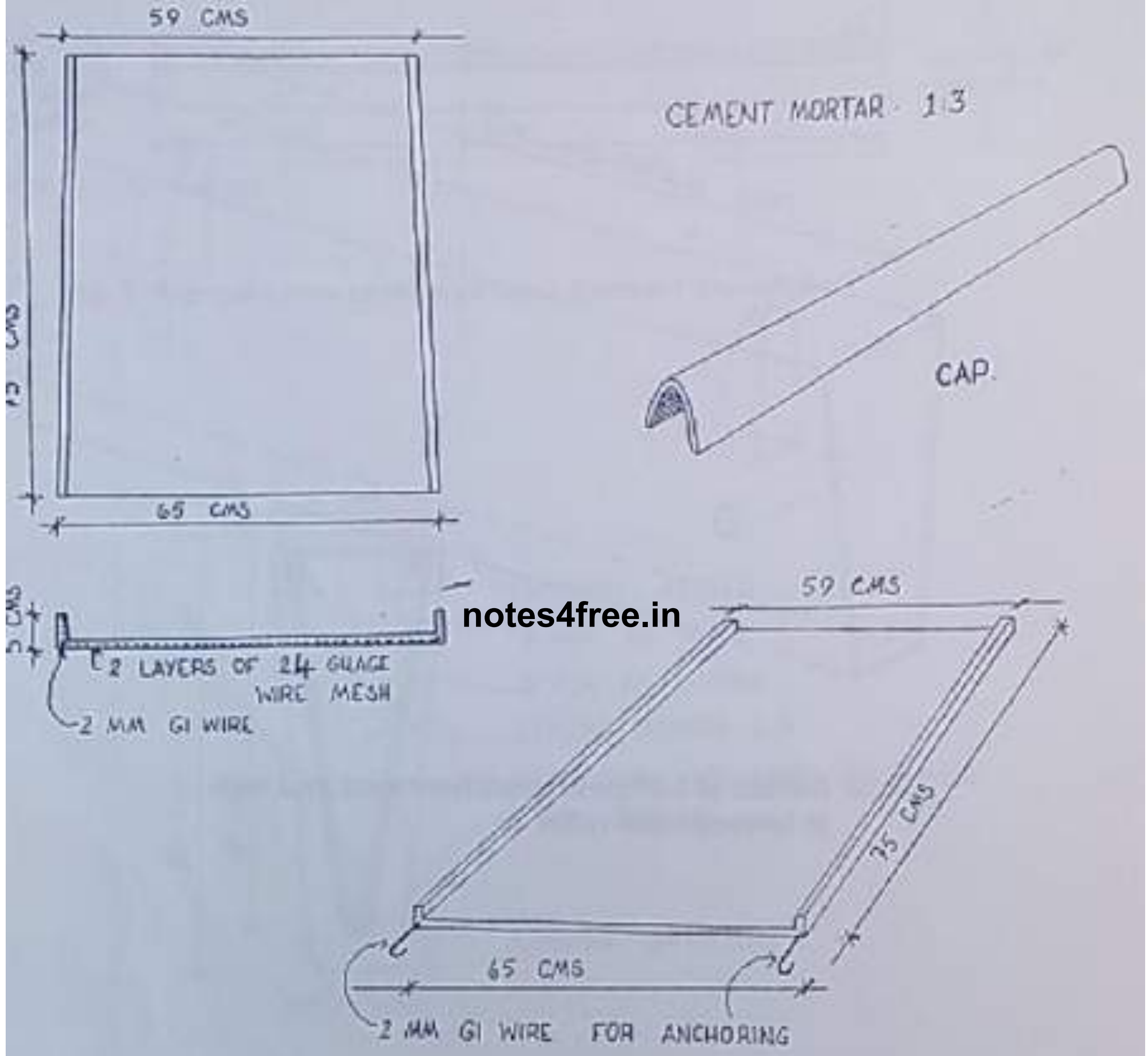


Fig. 4: Ferro-cement tile

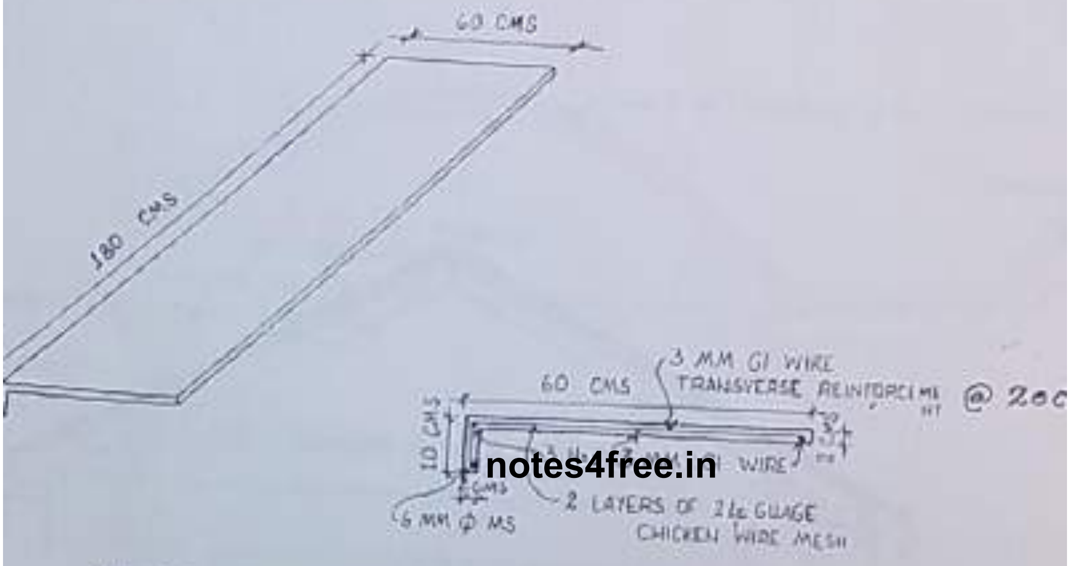
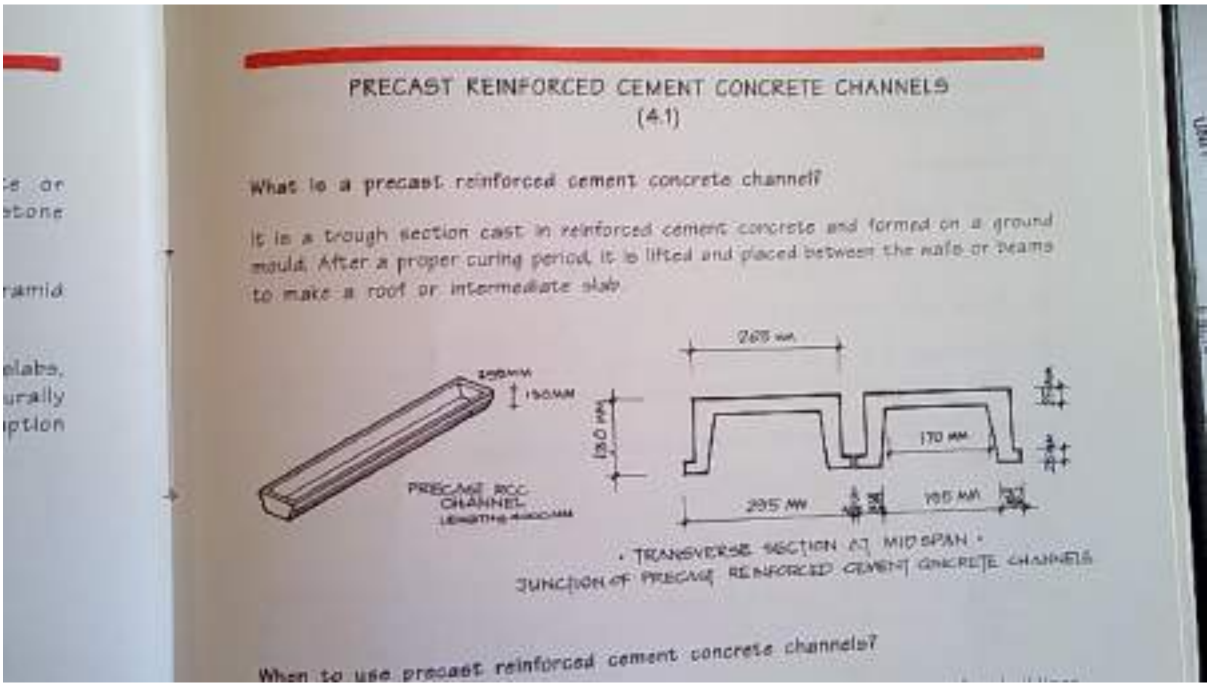
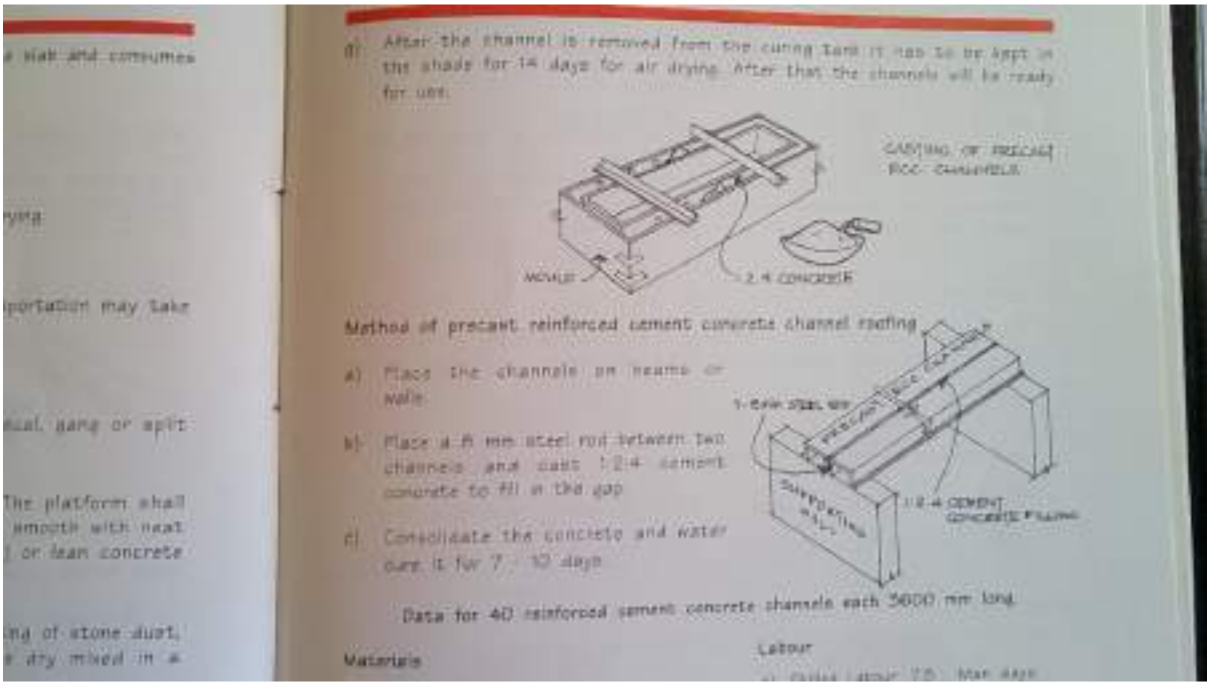


Fig. 5: Ferro-cement L-panel



Method of reinforced cement concrete channel production:

a) Steel moulds are fabricated first. They may be individual, gang or split mould.
b) A smooth levelled and hard surface in constructed. The plot form shall consist of 30 mm thk 1:3:6 cement concrete, finished smooth with neat cement, laid over a base of either brick soling (75mm) or lean concrete1:8:16
c) Channels are made of reinforced cement concrete consisting of stone dust, sand and 10mm down aggregate. The ingredients are dry mixed in a proportion of 1:2:4 and then water is added.
d) Prepare the reinforcement cage.
e) Inside surface of the mould is coated with waste oil and the reinforcement cage is placed inside. Care is to be taken so that clear cover to the reinforcement age from the mould is 15mm. Cast the concrete mix and by using a plate vibrator consolidated it properly.
f) After one day, demould the channel and keep it in the curing tank for 7-10 days.
g) After the channel is removed from the curing tank it has to be kept in the shade for 14 days for air drying. After that the channels will be ready for use.


d) After the channel is removed from the curing tank it has to be kept in the shade for 14 days for air drying. After that the channels will be ready for use.

CASTING OF PRECAST RCC CHANNELS

MOULD

1:2:4 CONCRETE

Method of precast reinforced cement concrete channel roofing

a) Place the channels on beams or walls

b) Place a 8 mm steel rod between two channels and cast 1:2:4 cement concrete to fill in the gap

c) Consolidate the concrete and water cure it for 7 - 10 days

PRECAST RCC CHANNEL

SUPPORTING WALL

1:2:4 CEMENT CONCRETE FILLING

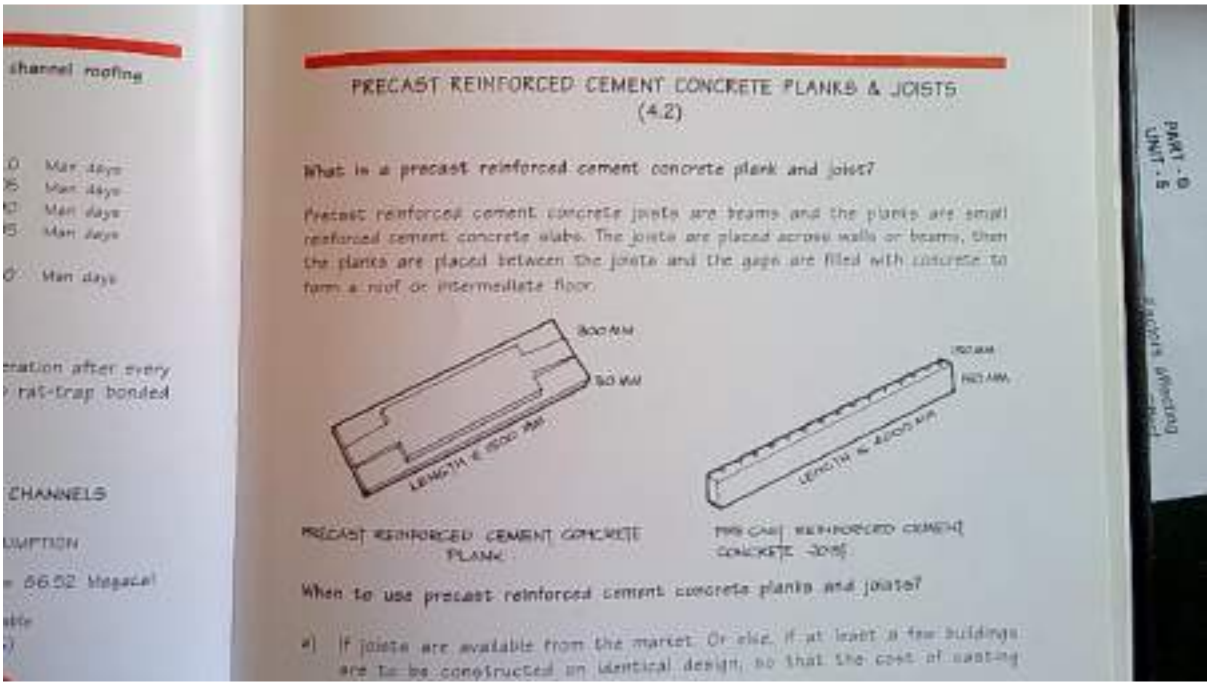
Data for 40 reinforced cement concrete channels each 3600 mm long

Materials

Labour

Method of precast reinforced cement concrete channel roofing:

a) Place the channels on beams or walls
b) Place a 8mm steel rod between two channels and cast 1:2:4 cement concrete to fill in the gap.
c) Consolidate the concrete and water cure it for 7-10 days


PRECAST REINFORCED CEMENT CONCRETE PLANKS & JOISTS (4.2)

What is a precast reinforced cement concrete plank and joist?

Precast reinforced cement concrete joists are beams and the planks are small reinforced cement concrete slabs. The joists are placed across walls or beams, then the planks are placed between the joists and the gaps are filled with concrete to form a roof or intermediate floor.

300 MM

50 MM

LENGTH ≤ 1500 MM

150 MM

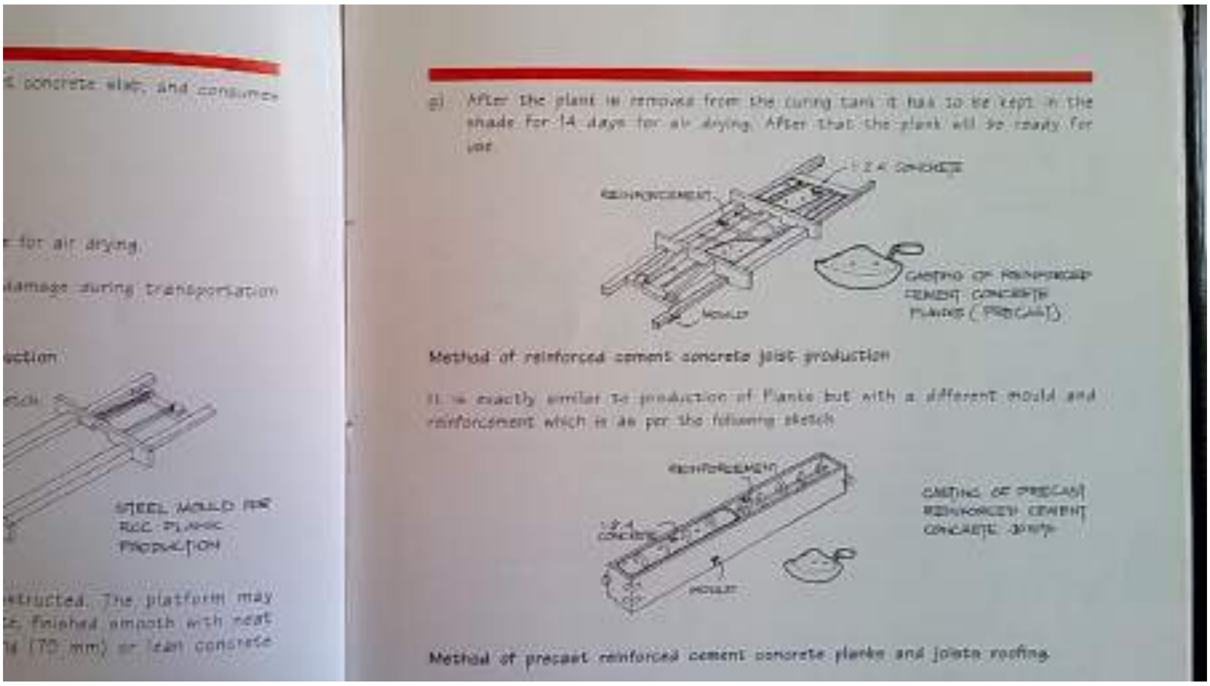
LENGTH ≤ 4000 MM

PRECAST REINFORCED CEMENT CONCRETE PLANK

PRECAST REINFORCED CEMENT CONCRETE JOIST

When to use precast reinforced cement concrete planks and joists?

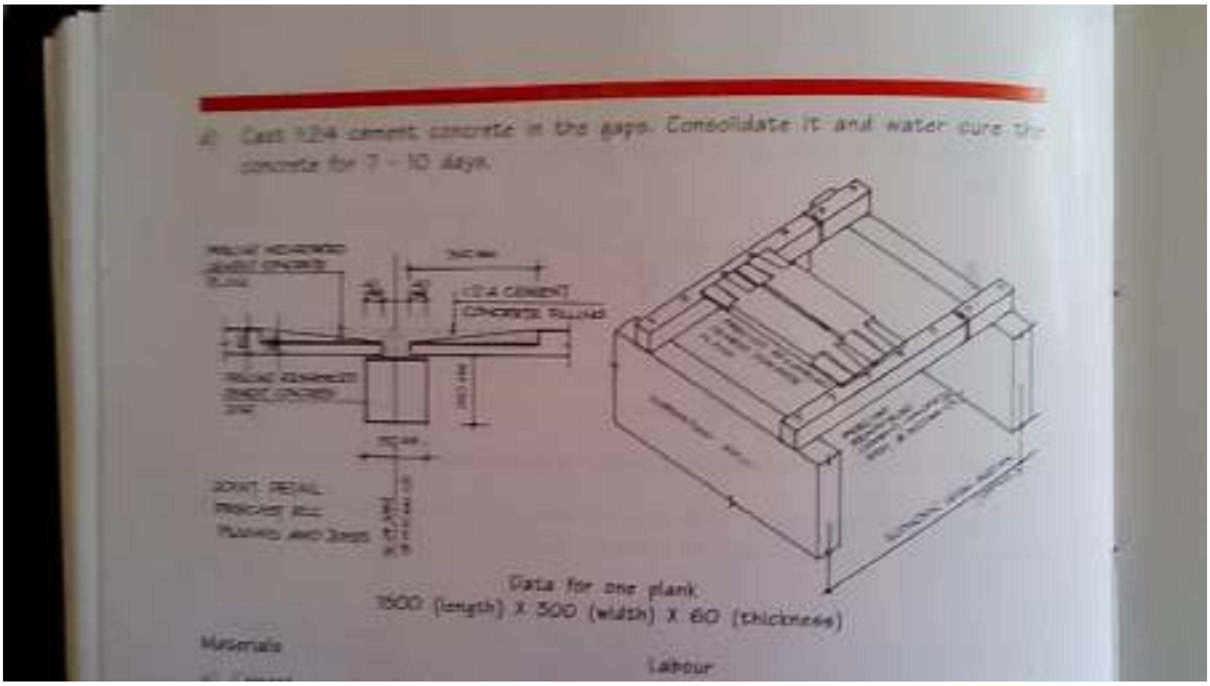
a) If joists are available from the market. Or else, if at least a few buildings are to be constructed on identical design, so that the cost of casting



Method of RCC plank production:

a) Steel moulds are fabricated first as in sketch.
b) A smooth levelled and hard surface is constructed. The platform may consist of 30mm thick 1:3:6 cement concrete, finished smooth with neat cement laid over a base of either brick soling (75mm) or lean concrete 1:8:18.

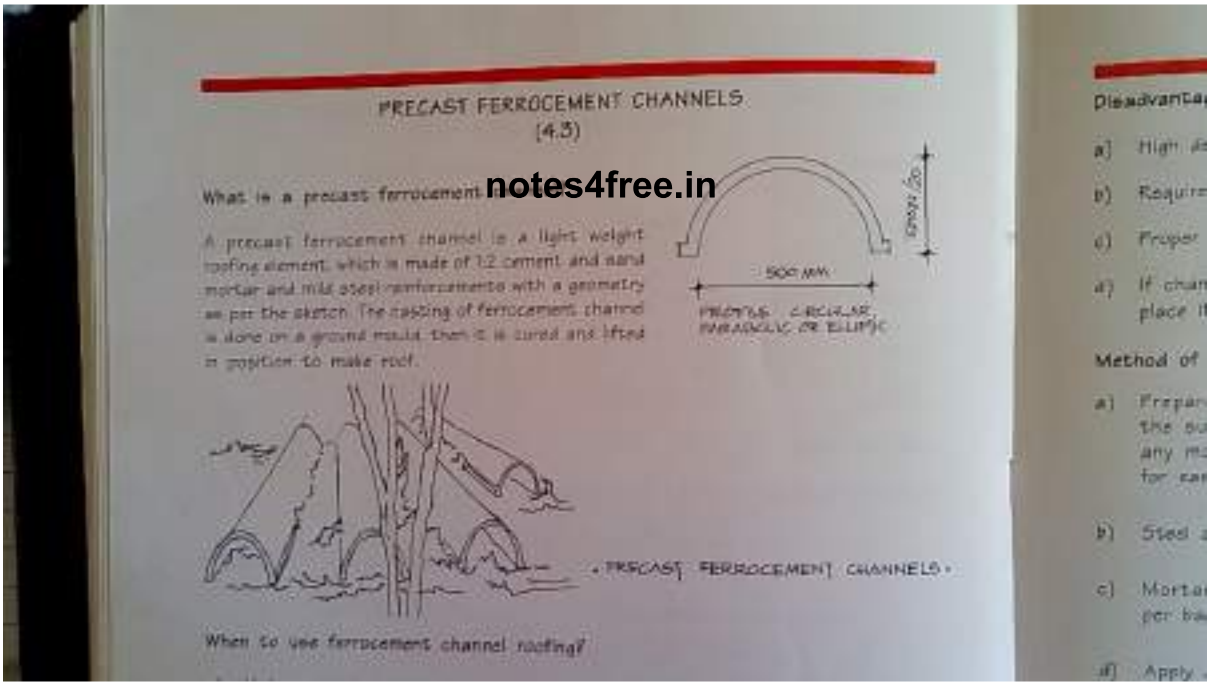
c) Planks are made of reinforced cement concrete, consisting of stone dust, sand and 10mm aggregate. The ingredients are dry mixed in a proportion of 1:2:4. Water is added to it and then remixed thoroughly.
d) Reinforcement is prepared.
e) Inside surface of the mould is coated with waste oil and the prepared reinforcement is placed in a cage from the mould is 15mm. Cast the concrete mix and by using a plate vibrator consolidate the concrete properly.
f) After one day demould the plank and keep it in the curing tank for 7-10 days.
g) After the plank is removed from the curing tank it has to be kept in the shade for 14 days for air dry. After the plank will be ready for use.


d) Cast 1:2:4 cement concrete in the gaps. Consolidate it and water cure the concrete for 7 - 10 days.

Data for one plank
1500 (length) X 300 (width) X 60 (thickness)

Materials

Labour


PRECAST FERROCEMENT CHANNELS
(4.3)

What is a precast ferrocement channel?

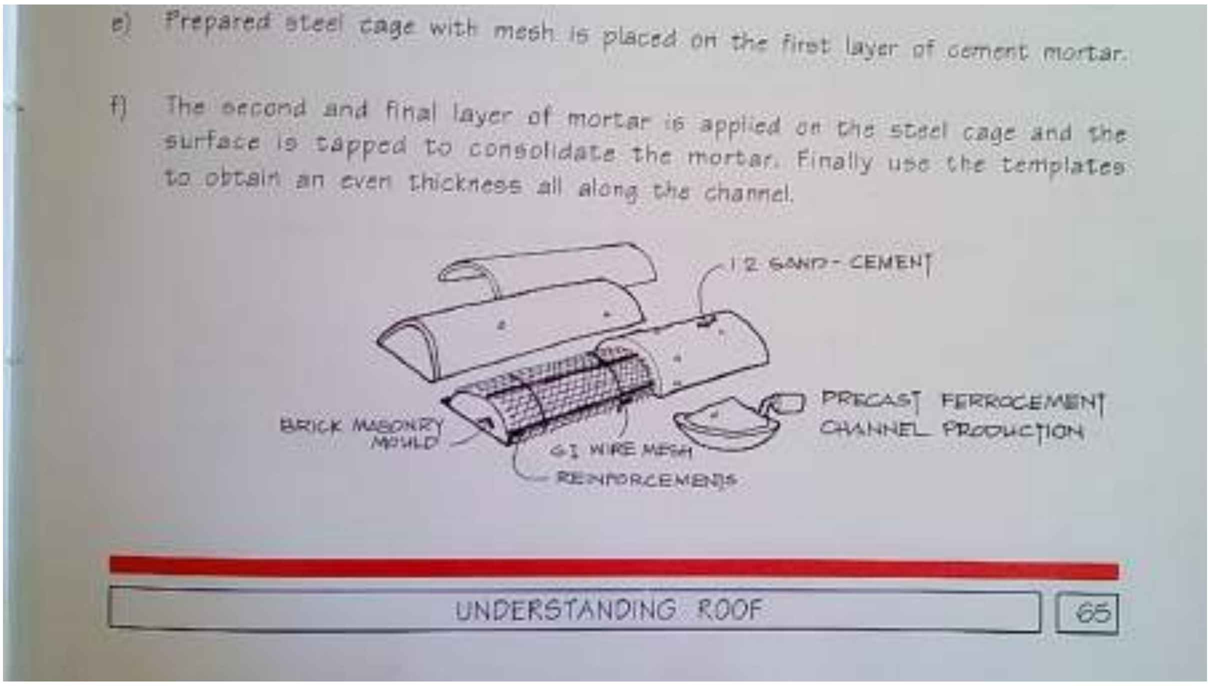
A precast ferrocement channel is a light weight roofing element which is made of 1:2 cement and sand mortar and mild steel reinforcements with a geometry as per the sketch. The casting of ferrocement channel is done on a ground mould, then it is cured and lifted in position to make roof.

• PRECAST FERROCEMENT CHANNELS •

When to use ferrocement channel roofing?

Disadvanta...

Method of ...



e) Prepared steel cage with mesh is placed on the first layer of cement mortar.

f) The second and final layer of mortar is applied on the steel cage and the surface is tapped to consolidate the mortar. Finally use the templates to obtain an even thickness all along the channel.

Method of ferrocement channel production:

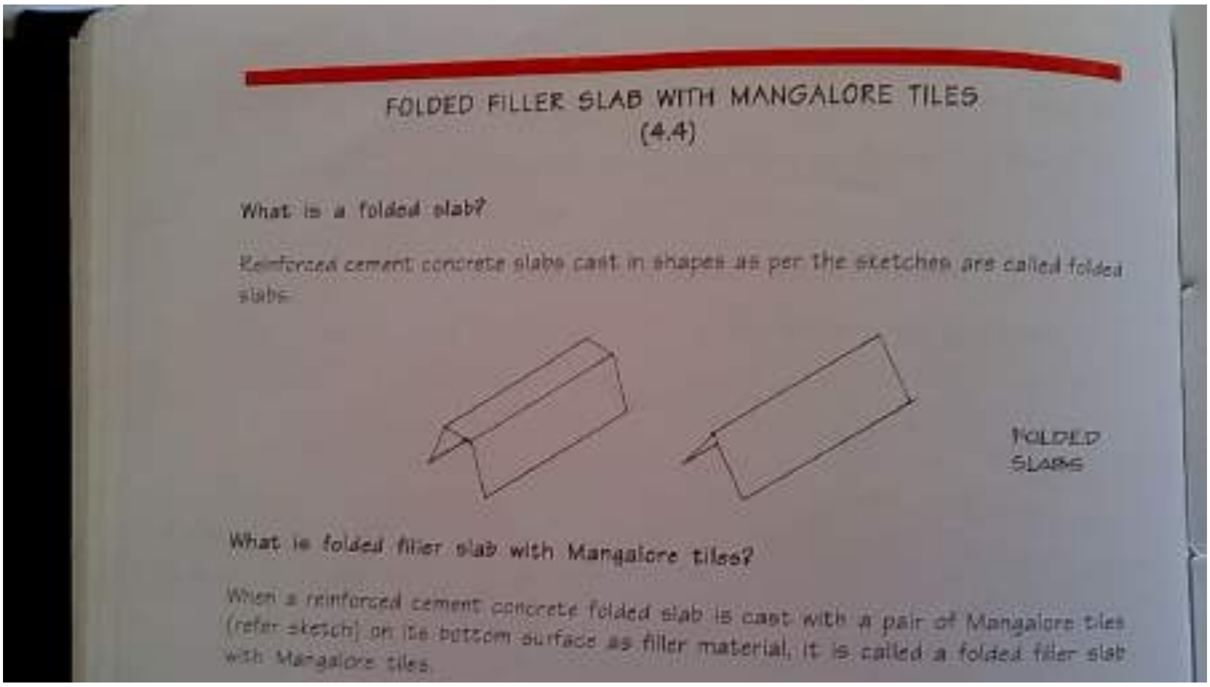
a) Prepare a brick masonry mould on the ground. After proper curing clean the surface and apply waste oil until the surface will not absorb any more. Next anthor coat of waste oil is applied on the surface for easy moulding.
b) Steel and galvanised iron wire mesh is prepared.

c) Mortar mix of 1:2 sand-cement is prepared with 22.5litres of water per bag of cement.
d) Apply a 5mm thk cement mortar on the surface of the mould.
e) Prepared steel cage with mesh is placed on the first layer of cement mortar.
f) The second and final layer of mortar is applied on the steel cage and the surface is tapped to consolidate the mortar. Finally use the template to obtain an even thickness all along the channel.
g) The channel is allowed to set on the mould for twenty four hours in shade.
h) After 24 hrs the channel is slightly lifted on one end and then fully lifted and carried manually by holding both ends to the curing tank.
i) Curing time is 7-10 days depending upon the weather conditions.

Method o precast ferrocement channel roof construction:

a) Place the chnnels side by side over supporting beams or walls. Use a 75mm thk band lintel on which the channels should rest.
b) Place one 10mm dia steel rod parallel to the channels and tie a strip of galvanised iron wire mesh along the entire length of the channels.

c) Cast 1:2 cement mortar in the gap b/n two channels, consolidate it and water cure the portion for 7-10 days.

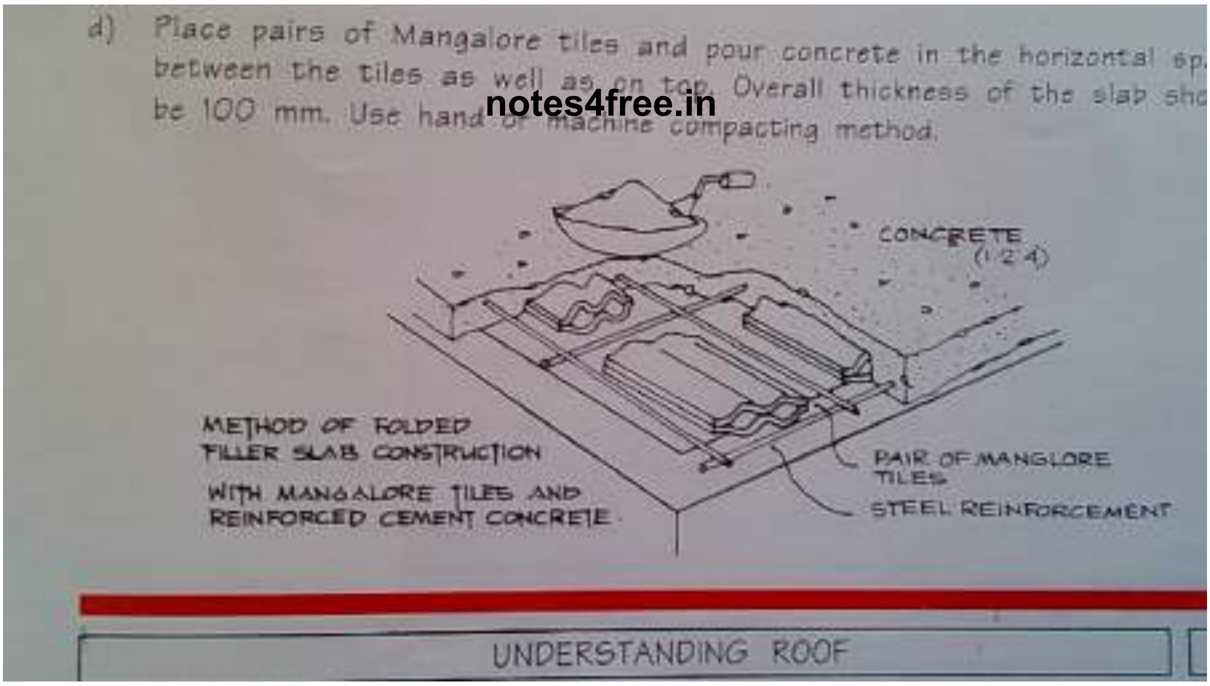

FOLDED FILLER SLAB WITH MANGALORE TILES
(4.4)

What is a folded slab?

Reinforced cement concrete slabs cast in shapes as per the sketches are called folded slabs.

What is folded filler slab with Mangalore tiles?

When a reinforced cement concrete folded slab is cast with a pair of Mangalore tiles (refer sketch) on its bottom surface as filler material, it is called a folded filler slab with Mangalore tiles.


d) Place pairs of Mangalore tiles and pour concrete in the horizontal sp between the tiles as well as on top. Overall thickness of the slab sho be 100 mm. Use hand or machine compacting method.

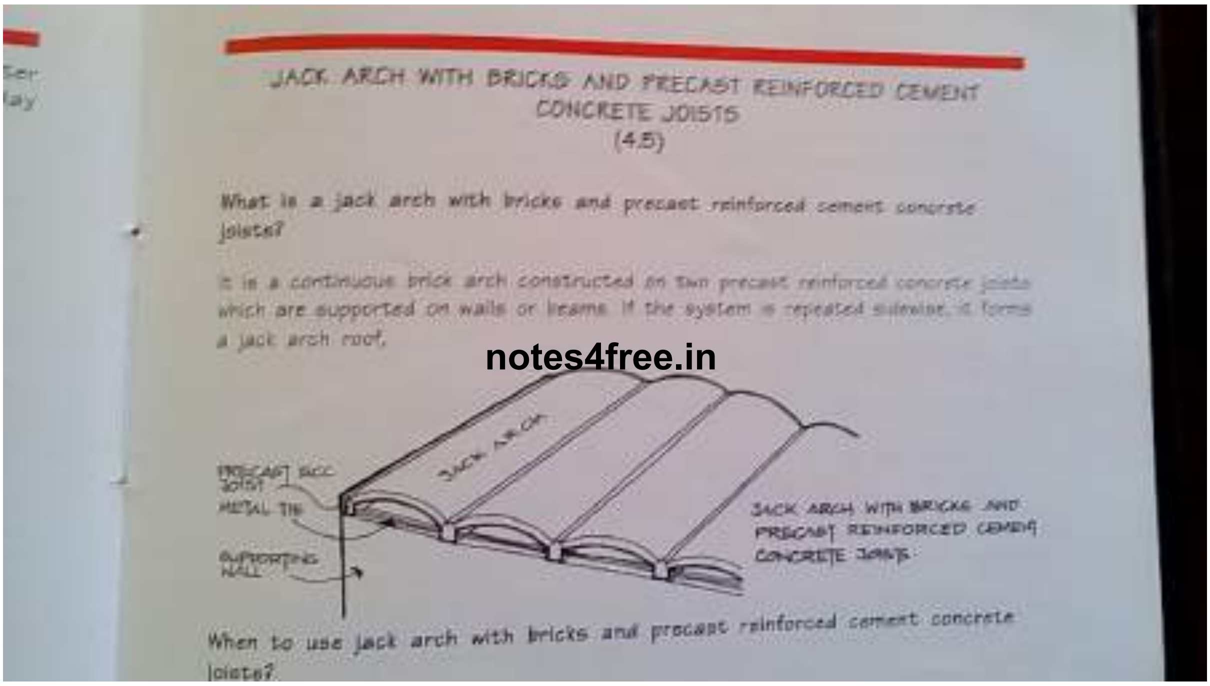
Method :

a) Prepare wooden or steel shuttering , and apply waste oil on the surface for easy de-shuttering.
b) Place the reinforcement with the clear cover os 15mm from the surface of shuttering.

c) Prepare a dry mix of 1:2:4 cement, corse sand and 20mm down stone chips. Add water at the rate of 25litres per bag of cement. Do the mixing thoroughly so that it is homogeneous and ready for use.

d) Place pairs of Mangalore tiles and pour concrete in the horizontal spaces b/n the tiles as well as on top. Overall thickness of the slab should be 100mm. Use hand or machine compacting method.

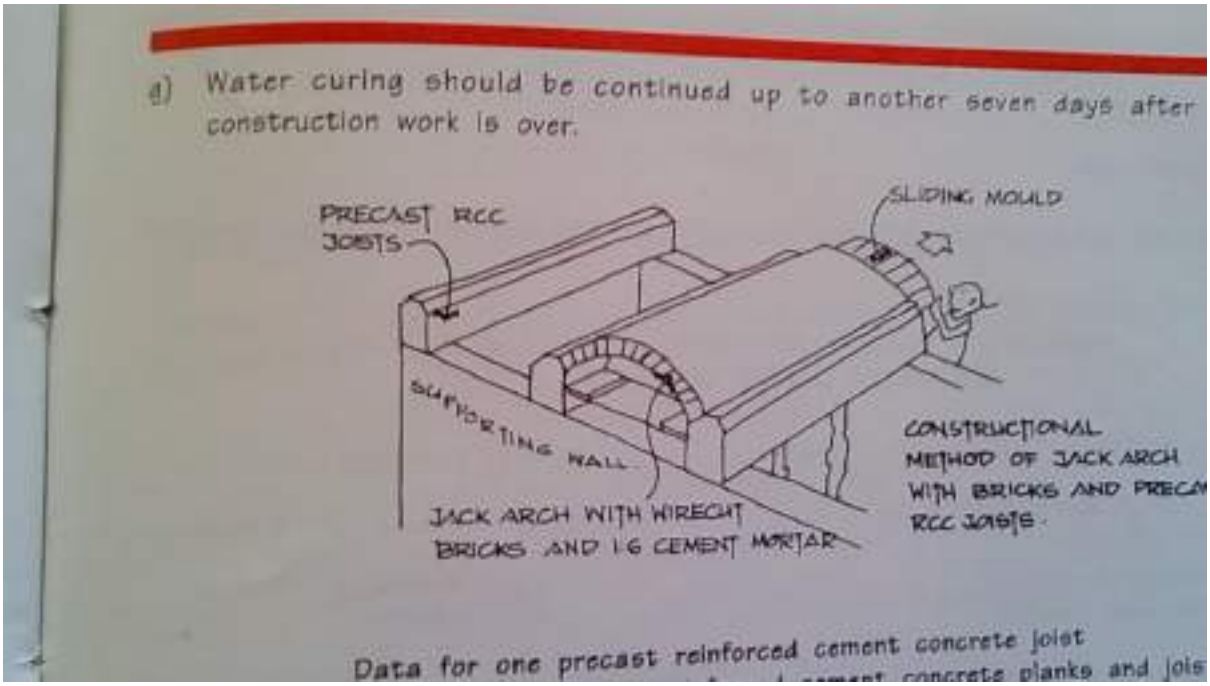
e) Cure the slanting surface by placing jute bags which will hold the waste for some time. Water curing should be done at least five times a day and should be continued for10-14 days depending upon span.


JACK ARCH WITH BRICKS AND PRECAST REINFORCED CEMENT CONCRETE JOISTS
(4.5)

What is a jack arch with bricks and precast reinforced cement concrete joists?

It is a continuous brick arch constructed on two precast reinforced concrete joists which are supported on walls or beams. If the system is repeated sidewise, it forms a jack arch roof.

When to use jack arch with bricks and precast reinforced cement concrete joists?



Method:

a) For the production of precast reinforced cement concrete joists, refer to the section on precast reinforced cement concrete planks and joists.

b) Joists are placed b/n walls or beams and steel ties are to be provided to arrest lateral movements of the joists.

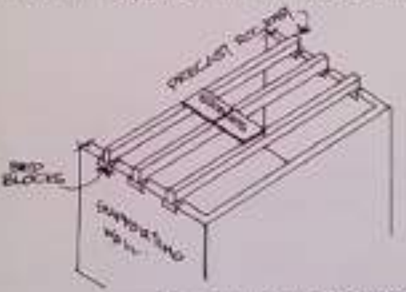
c) A sliding type of mould is placed b/n two joists.

d) Arch with wire cut bricks in 1:6 cement mortar is constructed immediate de-molding of the newly constructed arch is done by sliding the mould to the position where the next arch is to be constructed.

STONE ROOFING ON PRECAST REINFORCED CEMENT CONCRETE JOISTS (4.6)

What is sand stone roofing on precast reinforced cement concrete joists?

This type of roofing is made up of sand stone panels suppored by precast reinforced concrete joists which are supported on walls or beams.



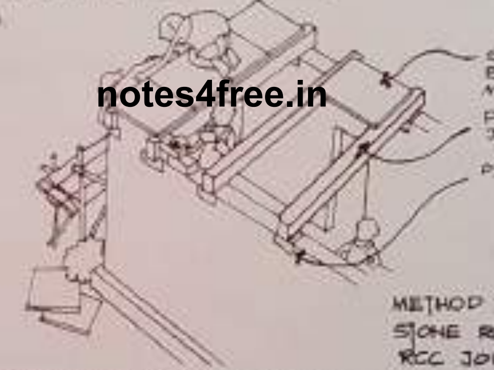
SANDSTONE ROOFING ON PRECAST RCC JOISTS

When to use sand stone roofing on precast reinforced cement concrete joists?

... market. Or else if at least a few buildings

Method

Method of construction is same as for the jack arch but with stone slabs in place of brick arches.



METHOD OF CONSTRUCTION OF STONE ROOFING ON PRECAST RCC JOISTS.

Data for one precast reinforced cement concrete joist 2470 mm long *(refer page No. 62)*

Data for 10.00 square metres of stone roofing on precast reinforced cement concrete ...

MICRO CONCRETE TILES ON STEEL UNDER STRUCTURE (4.7)

What is a micro concrete tile?

Micro concrete tiles are made of plain cement concrete using small stone chips (maximum size not more than 5 mm). Hence, it is called micro as concrete.

MICRO CONCRETE TILES ON STEEL UNDERSTRUCTURE

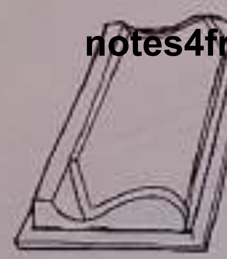
What is MCT roofing?

Roofing with MCTs is similar to conventional Mangalore tiled roof. Therefore it needs primary members like rafter and purline to ...

... will produce roughly 87 pan tiles.

e) The prepared mix is placed on a piece of plastic sheet attached to the frame. The frame, attached to the vibrating table defines the boundaries and thickness of the tile. The vibrating table is switched on until the mix is consolidated and a tile is formed.

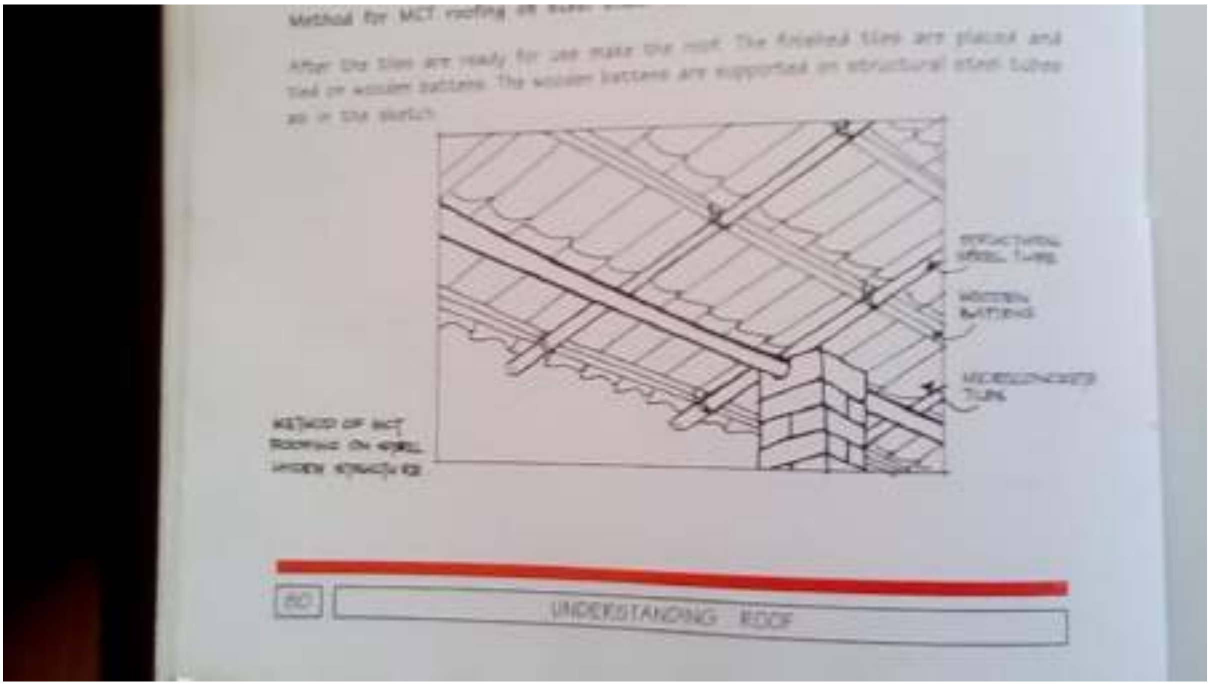
TABLE VIBRATOR



CASTING MCT ON MOULD

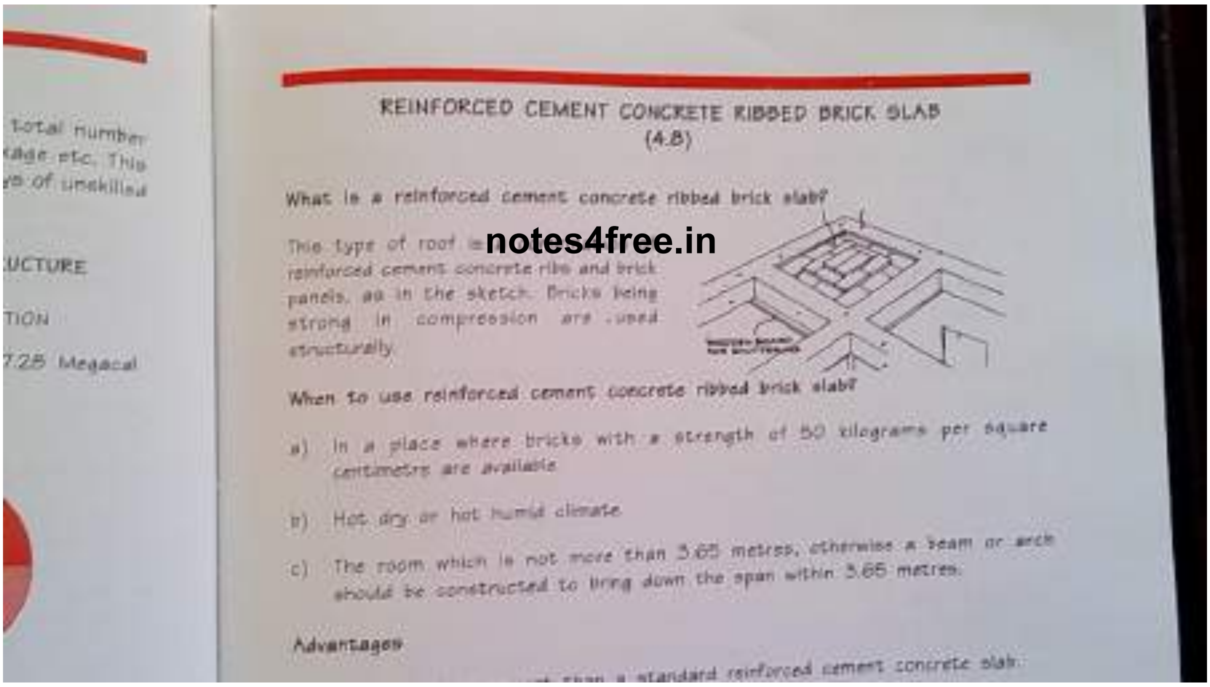
FINISHED PRODUCT

UNDERSTANDING ROOF 79


Method for MCT roofing on steel ...

After the tiles are ready for use make the roof. The finished tiles are placed and tied on wooden battens. The wooden battens are supported on structural steel tubes as in the sketch.

80 UNDERSTANDING ROOF


total number
kage etc. This
ys of unskilled

UCTURE

TION

7.28 Megacal

REINFORCED CEMENT CONCRETE RIBBED BRICK SLAB
(4.8)

What is a reinforced cement concrete ribbed brick slab?

This type of roof is ... reinforced cement concrete ribs and brick panels, as in the sketch. Bricks being strong in compression are used structurally.

When to use reinforced cement concrete ribbed brick slab?

a) In a place where bricks with a strength of 50 kilograms per square centimetre are available.

b) Hot dry or hot humid climate.

c) The room which is not more than 3.65 metres, otherwise a beam or arch should be constructed to bring down the span within 3.65 metres.

Advantages

... than a standard reinforced cement concrete slab.

HOME PAGE

CHAPTER 10

Batching, Mixing, Transporting, and Handling Concrete

The specification, production, and delivery of concrete are achieved in different ways. The basic processes and common techniques are explained here. ASTM C 94 provides standard specifications for the manufacture and delivery of freshly mixed concrete. Standards of the Concrete Plant Manufacturers Bureau, Truck Mixer Manufacturers Bureau, and Volumetric Mixer Manufacturers Bureau can be found on the National Ready Mixed Concrete Association's website at http://www.nrmca.org.

Three options for ordering or specifying concrete are described in ASTM C 94:

1. Option A is performance based. It requires the purchaser to specify the compressive strength only, while the concrete producer selects the mixture proportions needed to obtain the required compressive strength.
2. Option B is prescription based. The purchaser specifies mixture proportions, including cement, water and admixture contents.
3. Option C is a mixed option. It requires the concrete producer to select the mix proportions with the minimum allowable cement content and compressive strength specified by the purchaser.

BATCHING

Batching is the process of measuring concrete mix ingredients by either mass or volume and introducing them into the mixer. To produce concrete of uniform quality, the ingredients must be measured accurately for each batch. Most specifications require that batching be done by mass rather than by volume (ASTM C 94 or AASHTO M 157). Water and liquid admixtures can be measured accurately by either volume or mass. Volumetric batching (ASTM C 685 or AASHTO M 241) is used for concrete mixed in continuous mixers.

Specifications generally require that materials be measured for individual batches within the following percentages of accuracy: cementitious material ±1%, aggregates ± 2%, water ±1%, and admixtures ± 3%.

Equipment should be capable of measuring quantities within these tolerances for the smallest batch regularly used as well as for larger batches (Fig. 10-1). The accuracy of scales and batching equipment should be checked periodically and adjusted when necessary.

Liquid chemical admixtures should be charged into the mixture as aqueous solutions. The volume of liquid, if significant, should be subtracted from the batched quantity of mixing water. Admixtures that cannot be added in solution can be either batched by mass or volume as directed by the manufacturer. Admixture dispensers should be checked frequently since errors in dispensing admixtures, particularly overdoses, can lead to serious problems in both fresh and hardened concrete.

Fig. 10-1. Control room for batching equipment in a typical ready mixed concrete plant. (69894)

MIXING CONCRETE

All concrete should be mixed thoroughly until it is uniform in appearance, with all ingredients evenly distributed. Mixers should not be loaded above their rated capacities and should be operated at the mixing speed recommended by the manufacturer. Increased output should be obtained by using a larger mixer or additional mixers, rather than by speeding up or overloading the equipment on hand. If the blades of a mixer become worn or coated with hardened concrete, mixing action will be less efficient. These conditions should be corrected.

If concrete has been adequately mixed, samples taken from different portions of a batch will have essentially the same density, air content, slump, and coarse-aggregate content. Maximum allowable differences to evaluate mixing uniformity within a batch of ready mixed concrete are given in ASTM C 94 (AASHTO M 157).

Structural low-density concrete can be mixed the same way as normal-density concrete when the aggregates have less than 10% total absorption by mass or when the absorption is less than 2% by mass during the first hour after immersion in water. For aggregates not meeting these limits, mixing procedures are described in PCA (1986).

Stationary Mixing

Concrete is sometimes mixed at the jobsite in a stationary mixer or a paving mixer (Fig. 10-2). Stationary mixers include both onsite mixers and central mixers in ready mix plants. They are available in sizes up to 9.0 m^3 (12 yd^3) and can be of the tilting or nontilting type or the open-top revolving blade or paddle type. All types may be equipped with loading skips and some are equipped with a swinging discharge chute. Many stationary mixers have timing devices, some of which can be set for a given mixing time and locked so that the batch cannot be discharged until the designated mixing time has elapsed.

Fig. 10-2. Concrete can be mixed at the jobsite in a stationary mixer. (58642)

Careful attention should be paid to the required mixing time. Many specifications require a minimum mixing time of one minute plus 15 seconds for every cubic meter (yard), unless mixer performance tests demonstrate that shorter periods are acceptable and will provide a uniform concrete mixture. Short mixing times can result in nonhomogenous mixtures, poor distribution of air voids (resulting in poor frost resistance), poor strength gain, and early stiffening problems. The mixing period should be measured from the time all cement and aggregates are in the mixer drum, provided all the water is added before one-fourth of the mixing time has elapsed (ACI 304R-00).

Under usual conditions, up to about 10% of the mixing water should be placed in the drum before the solid materials are added. Water then should be added uniformly with the solid materials, leaving about 10% to be added after all other materials are in the drum. When heated water is used in cold weather, this order of charging may require some modification to prevent possible rapid stiffening when hot water contacts the cement. In this case, addition of the cementitious materials should be delayed until most of the aggregate and water have intermingled in the drum. Where the mixer is charged directly from a batch plant, the materials should be added simultaneously at such rates that the charging time is about the same for all materials. If supplementary cementing materials are used, they should be added after the cement.

If retarding or water-reducing admixtures are used, they should be added in the same sequence in the charging cycle each time. If not, significant variations in the time of initial setting and percentage of entrained air may result. Addition of the admixture should be completed not later than one minute after addition of water to the cement has been completed or prior to the start of the last three-fourths of the mixing cycle, whichever occurs first. If two or more admixtures are used in the same batch of concrete, they should be added separately; this is intended to avoid any interaction that might interfere with the efficiency of any of the admixtures and adversely affect the concrete properties. In addition, the sequence in which they are added to the mix can be important too.

Ready Mixed Concrete

Ready mixed concrete is proportioned and mixed off the project site and is delivered to the construction area in a freshly mixed and unhardened state. It can be manufactured by any of the following methods:

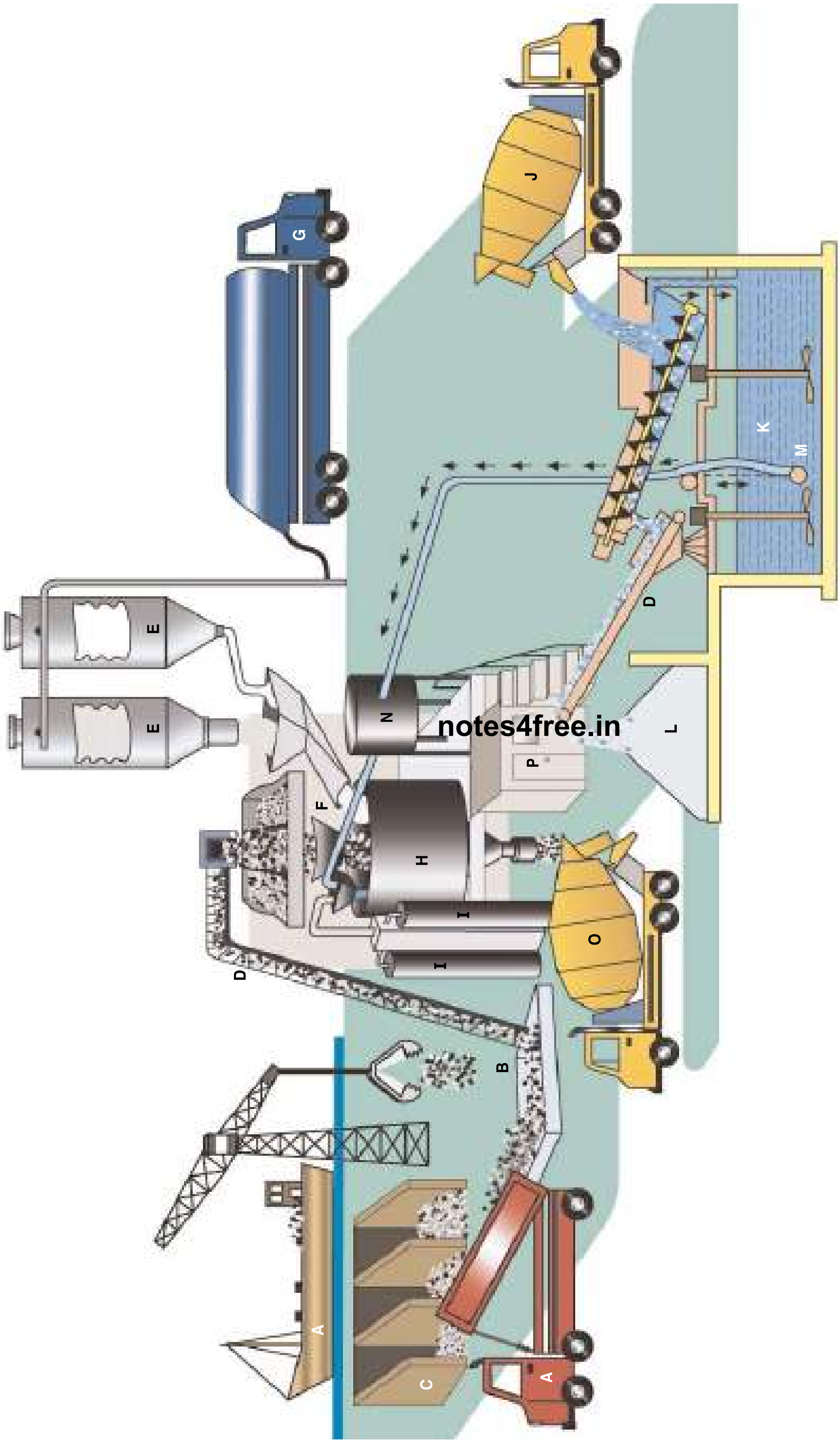
1. Central-mixed concrete is mixed completely in a stationary mixer (Fig. 10-3) and is delivered either in a truck agitator (Fig. 10-4 bottom), a truck mixer operating at agitating speed (Fig. 10-3), or a nonagitating truck (Fig. 10-4 top). Fig. 10-5 illustrates a central mix ready mix plant.
2. Shrink-mixed concrete is mixed partially in a stationary mixer and completed in a truck mixer.
3. Truck-mixed concrete is mixed completely in a truck mixer (Fig. 10-6).

ASTM C 94 (AASHTO M 157) notes that when a truck mixer is used for complete mixing, 70 to 100 revolutions of the drum or blades at the rate of rotation designated by the manufacturer as *mixing speed* are usually required to produce the specified uniformity of concrete. All revolutions after 100 should be at a rate of rotation designated by the manufacturer as *agitating speed*. Agitating speed is usually about 2 to 6 rpm, and mixing speed is generally about 6 to 18 rpm. Mixing at high speeds for long periods of time, about 1 or more hours, can result in concrete strength loss, temperature rise, excessive loss of entrained air, and accelerated slump loss.

When truck mixers are used, ASTM C 94 (AASHTO M 157) also limits the time between batching and complete discharge of the concrete at the job site; this time is 1½ hours or before the drum has revolved 300 times after introduction of water to the cement and aggregates or the cement to the aggregates. Mixers and agitators should always be operated within the limits for volume and speed of rotation designated by the equipment manufacturer.

Fig. 10-3. Central mixing in a stationary mixer of the tilting drum type with delivery by a truck mixer operating at agitating speed. (69926)

Fig 10-4. (top) Nonagitating trucks are used with central-mix batch plants where short hauls and quick concrete discharge allows the rapid placement of large volumes of concrete. (bottom) Truck agitators are also used with central-mix batch plants. Agitation mixing capabilities allow truck agitators to supply concrete to projects with slow rates of concrete placement and at distances greater than nonagitating trucks. (69897, 69898)



A Aggregate delivery
B Aggregate receiving hopper
C Aggregate storage
D Conveyor belt
E Cementitious material storage
F Weigh hopper
G Cement delivery
H Mixer
I Admixtures
J Ready mix truck with returned concrete
K Recycled water
L Reclaimed aggregates
M Pump
N Water storage
O Concrete loaded in ready-mix truck
P Control Room

Fig. 10-5. Schematic of a ready mix plant.

Fig. 10-6. Truck-mixed concrete is mixed completely in a truck mixer. (1153)

Fig. 10-7. Mobile batcher measures materials by volume and continuously mixes concrete as the dry ingredients, water, and admixtures are fed into a mixing trough at the rear of the vehicle. (54087)

Mobile Batcher Mixed Concrete (Continuous Mixer)

Mobile volumetric mixers are special trucks (Fig. 10-7) that batch by volume and continuously mix concrete as the dry concrete ingredients, water, and admixtures are continuously fed into a mixing trough, typically an auger system. The concrete must conform to ASTM C 685 (AASHTO M 241) specifications and is proportioned and mixed at the jobsite in the quantities needed. The concrete mixture is also easily adjusted for project placement and weather conditions.

Remixing Concrete

Fresh concrete that is left to agitate in the mixer drum tends to stiffen before initial set develops. Such concrete may be used if upon remixing it becomes sufficiently plastic to be compacted in the forms. ASTM C 94 (AASHTO M 157) allows water to be added to remix the concrete when the truck arrives on the jobsite and the slump is less than specified providing the following conditions are met: (1) maximum allowable water-cement ratio is not exceeded as calculated including surface water on aggregates as well as batch water and water added on site; (2) maximum allowable slump is not exceeded; (3) maximum allowable mixing and agitating time (or drum revolutions) are not exceeded; and (4) concrete is remixed for a minimum of 30 revolutions at mixing speed or until the uniformity of the concrete is within the limits described in ASTM C 94 (AASHTO M 157). Water should not be added to a partial load. If early setting becomes a persistent problem, a retarder may be used to control early hydration, especially in high-cement-content mixes. Mixture adjustments at the jobsite for air entrainment, and the addition of other admixtures, is permitted, followed by sufficient mixing.

Indiscriminate addition of water to make concrete more fluid should not be allowed because this lowers the quality of concrete. The later addition of water and remixing to retemper the mixture can result in marked strength reduction.

TRANSPORTING AND HANDLING CONCRETE

Good advanced planning can help choose the appropriate handling method for an application. Consider the following three occurrences that, should they occur during handling and placing, could seriously affect the quality of the finished work:

Delays. The objective in planning any work schedule is to produce the fastest work with the best labor force and the proper equipment for the work at hand. Machines for transporting and handling concrete are being improved all the time. The greatest productivity will be achieved if the work is planned to get the most out of personnel and equipment and if the equipment is selected to reduce the delay time during concrete placement.

Early Stiffening and Drying Out. Concrete begins to stiffen as soon as the cementitious materials and water are mixed, but the degree of stiffening that occurs in the first 30 minutes is not usually a problem; concrete that is kept agitated generally can be placed and compacted within 1½ hours after mixing unless hot concrete temperatures or high cement contents speed up hydration excessively. Planning should eliminate or minimize any variables that would allow the concrete to stiffen to the extent that full consolidation is not achieved and finishing becomes difficult. Less time is available during conditions that hasten the stiffening process, such as hot and dry weather, use of accelerators, and use of heated concrete.

Segregation. Segregation is the tendency for coarse aggregate to separate from the sand-cement mortar. This results in part of the batch having too little coarse aggregate and the remainder having too much. The former is likely to shrink more and crack and have poor resistance to abrasion. The latter may be too harsh for full consolidation and finishing and is a frequent cause of honeycombing. The method and equipment used to transport and handle the concrete must not result in segregation of the concrete materials.

Methods and Equipment for Transporting and Handling Concrete

Table 10-1 summarizes the most common methods and equipment for moving concrete to the point where it is needed.

Table 10-1. Methods and Equipment for Transporting and Handling Concrete

Equipment	Type and range of work for which equipment is best suited	Advantages	Points to watch for
Belt conveyors	For conveying concrete horizontally or to a higher or lower level. Usually positioned between main discharge point and secondary discharge point.	Belt conveyors have adjustable reach, traveling diverter, and variable speed both forward and reverse. Can place large volumes of concrete quickly when access is limited.	End-discharge arrangements needed to prevent segregation and leave no mortar on return belt. In adverse weather (hot, windy) long reaches of belt need cover.
Belt conveyors mounted on truck mixers	For conveying concrete to a lower, horizontal, or higher level.	Conveying equipment arrives with the concrete. Adjustable reach and variable speed.	End-discharge arrangements needed to prevent segregation and leave no mortar on return belt.
Buckets	Used with cranes, cableways, and helicopters for construction of buildings and dams. Convey concrete directly from central discharge point to formwork or to secondary discharge point.	Enables full versatility of cranes, cableways, and helicopters to be exploited. Clean discharge. Wide range of capacities.	Select bucket capacity to conform to size of the concrete batch and capacity of placing equipment. Discharge should be controllable.
Chutes on truck mixers	For conveying concrete to a lower level, usually below ground level, on all types of concrete construction.	Low cost and easy to maneuver. No power required; gravity does most of the work.	Slopes should range between 1 to 2 and 1 to 3 and chutes must be adequately supported in all positions. End-discharge arrangements (downpipe) needed to prevent segregation.
Cranes and buckets	The right equipment for work above ground level.	Can handle concrete, reinforcing steel, formwork, and sundry items in bridges and concrete-framed buildings.	Has only one hook. Careful scheduling between trades and operations is needed to keep crane busy.
Dropchutes	Used for placing concrete in vertical forms of all kinds. Some chutes are one piece tubes made of flexible rubberized canvas or plastic, others are assembled from articulated metal cylinders (elephant trunks).	Dropchutes direct concrete into formwork and carry it to bottom of forms without segregation. Their use avoids spillage of grout and concrete on reinforcing steel and form sides, which is harmful when off-the-form surfaces are specified. They also will prevent segregation of coarse particles.	Dropchutes should have sufficiently large, splayed-top openings into which concrete can be discharged without spillage. The cross section of dropchute should be chosen to permit inserting into the formwork without interfering with reinforcing steel.
Mobile batcher mixers	Used for intermittent production of concrete at jobsite, or where only small quantities are required.	A combined materials transporter and mobile batching and mixing system for quick, precise proportioning of specified concrete. One-man operation.	Trouble-free operation requires good preventive maintenance program on equipment. Materials must be identical to those in original mix design.

Table 10-1. Methods and Equipment for Transporting and Handling Concrete (Continued)

Equipment	Type and range of work for which equipment is best suited	Advantages	Points to watch for
Nonagitating trucks	Used to transport concrete on short hauls over smooth roadways.	Capital cost of nonagitating equipment is lower than that of truck agitators or mixers.	Concrete slump should be limited. Possibility of segregation. Height is needed for high lift of truck body upon discharge.
Pneumatic guns (shotcrete)	Used where concrete is to be placed in difficult locations and where thin sections and large areas are needed.	Ideal for placing concrete in freeform shapes, for repairing structures, for protective coatings, thin linings, and building walls with one-sided forms.	Quality of work depends on skill of those using equipment. Only experienced nozzlemen should be employed.
Pumps	Used to convey concrete directly from central discharge point at jobsite to formwork or to secondary discharge point.	Pipelines take up little space and can be readily extended. Delivers concrete in continuous stream. Pump can move concrete both vertically and horizontally. Truck-mounted pumps can be delivered when necessary to small or large projects. Tower-crane mounted pump booms provide continuous concrete for tall building construction.	Constant supply of freshly-mixed concrete is needed with average consistency and without any tendency to segregate. Care must be taken in operating pipeline to ensure an even flow and to clean out at conclusion of each operation. Pumping vertically, around bends, and through flexible hose will considerably reduce the maximum pumping distance.
Screw spreaders	Used for spreading concrete over large flat areas, such as in pavements and bridge decks.	With a screw spreader a batch of concrete discharged from a bucket or truck can be quickly spread over a wide area to a uniform depth. The spread concrete has good uniformity of compaction before vibration is used for final compaction.	Screw spreaders are normally used as part of a paving train. They should be used for spreading before vibration is applied.
Tremies	For placing concrete underwater.	Can be used to funnel concrete down through the water into the foundation or other part of the structure being cast.	Precautions are needed to ensure that the tremie discharge end is always buried in fresh concrete, so that a seal is preserved between water and concrete mass. Diameter should be 250 to 300 mm (10 to 12 in.) unless pressure is available. Concrete mixture needs more cement, 390 kg/m^3 (658 lb/yd^3), and greater slump, 150 to 230 mm (6 to 9 in.), because concrete must flow and consolidate without any vibration.
Truck agitators	Used to transport concrete for all uses in pavements, structures, and buildings. Haul distances must allow discharge of concrete within 1½ hours, but limit may be waived under certain circumstances.	Truck agitators usually operate from central mixing plants where quality concrete is produced under controlled conditions. Discharge from agitators is well controlled. There is uniformity and homogeneity of concrete on discharge.	Timing of deliveries should suit job organization. Concrete crew and equipment must be ready onsite to handle concrete.
Truck mixers	Used to transport concrete for uses in pavements, structures, and buildings. Haul distances must allow discharge of concrete within 1½ hours, but limit may be waived under certain circumstances.	No central mixing plant needed, only a batching plant, since concrete is completely mixed in truck mixer. Discharge is same as for truck agitator.	Timing of deliveries should suit job organization. Concrete crew and equipment must be ready onsite to handle concrete. Control of concrete quality is not as good as with central mixing.
Wheelbarrows and buggies	For short flat hauls on all types of onsite concrete construction, especially where accessibility to work area is restricted.	Very versatile and therefore ideal inside and on jobsites where placing conditions are constantly changing.	Slow and labor intensive.

There have been few, if any, major changes in the principles of conveying concrete during the last 75 years. What has changed is the technology that led to development of better machinery to do the work more efficiently. The wheelbarrow and buggy, although still used, have advanced to become the power buggy (Fig. 10-8); the bucket hauled over a pulley wheel has become the bucket and crane (Fig. 10-9); and the horse-drawn wagon is now the ready mixed concrete truck (Figs. 10-10 and 10-11).

Fig. 10-8. Versatile power buggy can move all types of concrete over short distances. (54088)

Fig. 10-9. Concrete is easily lifted to its final location by bucket and crane. (69687)

Fig. 10-10. Ready mixed concrete can often be placed in its final location by direct chute discharge from a truck mixer. (54955)

Fig. 10-11. In comparison to conventional rear-discharge trucks, front-discharge truck mixers provide the driver with more mobility and control for direct discharge into place. (70006)

Years ago concrete was placed in reinforced concrete buildings by means of a tower and long chutes. This was a guyed tower centrally placed on the site with a hopper at the top to which concrete was hauled by winch. A series of chutes suspended from the tower allowed the concrete to flow by gravity directly to the point required. As concrete-framed buildings became taller, the need to hoist reinforcement and formwork as well as concrete to higher levels led to the development of the tower crane—a familiar sight on the building skyline today (Fig. 10-12). It is fast and versatile, but the fact that it has only one hook must be considered when planning a job.

The conveyer belt is old in concept and much changed over the years (Fig. 10-13). Recently, truck-mixer-mounted conveyor belts have come into use (Fig. 10-14). The pneumatic process for shotcreting was patented in 1911 and is

Fig. 10-12. The tower crane and bucket can easily handle concrete for tall-building construction. (69969)

Fig. 10-13. The conveyor belt is an efficient, portable method of handling concrete. A dropchute prevents concrete from segregating as it leaves the belt; a scraper prevents loss of mortar. Conveyor belts can be operated in series and on extendable booms of hydraulic cranes. (69896)

Fig. 10-14. A conveyor belt mounted on a truck mixer places concrete up to about 12 meters (40 feet) without the need for additional handling equipment. (53852)

literally unchanged (see Chapter 18). The first mechanical concrete pump was developed and used in the 1930s and the hydraulic pump was developed in the 1950s. The advanced mobile pump with hydraulic placing boom (Fig. 10-15) is probably the single most important innovation in concrete handling equipment. It is economical to use in placing both large and small quantities of concrete, depending on jobsite conditions. For small to medium size projects, a combination of truck mixer and boom pump can be used to transport and place concrete. The screw spreader (Fig. 10-16) has been very effective in placing and distributing concrete for pavements. Screw spreaders can place a uniform depth of concrete quickly and efficiently.

Fig. 10-15. (top) A truck-mounted pump and boom can conveniently move concrete vertically or horizontally to the desired location. (bottom) View of concrete discharging from flexible hose connected to rigid pipeline leading from the pump. Rigid pipe is used in pump booms and in pipelines to move concrete over relatively long distances. Up to 8 m (25 ft) of flexible hose may be attached to the end of a rigid line to increase placement mobility. (69968, 69966)

Fig. 10-16. The screw spreader quickly spreads concrete over a wide area to a uniform depth. Screw spreaders are used primarily in pavement construction. (69895)

See Panarese (1987) for extensive information on methods to transport and handle concrete.

Choosing the Best Method

The first thing to look at is the type of job, its physical size, the total amount of concrete to be placed, and the time schedule. Studying the job details further will tell how much of the work is below, at, or above ground level. This aids in choosing the concrete handling equipment necessary for placing concrete at the required levels.

Concrete must be moved from the mixer to the point of placement as rapidly as possible without segregation or loss of ingredients. The transporting and handling equipment must have the capacity to move sufficient concrete so that cold joints are eliminated.

Work At and Below Ground Level

The largest volumes of concrete in a typical job usually are either below or at ground level and therefore can be placed by methods different from those employed on the superstructure. Concrete work below ground can vary enormously—from filling large-diameter bored piles or massive mat foundations to the intricate work involved in basement and subbasement walls. A crane can be used to handle formwork, reinforcing steel, and concrete. However, the crane may be fully employed erecting formwork and reinforcing steel in advance of the concrete, and other methods of handling the concrete may have to be used to place the largest volume in the least time.

Possibly the concrete can be chuted directly from the truck mixer to the point needed. Chutes should be metal or metal lined. They must not slope greater than 1 vertical to 2 horizontal or less than 1 vertical to 3 horizontal. Long chutes, over 6 meters (20 ft), or those not meeting slope standards must discharge into a hopper before distribution to point of need.

Alternatively, a concrete pump can move the concrete to its final position (Fig. 10-15). Pumps must be of adequate capacity and capable of moving concrete without segregation. The loss of slump caused by pressure that forces mix water into the aggregates as the mix travels from pump hopper to discharge at the end of the pipeline must be minimal—not greater than 50 mm (2 in). The air content generally should not be reduced by more than 2 percentage points during pumping. Air loss greater than this may be caused by a boom configuration that allows the concrete to fall excessively. In view of this, specifications for both slump and air content should be met at the discharge end of the pump. Pipelines must not be made of aluminum or aluminum alloys to avoid excessive entrainment of air; aluminum reacts with cement alkali hydroxides to form hydrogen gas which can result in serious reduction in concrete strength.

Belt conveyors are very useful for work near ground level. Since placing concrete below ground is frequently a matter of horizontal movement assisted by gravity, lightweight portable conveyors can be used for high output at relatively low cost.

Work Above Ground Level

Conveyor belt, crane and bucket, hoist, pump, or the ultimate sky-hook, the helicopter, can be used for lifting concrete to locations above ground level (Fig. 10-17). The tower crane (Fig. 10-12) and pumping boom (Fig. 10-18) are the right tools for tall buildings. The volume of concrete needed per floor as well as boom placement and length affect the use of a pump; large volumes minimize pipeline movement in relation to output.

The specifications and performance of transporting and handling equipment are being continuously improved. The best results and lowest costs will be realized if the work is planned to get the most out of the equipment and if the equipment is flexibly employed to reduce total job cost. Any method is expensive if it does not get the job done. Panarese (1987) is very helpful in deciding which method to use based on capacity and range information for various methods and equipment.

Fig. 10-17. For work aboveground or at inaccessible sites, a concrete bucket can be lifted by helicopter. (Source: Paschal)

Fig. 10-18. A pump boom mounted on a mast and located near the center of a structure can frequently reach all points of placement. It is especially applicable to tall buildings where tower cranes cannot be tied up with placing concrete. Concrete is supplied to the boom through a pipeline from a ground-level pump. Concrete can be pumped hundreds of meters (feet) vertically with these pumping methods. (49935)

REFERENCES

ACI Committee 304, *Guide for Measuring, Mixing, Transporting, and Placing Concrete,* ACI 304R-00, ACI Committee 304 Report, American Concrete Institute, Farmington Hills, Michigan, 2000.

ACI Committee 304, *Placing Concrete by Pumping Methods,* ACI 304.2R-96, ACI Committee 304 Report, American Concrete Institute, Farmington Hills, Michigan, 1996.

ACI Committee 304, *Placing Concrete with Belt Conveyors,* ACI 304.4R-95, ACI Committee 304 Report, American Concrete Institute, Farmington Hills, Michigan, 1995.

ACI Committee 301, *Specifications for Structural Concrete,* ACI 301-99, ACI Committee 301 Report, American Concrete Institute, Farmington Hills, Michigan, 1999.

Haney, James T., and Meyers, Rodney A., *Ready Mixed Concrete—Plant and Truck Mixer Operations and Quality Control,* NRMCA Publication No. 172, National Ready Mixed Concrete Association, Silver Spring, Maryland, May 1985.

Panarese, William C., *Transporting and Handling Concrete,* IS178, Portland Cement Association, 1987.

PCA, *Concrete for Small Jobs,* IS174, Portland Cement Association, http://www.portcement.org/pdf_files/IS174.pdf, 1988.

PCA, *Structural Lightweight Concrete,* IS032, Portland Cement Association, http://www.portcement.org/pdf_files/IS032.pdf, 1986.

Cost Effective Building Design

Basic Cost Concepts

If you decide to construct building, you will need raw material, labour and incur other incidental expenses to construct. These constitute the cost of construction. You will incur expenses till your products are sold. You need to learn the concept of cost, its elements and types etc. so that you can better learn the accounting of costs.

COST: MEANING AND ITS ELEMENTS

The term 'cost' means the amount of expenses [actual or notional] incurred on or attributable to specified thing or activity. As per Institute of cost and work accounts (ICWA) India, Cost is 'measurement in monetary terms of the amount of resources used for the purpose of production of goods or rendering services.

Cost of production/manufacturing consists of various expenses incurred on production/manufacturing of goods or services. These are the elements of cost which can be divided into three groups : Material, Labour and Expenses.

Material:

To produce or manufacture material is required. For example to manufacture shirts cloth is required and to produce flour wheat is required. All material which becomes an integral part of finished product and which can be conveniently assigned to specific physical unit is termed as "Direct Material". It is also described as raw material. The substance from which the product is made is known as material. It may be in a raw or manufactured state. Material is classified into two categories:

1. Direct Material
2. Indirect Material

Direct material

Direct Material is that material which can be easily identified and related with specific product, job, and process. Timber is a raw material for making furniture, cloth for making garments, sugarcane for making sugar, and Gold/ silver for making jewellery, etc are some examples of direct material.

Indirect material

Indirect Material is that material which cannot be easily and conveniently identified and related with a particular product, job, process, and activity. Consumable stores, oil and waste, printing and stationery etc, are some examples of indirect material. Indirect materials are used in the factory, the office, or the selling and distribution department.

Labour

Labour is the main factor of production. For conversion of raw material into finished goods, human resource is needed, and such human resource is termed as labour. Labour cost is the main element of cost in a product or service. Labour can be classified into two categories:

1. Direct Labour, and
2. Indirect labour

Direct labour

Labour which takes active and direct part in the production of a commodity. Direct labour is that labour which can be easily identified and related with specific product, job, process, and activity. Direct labour cost is easily traceable to specific products. Direct labour costs are specially and conveniently traceable to specific products. Direct labour varies directly with the volume of output. Cost of wages paid to carpenter for making furniture, cost of a tailor in producing readymade garments, cost of washer in dry cleaning unit are some examples of direct labour.

Indirect labour

Indirect labour is that labour which can not be easily identified and related with specific product, job, process, and activity. It includes all labour not directly engaged in converting raw material into finished product. It may or may not vary directly with the volume of output. Labour \ employed for the purpose of carrying out tasks incidental to goods or services provided is indirect labour. Indirect labour is used in the factory, the office, or the selling and distribution department. Wages of store-keepers, time-keepers, salary of works manager, salary of salesmen, etc, are all examples of indirect labour cost.

Expenses

All cost incurred in the production of finished goods other than material cost and labour cost are termed as expenses. Expenses are classified into two categories:

1. Direct expenses, and
2. Indirect

Direct expenses

These are expenses which are directly, easily, and wholly allocated to specific cost center or cost units. All direct cost other than direct material and direct labour are termed as direct expenses.

Direct expenses are also termed as chargeable expenses. Some examples of the direct expenses are hire of special machinery, cost of special designs, moulds or patterns, feed paid to architects, surveyors and other consultants, inward carriage and freight charges on special material, Cost of patents and royalties.

.

Indirect expenses

These expenses cannot be directly, easily, and wholly allocated to specific cost center or cost units. All indirect costs other than indirect material and indirect labour are termed as indirect expenses. Thus, Indirect Expenses = Indirect cost – Indirect material – Indirect labour.

Indirect expenses are treated as part of overheads. Rent, rates and taxes of building, repair, insurance and depreciation on fixed assets, etc, are some examples of indirect expenses.

OVERHEADS: MEANING

The term overhead has a wider meaning than the term indirect expenses. Overheads include the cost of indirect material, indirect labour and indirect expenses. This is the aggregate sum of indirect material, indirect labour and indirect expenses.

Overhead = Indirect material + Indirect labour + Indirect expenses

Overheads are classified into following three categories:

1. Factory/works/ production overheads
2. Office and administrative overheads
3. Selling and distribution overheads

Factory/works overheads

All indirect costs incurred in the factory for production of goods is termed as factory/works overheads. Such costs are concerned with the running of the factory or plant. These include indirect material, indirect labour and indirect expenses incurred in the factory. Some examples are as follows:

Indirect materials:

(i) Grease, oil, lubricants, cotton waste etc.

(ii) Small tools, brushes for sweeping, sundry supplies etc.

(iii) Cost of threads, gum, nails, etc.

(iv) Consumable stores

(v) Factory printing and stationery

Indirect wages

(i) Salary of factory manager, foremen, supervisors, clerks etc.

(ii) Salary of storekeeper

(iii) Salary and fee of factory directors and technical directors

(iv) Contribution to ESI, PF., Leave pay etc. of factory employee.

Indirect expenses

(i) Rent of factory buildings and land

(ii) Insurance of factory building, plant, and machinery

(iii) Municipal taxes of factory building

(iv) Depreciation of factory building, plant and machinery, and their repairs and maintenance charges

(v) Power and fuel used in factory

(vi) Factory telephone expenses.

Office and administrative overheads

These expenses are related to the management and administration of the business. They are incurred for the direction and control of an undertaking. These represent the aggregate of the cost of indirect material, indirect labour, and indirect expenses incurred by the office and administration department of an organisation. Some examples are as follows: Office printing and stationery, Cost of brushes, dusters etc. for cleaning office building and equipments, Postage and stamps. Salary of office manager, clerks, and other employees, Salary of administrative directors, Salaries of legal adviser, Salaries of cost accountants and financial accountants, Salary of computer operator. Rent, insurance, rates and taxes of office building, Office lighting, heating and cleaning, Depreciation and repair of office building, furniture, and Equipment etc., Legal charges, Bank charges, Trade subscriptions, Telephone charges, Audit fee etc.

Selling and distribution overheads

Selling and distribution overheads are incurred for the marketing of a commodity, for securing order for the articles, dispatching goods sold or for making efforts to find and retain customers. These expenses represent the aggregate of indirect material, indirect labour, and indirect expenses incurred by the selling and distribution department of the organisation. These overheads have two aspects

(i) procuring order

(ii) executing theorder.

Based upon this concept the selling and distributions are studied separately.

I. Selling overheads

Indirect costs incurred in relation to the procurement of sale orders are termed as selling overheads. Some of the examples of selling overheads are as follows

Indirect material

(i) Catalogues, price list (ii) Printing and stationery

(iii) Postage and stamps (iv) cost of sample

Indirect wages

(i) Salaries of sales managers, clerks and other employees

(ii) Salaries and commission of salesmen and technical representatives

(iii) Fees of sales directors

Indirect expenses

(i) Advertising

(ii) Bad debts

(iii) Rent and insurance of showroom

(iv) Legal charges incurred for recovery of debts

(v) Travelling and entertainment expenses

(vi) Expenses of sending samples

(vii) Market research expenses.

II. Distribution overheads

Indirect costs incurred in relation to the execution of the sales order is termed as distribution overheads. Some of the examples of distribution overheads are as follows:

Indirect material

(i) Cost of packing material

(ii) oil, grease, spare parts etc. for maintaining delivery vans

Indirect wages

(i) Salaries of godown employees

(ii) Wages of drivers of delivery vans

(iii) Wages of packers and dispatch staff.

Indirect expenses

(1) Packing expenses

(ii) Godown rent, insurance, depreciation, and repair etc.

(iii) Freight carriage outwards and other transport charges.

(iv) Running expenses of delivery vans, repair, and depreciation.

(v) Insurance in transit etc

Costs are classified into following categories:

1. **Cost behavior basis**

(a) Fixed Cost

(b) Variable cost

(c) Semi-variable cost

2. **Cost inventory basis**

(a) Product cost and

(b) Period cost

3. Cost Relation to Cost Centre basis

(a) Direct and

(b) Indirect costs

4. **Cost behavior basis**

(a) Fixed Cost

A cost that remains constant within a given period of time and range of activity in spite of fluctuations in production. Per unit fixed cost varies with the change in the volume of production. If the production increases, fixed cost per unit decreases and as there is decrease in production, the fixed cost per unit increases. Rent and insurance of building, depreciation on plant and machinery, salary of employees etc., are some examples of fixed costs.

Fixed Cost, Total same but per unit goes on changing.

Labour

Labour is the main factor of production. For conversion of raw material into finished goods, human resource is needed, and such human resource is termed as labour. Labour cost is the main element of cost in a product or service. Labour can be classified into two categories:

1. Direct Labour, and
2. Indirect labour

Direct labour

Labour which takes active and direct part in the production of a commodity. Direct labour is that labour which can be easily identified and related with specific product, job, process, and activity. Direct labour cost is easily traceable to specific products. Direct labour costs are specially and conveniently traceable to specific products. Direct labour varies directly with the volume of output. Direct labour is also known as process labour, productive labour, operating labour, direct wages, manufacturing wages, etc. Cost of wages paid to carpenter for making furniture, cost of a tailor in producing readymade garments, cost of washer in dry cleaning unit are some examples of direct labour.

Indirect labour

Indirect labour is that labour which can not be easily identified and related with specific product, job, process, and activity. It includes all labour not directly engaged in converting raw material into finished product. It may or may not vary directly with the volume of output. Labour employed for the purpose of carrying out tasks incidental to goods or services provided is indirect labour. Indirect labour is used in the factory, the office, or the selling and distribution department. Wages of store-keepers, time-keepers, salary of works manager, salary of salesmen, etc, are all examples of indirect labour cost.

(b) Variable cost

Variable costs are those cost which vary directly in proportion to change in volume of production/output. The cost which increases or decreases in the same proportion in which the units produced is termed as variable cost. Direct material, direct labour, direct expenses, variable overheads are some examples of variable cost. Variable costs, per unit same but total goes on fluctuating depending upon volume of production/level of activity. Thus, the variable cost per unit same and doses not change if the total number of output units increases.

(c) Semi-variable cost

A cost contains both fixed and variable component and which is thus partly affected by fluctuations in the level of activity. Semi-variable costs is that cost of which some part remains fixed at the given level of production and other part varies with the change in the volume of production but not in the same proportion of change in production. For example, expenses may not change if output is upto 50% capacity but may increase by 5% for every 20% increase in output over 50% but up to 70%. For example, Telephone expenses of which rent portion

COST-SAVING BUILDING TECHNOLOGIES IN PLANNING, DESIGNING AND CONSTRUCTION TECHNIQUES

The cost-saving construction methods presented in this model are technically oriented, and focus on the design and construction of particular features in and around the home. They can be generally classified into basic suggestions that:

- Substitute materials that are less expensive to purchase and/or install than more common alternatives. Examples include use of less expensive sheathing products, plastic plumbing products instead of copper, and corrugated stainless steel gas pipe instead of black iron pipe;
- Involve more innovative alternative products that simplify overall construction, such as mechanical plumbing vents in lieu of through foundation systems instead of deep footings in cold climates;
- Save money by eliminating overdesigned or unnecessary features, including 24-inch stud spacing rather than 16-inch, 2 x 3 studs instead of 2 x 4s in nonbearing walls, and reduced plumbing vent pipe sizes; and

- Focus on residential land planning and land development, such as increased density, clustered development reduced street widths, and elimination or simplification of technically questionable development requirements.

FOUNDATIONS

Foundations typically consist of a concrete block or poured concrete wall placed on top of a concrete spread footing that rests on the soil. They are designed to support all building loads safely, and are located at a depth that is sufficient to prevent frost heave. New methods and materials that achieve these design objectives have been gaining popularity as cost-saving alternatives to the more traditional approaches. Methods and materials that offer potential savings are discussed below.

1. Arch foundation: Already explained
2. Monolithic Slab-on-Grade Foundation

The number of steps involved in foundation construction can be reduced by using a monolithic slab-on-grade foundation design. A monolithic slab-on-grade installation consolidates the operation of casting a separate footing and pouring a floor slab. These both reduce labor, and also cuts the time required to build a typical slab on – grade foundations by 1 or 2 days.

WALLS:

1. Rat trap bonded brick masonry
2. Cement stabilized mud block masonry
3. Interlocking cement stabilized mud block masonry
4. Stone concrete block
5. Combined wire cut and country brick masonry

OPENIGNS:

1. Precast reinforced cement concrete lintel
2. Brick and reinforced cement concrete lintel
3. Brick arch

ROOFS:

1. Precast reinforced cement concrete channels
2. Precast reinforced cement concrete planks & joists
3. Precast Ferro-cement channels
4. Folded filler slab with Mangalore tiles
5. Jack arch with bricks and precast reinforced cement concrete joist
6. Stone roofing on precast reinforced cement concrete joist
7. Micro concrete tiles on steel under structure.
8. Reinforced cement concrete ribbed brick slab
9. Corbelled brick pyramid.
10. Corbelled brick arch roof.

DOORS AND WINDOWS:

1. Brick jails
2. Ferro cement door frames
3. Fibre doors
4. Plastic doors

FRAMING

Framing offers some of the best opportunities to reduce costs during rehabilitation and new construction. Considerable effort has been directed at value-engineering residential framing. Examples of some of the most widely used cost-saving methods are discussed below.

Use of Optimum Value-Engineered(OVE) Framing

With in-line framing, all floor, wall, and roof framing is spaced identically so the respective structural members bear the load directly over each other. Thus, loads from the roof and walls are transferred directly through the lower members to the foundation. The result is a more efficient structure and a reduction in or Elimination of some of the framing members used to distribute the load. In high wind or seismic areas, be sure to check with local code officials to determine whether this technique is appropriate before deviating from approved framing practices.

Increased Spacing of Framing Members

Conventional framing typically uses members spaced I6 inches on center. It is widely recognized, however, that 24-inch on-center stud, joist, and truss spacings are acceptable for structural purposes. Perhaps the most broadly applicable of these measures is 24-inch spacing of 2 x 4 partition wall studs. Increased spacing both saves framing lumber, and improves energy efficiency because it increases the proportion of overall wall area that can contain cavity insulation.

Eliminate Unnecessary Framing

Over the years, residential framing methods have evolved based largely on tradition. As a result, unneeded framing members have found their way into conventional practice.

Electrical

Electrical installation is typically governed by provisions of the national electrical codes or similar codes. Even within these stringent codes, however, there are ways to reduce costs using low-cost products that are meet the intent of the codes.

Surface mount electrical conduit and behind –baseboard installation:

Traditional methods for installing electrical wiring inside walls work well with new construction, but this approach is much more difficult and costly in rehabilitation work. Surface –mount electrical conduit and behind installations are two alternative approaches. surface mount conduit is fairly well known, but behind –baseboard raceways systems, are likely to be more acceptable to occupants. An example of this type of system is plastic base board that has a hallow space to fish electric wiring through. Sometimes have multiple raceways built into the baseboard so that a number of cables can be routed through the system.

Savings from Surface-Mount Conduits and Baseboard Raceways

Installing surface-mount electrical conduits or baseboard raceways can save from 25 to 40 percent on electrical costs when compared with traditional methods of running electric wire. Surface mounting leaves sound walls undisturbed and avoids problems with concrete floors.

Plastic electric boxes:

In many areas, metal electric boxes are the norm for light switches, wall outlets, and other applications. The plastic electric box, however, is a low cost alternative that is widely available and relatively simple to install. Plastic electric boxes are generally accepted under national electric codes.

Saving from Plastic Electric Boxes

Typically, elastic electrical boxes are at least 10 percent less expensive and 20 percent more efficient than traditional metal boxes.

The introduction of mechanical vents has eliminated this need, instead allowing the vent to terminate just above the fixture. These devices are useful in situations where it is difficult to install vents for fixtures-they can eliminate the need to open additional walls and floors in a rehabilitation project. Mechanical vents are accepted in most major plumbing codes and are available through the-wall vents.") Before installing a sidewall vent,allow sewer gas to reenter the building.

Plumbing:

For years, plumbers have followed numerous rules of thumb which, although based on years of practical experience, do not apply to many of today's plumbing materials. Research that supports the newer cost effective approaches has begun to find its way into the codes.

Mechanical plumbing:

Traditionally, plumbing vents are installed for each fixture and extend up through the roof. The introduction of mechanical vents has eliminated this need, instead allowing the vent to terminate just above the fixture. These devices are useful in situations where it is difficult to install vents for fixtures-they can eliminate the need to open additional walls and floors in a rehabilitation project. Mechanical vents are accepted in most major plumbing codes and are available through plumbing supply and building supply store.

Direct venting of drain waste-vent pipes:

Like mechanical plumbing vents, dirct venting is useful when it is difficult or costly to install a traditional "through-the- roof" plumbing vent. Direct vents are plumbing vents that terminate through a wall directly to the exterior.

Stack or wet venting of drain-waste vent pipe:

Stack and wet venting of DWV pipe amount of total pipe in the plumbing system by reducing the requirement for a separate vent for each fixture. For example, where plumbing fixtures on one floor are located above or below fixtures on another floor, both may be vented through the same pipe

Pipe materials:

In most major model codes, acceptable water service pipes materials include polyvinyl chloride and other plastics that are often less costly than copper pipe. For example, polybutylene plastic pipe, a flexible pipe that requires fewer fittings than rigid pipes easier to install and thus less costly than rigid pipes.PVC and polyethylene water service pipes should only be used for cold water distribution.

Savings from Use of Alternate Pipe Materials

Polybutylene supply pipe was used instead of copper. As a result, plumbing costs were reduced by Rs 65 per unit. Field studies have shown 30 to 50 percent savings when flexible polybutylene supply piping is substituted for rigid pipe materials.

Finishes and trim:

The finish stages of construction offer additional opportunities for cost savings in both new construction and rehabilitation projects.

Gypsum Laminate (Cover)

When traditional methods are used in repair badly cracked plaster during rehabilitation, complete new plaster sections. This is a time-consuming, costly procedure. In many cases, an alternative approach is to install gypsum board over the existing wall, which eliminates the need to work with plaster.

Open kitchen and bathroom shelves:

Open shelves in the bathroom and kitchens, instead of typical cabinets and vanities, provide needed storage space at lower costs. Moreover, some homeowners can also install these types of shelves themselves, which would eliminate labor costs altogether. Cabinets can be installed latter as homeowner resources allow.

Eliminate Partitions:

It may not be necessary to replace non load bearing partition removed during rehabilitation, especially with recent emphasis on open interiors.

Water services:

Insulating utilities, both main lines and service laterals, offers significant opportunities to reduce new construction costs.

Common lateral water pipes

Many communications require that each property have its own water services, but a common or shared water service pipes, sized to handle the required water flow, can serve several homes, saving labor and material cost.

Common Trench for Water and Sewer Pipes

Traditionally water and sewer pipes have been placed in separate trenches as a precaution against sewer pipe leakage that could contaminate drinking water. Today, most major codes allows for installation of both pipes in a single trench. Provided that the water pipes are at least 12inches above the sewer pipe line with a minimum horizontal separation of 18 inches.

SEWAGE DISPOSAL

Cost-saving technologies can be used for both publicly sewered property and for homes served by individual on-site waste treatment and disposal systems. Although the latest sewage disposal technologies are mainly intended for new construction, several also have rehabilitation potential, particularly on-site disposal methods. New sewage technologies can often be applied to older buildings that have failing septic systems. In fact, these methods may be the only economically sound way to rehabilitate the property.

Common Lateral Sewer Pipes

Many communities require that every home have a separate lateral sewer pipe that connects to the main sewer pipe. A common or shared lateral sewer pipe , sized to handle required flow, can be used to serve several homes.

Common Trench for Water and Sewer Pipes Sand Mound Septic System

In areas where the groundwater table is elevated, where there is a shallow barrier below the soil, or where soils are slowly permeable, a conventional septic system is not suitable for wastewater disposal. Many jurisdictions do not permit new systems in these sites, which effectively reduces the land available for housing. When older, existing systems in areas with poor soil conditions fail they must be replaced with properly operating systems.

One solution in these areas is to install a sand mound or mound system. A mound system is a drainfield that is installed in a mound above the natural lot elevation on a suitable fill, usually a medium textured sand. Sand mound system design criteria are available from a variety of sources, including the U.S. Environmental Protection

Sand Mound Septic System

In areas where the groundwater table is elevated, where there is a shallow barrier below the soil, or where soils are slowly permeable, a conventional septic system is not suitable for wastewater disposal. Many jurisdictions do not permit new systems in these sites, which effectively reduces the land available for housing. When older, existing systems in areas with poor soil conditions fail they must be replaced with properly operating systems.

One solution in these areas is to install a sand mound or mound system. A mound system is a drainfield that is installed in a mound above the natural lot elevation on a suitable fill, usually a medium textured sand. Sand mound system design criteria are available from a variety of sources, including the U.S. Environmental Protection

Recirculating Sand Filter Septic Systems

In many unsewered areas, conventional septic systems are unacceptable because of slowly permeable soils. Land on these soils is, therefore, deemed” nonbuildable.” Furthermore, many rehabilitation projects are severely limited in tions on the amount of living space; i.e., system expansion is not permitted because the sewerage from a larger home might exceed the capacity of a system that is already failing. Recirculating sandfilter systems can be used in areas with slowly permeable soil, and also provide higher quality effluent. Although a recirculating sand filter contains many of the features of a conventional septic system, it also has a sand filter installed between the septic tank and the drainfield. Wastewater is sprayapplied to the filter and then recirculated several times back to the septic tank, or to a separate Wastewater effluent from a sand filter system is of higher quality than septic tank effluent. The higher quality increases the ”acceptance rate” of the soil by a factor as high as 7 to 8. This translates into a smaller drainfield, and means that smaller lots can be served by a sand filter system than by a conventional septic system. Although they have been shown to work effectively, circulating sand filters are not yet widely recognized. Thus, local health officials should be Wastewater effluent from a sand filter system is of higher quality than septic tank effluent. The higher quality increases the ”acceptance rate” of the soil by a factor as high as 7 to 8. This translates into a smaller drainfield, and means that smaller lots can be served by a sand filter system than by a conventional septic system. Although they have been shown to work effectively, circulating sand filters are not yet widely

recognized. Thus, local health officials should be consulted before using this type of system. Design guidelines for sand filter systems have been produced by the U.S. Environmental Protection

LAND PLANNING AND DENSITY

The rising cost of developing residential lots is the single most important reason for the increased price of homes. Zoning requirements, land development standards, environmental policies, and infrastructure regulations—mostly under local control—all contribute to the high costs of lots.

Local zoning ordinances largely determine the amount of land available for residential development. Areas that are zoned for residential use are assigned maximum housing densities—the maximum number of dwelling units permitted per holding tank. acre. Obviously, the more homes allowed on each acre of land, the lower the per-lot cost, and the that requires low density, excessive house frontage lower the house sales price. Restrictive zoning and deep setbacks, large lots, and an abundance of open space leaves less land for homes. Inadequate supply of land to meet the demand increases the price of homes.

Many zoning ordinances restrict or prohibit higher density and the resulting smaller lots. But communities that have increased density limits and thus reduced the minimum lot size have demonstrated that smaller lot, higher density developments can be attractive, desirable, and affordable. Land development costs-for streets, storm water control, utilities, and so forth-are also lower for smaller lots. It is difficult to change zoning ordinances, however, certain exceptions to density restrictions sometimes exist for affordable housing.

Small lot district:

Small lots are often allowed within areas already controlled by planned unit development (PUD),

planned residential development (PRD), community unit plan (CUP), and comprehensive residential development (CRD) ordinances. PUDs, etc., typically allow for reducing lot size without increasing the overall density within the development. The number of homes in the development is averaged across the entire development tract instead of measured on a per-lot basis, as in traditional zoning. The smaller than normal lots are typically "clustered" around a common area-a court, cul-desac, parking, or an amenity-and the remaining area is left undeveloped. Smaller, clustered lots have lower overall site development costs, benefit from open space within the development, and, when designed under a PUD-type ordinance, maintain the zoned density. PUDs usually incorporate a variety of single-family and multifamily housing types. Setbacks, frontages, floor/ area ratio, space between units, and other site requirements are usually flexible. Land development standards are typically less stringent and performance based in these developments.

Setback Requirements

Reduction of the generally arbitrarily determined minimum front yard, side yard, and rear yard setbacks as well as space between units, can save land costs as well as utility and infrastructure costs. Large setbacks from all boundaries place the house near the center of the lot and reduce its usability. Using the "zero-lot-line" technique, homes can be located on one or more lot-lines, creating a single, usable yard area rather than two narrow unusable sideyards. To ease privacy concerns, walls that are located on the lot lines may be required to be windowless, with a small easement granted for maintenance. (Figure 17) 20-Cost-Saving Construction Opportunities and the HOME Program the greater the number of homes to share land ment costs per home are less for 100 homes built on a 10-acre tract than for 40 homes on the same tract. Smaller lots also reduce the linear footage of curbs, gutters, and utilities required for each house.

Site development:

Two costs are associated with developing a site for housing- the cost of purchasing raw or under developed land and cost of improving or developing that land. Not only have the cost of raw lots increased, but so also have land development costs, largly as a result of excessive local requirements , i.e, wide streets and rights –of- way, and overdesigned water and utility supply system.

Housing density also effects land development costs-the higher the number of homes per acre, the greater the number of homes to share land development costs. For example, land development costs per homeare less for 100 homes built on a 10-acre tract than 40 home on the same tract. Smaller lots also reduce the linear footage of curbs, gutters, and utilities required for each house.

COST CONTROL IN BUILDING DESIGN AND CONSTRUCTION

A development budget study is undertaken to determine the total costs and returns expected from the project. A cost plan is prepared to include all construction costs, all other items of project cost including professional fees and contingency. All costs included in the cost plan will also be included in the development budget in addition to the developer’s returns and other extraneous items such as project insurance, surveys and agent’s or other specialist advisers’ fees.

The purpose of the cost plan is to allocate the budget to the main elements of the project to provide a basis for cost control. The terms budget and cost plan are often regarded as synonymous. However, the difference is that the budget is the limit of expenditure defined for the project, whereas the cost plan is the definition of what the money will be spent on and when. The cost plan should, therefore, include the best possible estimate of the cash flow for the project and should also set targets for future running costs. The cost plan should cover all stages of the project and will be the essential reference against which the project costs are managed.

The method used to determine the budget will vary at different stages of the project, although the degree of certainty should increase as project elements become better defined. The budget should be based on the client’s business case and should change only if the business case changes. The aim of cost control is to produce the best possible building within the budget

The cost plan provides the basis for a cash flow plan, allocating expenditure and income to each period of the client’s financial year. The expenditures should be given at a stated base-date level and at out-turn levels based upon a stated forecast of inflation.

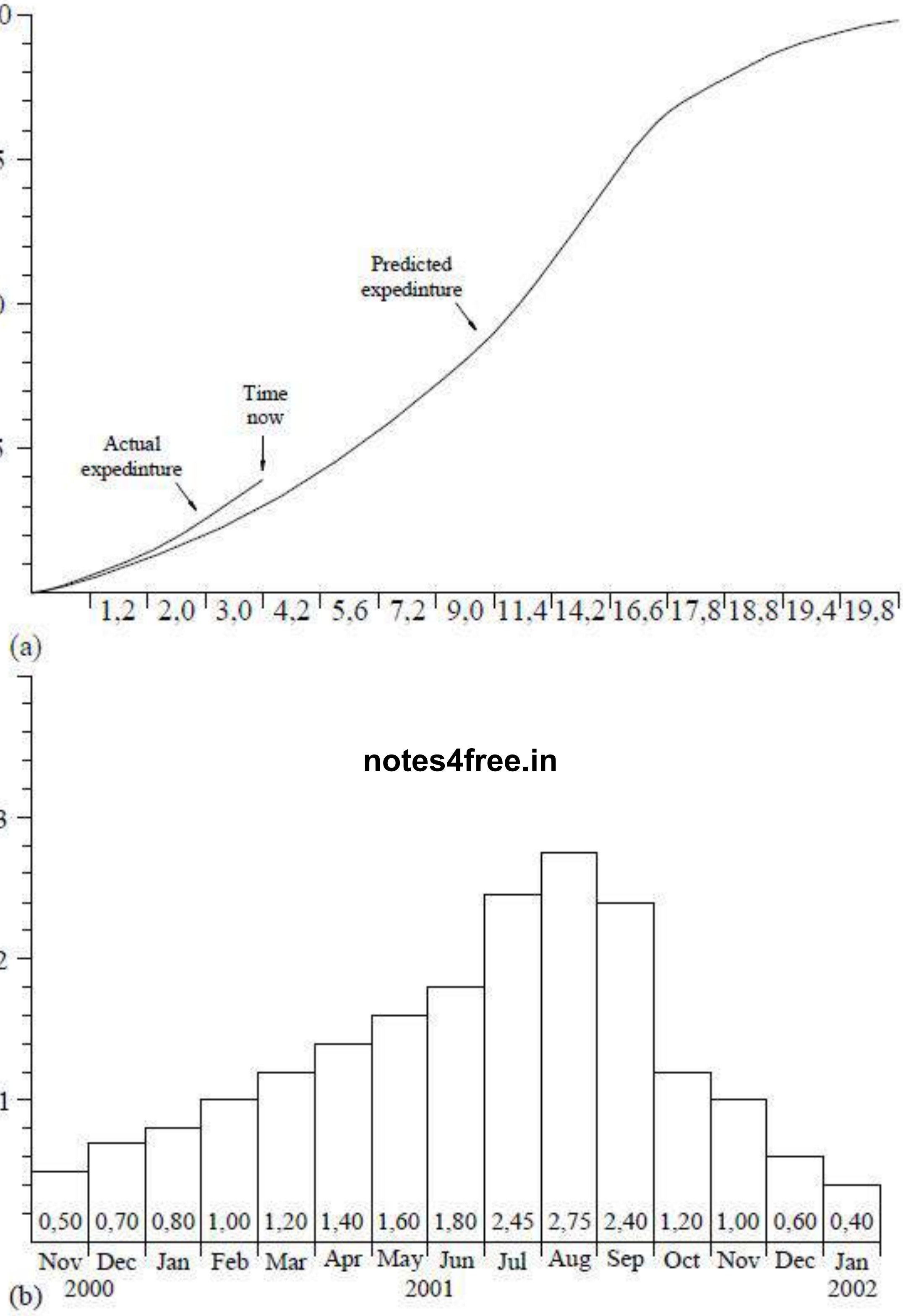


Figure: Examples of a construction expenditure graph and cash flow histogram.

The objective of cost control is to manage the delivery of the project within the approved budget. Regular cost reporting will facilitate, at all times, the best possible estimate of:

- Established project cost to date.
- Anticipated final cost of the project.
- Future cash flow.

In addition cost reporting may include assessments of:

- Ongoing risks to costs.
- Costs in the use of the completed facility.
- Potential savings.

Monitoring expenditure to any particular date does not exert any control over future expenditure and, therefore, the final cost of the project. Effective cost control is achieved when the whole of the project team adopts the correct attitude to cost.

Effective cost control will require the following actions to be taken:

- Establishing that all decisions taken during design and construction are based on a forecast of the cost implications of the alternatives being considered, and that no decisions are taken whose cost implications would cause the total budget to be exceeded.
- Encouraging the project team to design within the cost plan at all stages and follow the variation/change and design development control procedures for the project. It is generally acknowledged that 80% of cost is determined by design and 20% by construction. It is important that the project team is aware that no member of the team has the authority to increase costs on its section or element of the work. Increased costs on one item must always be balanced by savings on another.
- Regularly updating and reissuing the cost plan and variation orders causing any alterations to the brief.
- Adjusting the cash flow plan to reflect alterations in the target cost, the master schedule or the forecast of inflation.
- Developing the cost plan in liaison with the project team as design and construction progress. At all times it should comprise the best possible estimate of the final cost of

the project and of the future cash flow. Adherence to design freezes will aid cost control. Developing the cost pan also involves adding detail as more information about the work is assembled, replacing cost forecasts with more accurate forecasts or actual costs whenever better information can be obtained.

- Reviewing contingency and risk allowances at intervals and reporting the assessments is an essential part of risk management procedures. Developing the cost plan should not involve increasing the total cost.
- Checking that the agreed change management process is strictly followed at all stages of the project. The procedure should only be carried out retrospectively, and then only during the construction phase of the project, when it can be demonstrated that otherwise significant delay, cost or danger would have been incurred by awaiting responses.
- Arranging for the contractor to be given the correct information at the correct time in order to minimise claims. Any anticipated or expected claims should be reported to the client and included in the regular cost reports.
- Contingency provisions are based on a thorough evaluation of the risks and are available to pay for events which are unforeseen and unforeseeable. It should not be used to cover; changes in the specification, changes in the client's requirements or variations resulting from errors or omissions. Should the consultants consider that there is no alternative but to exceed the budget, a written request must be submitted to the client and the correct authorisation received. This must include the following:

1. Details of variations leading to the request.
2. Confirmation that the variations are essential.
3. Confirmation that compensating savings are not possible without having an unacceptable effect on the quality or function of the completed project.

- Submitting regular, up-to-date and accurate cost reports to keep the client well informed of the current budgetary and cost situation.
- Ensuring that all parties are clear about the meaning of each entry in the cost report. No data should be incorrectly entered into the budget report or any incorrect deductions made from it.
- Ensuring that the project costs are always reported back against the original approved budget. Any subsequent variations to the budget must be clearly indicated in the cost reports.

- Plotting actual expenditure against predicted to give an indication of the project's progress.

With construction costs, savings are in the details

- Design & Construction

Effective cost management requires preconstruction planning that clearly communicates and analyzes the costs of individual project components and systems. The cost-management process uses estimating, benchmarking and value engineering not as discrete tools, but as preconstruction planning services.

Benchmarking is used both for developing estimates and for verifying that the costs of each component and system fall within the proper range for projects of that type. Value engineering looks at a project's performance goals and analyzes the most cost-effective ways to meet them. The experienced construction manager maintains a database for projects of similar scope and building type from which to draw, analyze and compare costs.

Communications Tool

Clearly, the key to effective cost management is information — estimating, benchmarking and value engineering analyses that are carefully compiled and presented. In the right hands, such data can go a long way toward ensuring a project that is designed within budget objectives, meets agreed-to performance and quality goals and provides information that shortens the project schedule.

To ease decision making, project budgets should be configured so that each component and building or process system is isolated and presented. This allows system component costs to be compared to those of similar projects for the development of a benchmark analysis. This approach varies from the structure generally used, in which cost information is presented for the entire project according to a Construction Specifications Institute format. That format identifies the total cost of concrete, masonry, carpentry, plumbing, electrical and other specification categories.

The standard estimating technique often does not take into account the kinds of information needed to make cost-effective decisions. Consider a planned corporate headquarters comprising a dining facility, conference center, fitness center and office buildings. The typical approach would be to estimate the total cost of each CSI specification category.

A more effective means of communicating costs is first to dissect the components. Analyze the costs of the dining facility, conference center, fitness center and office buildings individually and compare them with those of similar corporate projects. Doing so would allow the facility executive to identify whether certain elements of the project, such as the fitness center, need to be scaled down or eliminated based on their cost relative to the whole project. Alternatively, it might allow the facility executive to be convinced that some elements represent a cost-effective investment.

Explanatory Tools

Next, the estimating and benchmarking process should examine not the total cost of concrete, for example, but rather the individual costs of the foundation system versus the structural system. By separating these, it is possible to attribute the cost of the foundation when benchmarked against those of similar projects. Hypothetically, a higher cost might be caused by the configuration of the site. If the project is being built into a hill, for example, foundations will cost more than those of similar projects.

As the project design progresses, benchmarked estimates provide increasing levels of detail. At every step, the process develops details needed to understand whether each component's estimated cost fits within a benchmarked range and if not, why not. The process also enables the project team to examine whether there are more cost-effective ways to meet performance goals.

Isolating and benchmarking costs identifies areas where the greatest cost savings exist without sacrificing scope, quality or architectural appeal.

An effective approach to value engineering asks how buildings can be designed to cost-effectively meet design and functional goals. To take this approach, look first at how individual components and systems meet the building's performance goals, then at the design standards and sizes of systems and components, and finally at the details and materials.

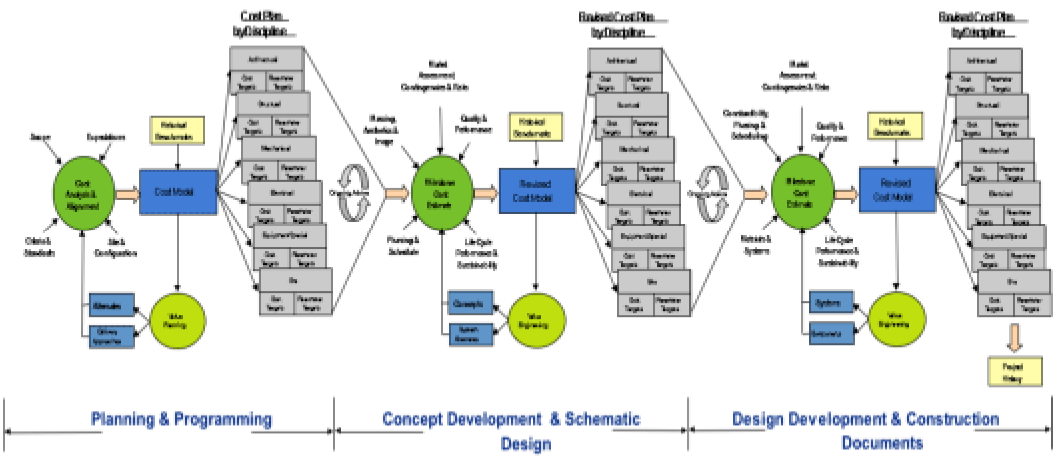
Utilize Cost Management

Throughout a project's planning, design, and construction phases, Cost Management is employed as a means of balancing a project's scope and expectations of quality and budget.

The approach can be summarized as requiring the following three steps:

1. Define the scope, the level of quality desired, and the budget
2. Ensure that the scope, quality, and budget are aligned
3. Monitor and manage the balance of these three components throughout the life of the project

This process involved is represented graphically as follows:



Milestone cost estimates at various stages of the process are critical components of the cost management activity. Cost Management encompasses more than cost estimates however—it also includes Risk Management and in the federal arena, can include Earned Value Analysis. Risk Assessment and Management are important as identified risks on construction projects are typically financial in nature. Therefore early in the project an assessment of risk is crucial to establish the budget parameters within which the project must be completed. The calculation of project contingencies should be based on an assessment of the risk surrounding the project (site issues, availability of bidders, method of procurement, and critically the market conditions in the location of the project. As risks are mitigated (site investigation is done, market survey completed, program finalized, design started, and so forth) then contingencies can be reduced and the range of estimated final cost narrowed.

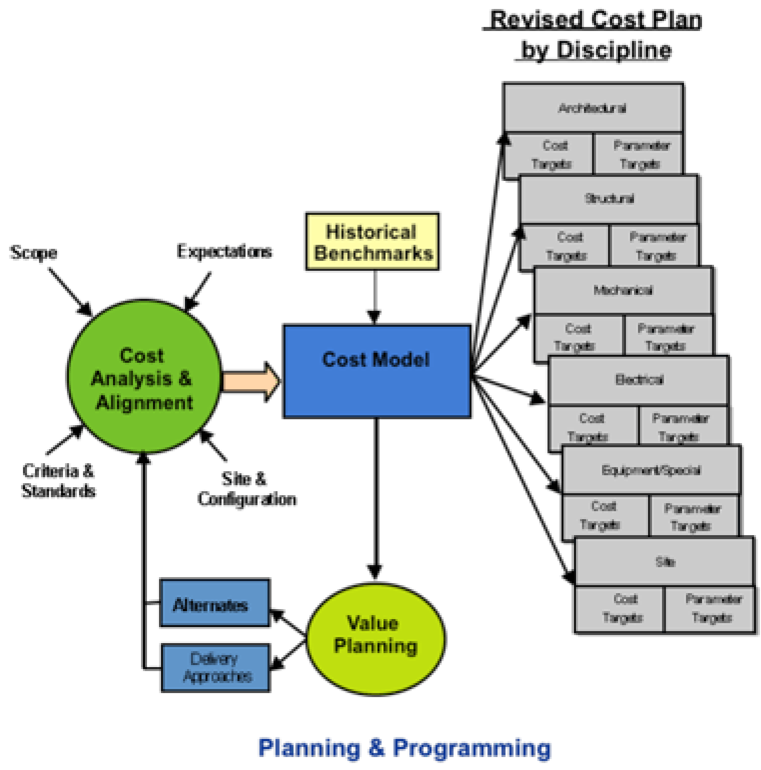
The firm charged with managing the costs of the project should ideally be hired directly by the owner, early in the process, and should be independent of both the architect/engineer and the construction contractor.

Planning Phase

Cost Management differs from Building Economics in that it is typically concerned with the initial costs—or first costs—of accomplishing new construction or renovation projects. A project must start right in order for it to finish right, so the establishment of an appropriate budget is critical. Early in the planning stages, both building owners and designers must agree on an anticipated cost of the project at bid award. This is a critical stage in the cost management

process—an inaccurate budget can doom a project to continual stress and compromise, with neither the owner, end-user, nor design team being completely satisfied at the end. A common mistake at this stage is to take a program of areas and apply those to historical costs without making adjustments for the myriad factors which affect construction costs—size of the project, renovation versus new, location (has a market survey been done?), price increases since the date of the data used, method of procurement, overall quality of the space envisioned, LEED rating desired if any, access and locational factors such as dense urban, traffic and sidewalk protection, water location, bid competitiveness in the local market, etc.

Preliminary Estimates are employed in the early planning phases of a proposed project to match an owner's needs, expressed as written programmatic requirements, with budget constraints in order to establish its overall scope (size) and quality expectations.



The proposed method of procurement, or delivery approach in the above graphic, should be identified at this stage. The options available today are more numerous than in the past—traditional Lump Sum, Construction Manager as Constructor (CMC) (also known as CM at Risk), Design/Build, Integrated Project Delivery (IPD) and so forth. Each method has pros and cons relative to cost and risk, so the method selected should also be factored in to the project budget. These can generally be summarized as follows:

Traditional Design-Bid-Build		
Issues	Advantages	Disadvantages
Cost and Budget Management	• "Best price" potential • Perception of "best price"	• Cost not finalized until bids • Cost overruns after bid require expensive redesign • Bidders may seek to "get low" by omitting owrk not clearly shown
Schedule Impact and Management	• Delivery schedule stipulated in contract	• Construction difficult to start before design is finished • Extended/compressed schedules may add cost & not be evident

		• Schedule changes after award difficult to implement
Construction Manager at Risk		
Issues	Advantages	Disadvantages
Cost and Budget Management	• Cost "guarantee" prior to design completion • Improved perception of control • Cost saving incentives are feasible	• After GMP, costs may increase due to detailing not correctly reflected in the GMP • CM may "expand" budget to create opportunity for future "savings"
Schedule Impact and Management	• Construction can start before design is complete • Cost impact of extended/compressed schedule can be addressed proior to GMP	• Schedule changes during construction difficult to implement
Design-Build		
Issues	Advantages	Disadvantages
Cost and Budget Management	• Early cost guarantee • Price tends to match quality • Can obtain best price for performance	• Fair price competition difficult to verify • Cost impact of risk issues may not be evident in initial pricing • Owner over-emphasis on price as a selection criteria may force the design-builder to compromise quality to reduce price
Schedule Impact and Management	• Construction can start after very preliminary design • Generally considered as most beneficial schedule approach	• Schedule changes at any point after pricing difficult to implement • Use of "bridging" type approach may expand schedule

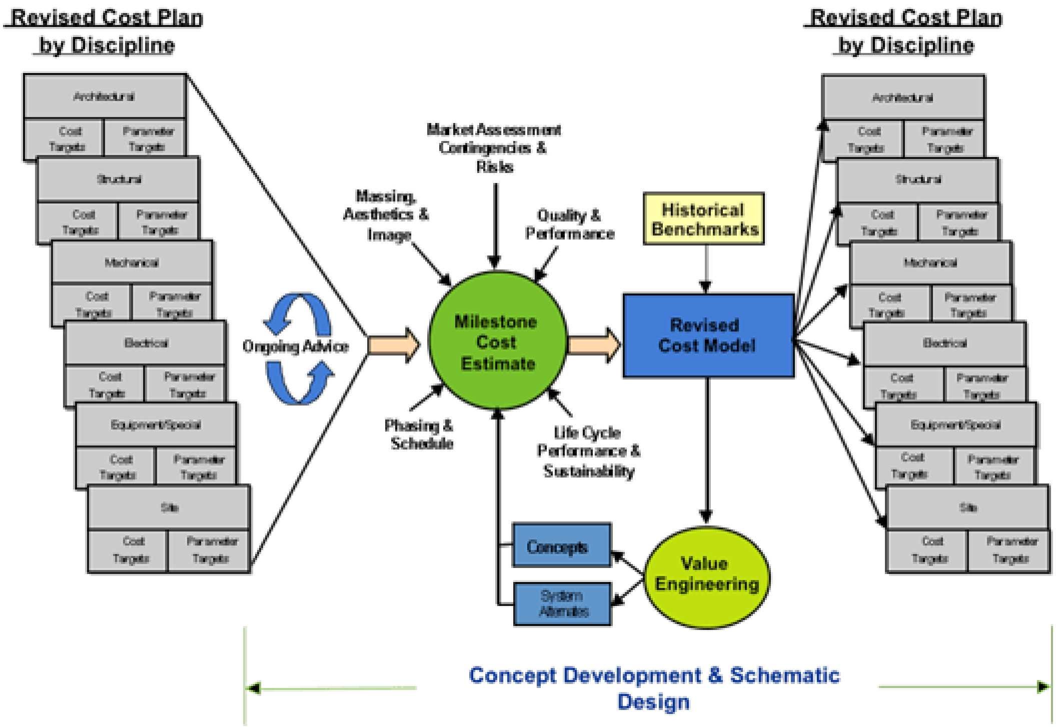
Integrated Project Delivery as a procurement method is gaining some traction in the industry, although it still only is used on 1–2% of projects and legal difficulties around liability remain a hurdle for broader acceptance. From a cost management perspective the benefits remain elusive as the various parties on the team generally have differing objectives, although doubtless the coordination of the trades and cohesiveness of the design may impart some time savings and reduced change orders during construction. The use of Building Information Modeling (BIM) is likewise a growing trend and from an owner's perspective a very useful tool, with similar benefits to IPD but few documented advantages related to cost management. While the technology is improving, the quality of estimates produced from BIM models is still fairly uneven. Quantity take-offs are becoming more accurate (although still highly dependent on the accuracy of the data entered into the model) but the pricing aspects and the capture of components not yet in the model still require considerable scrutiny by the cost estimator.

Value Engineering should also be considered at this stage. Any changes to the program at this early phase have very little, if any, impact on schedule and A/E time and redesign costs, but the benefits in terms of solidifying the program and establishing project goals can be huge.

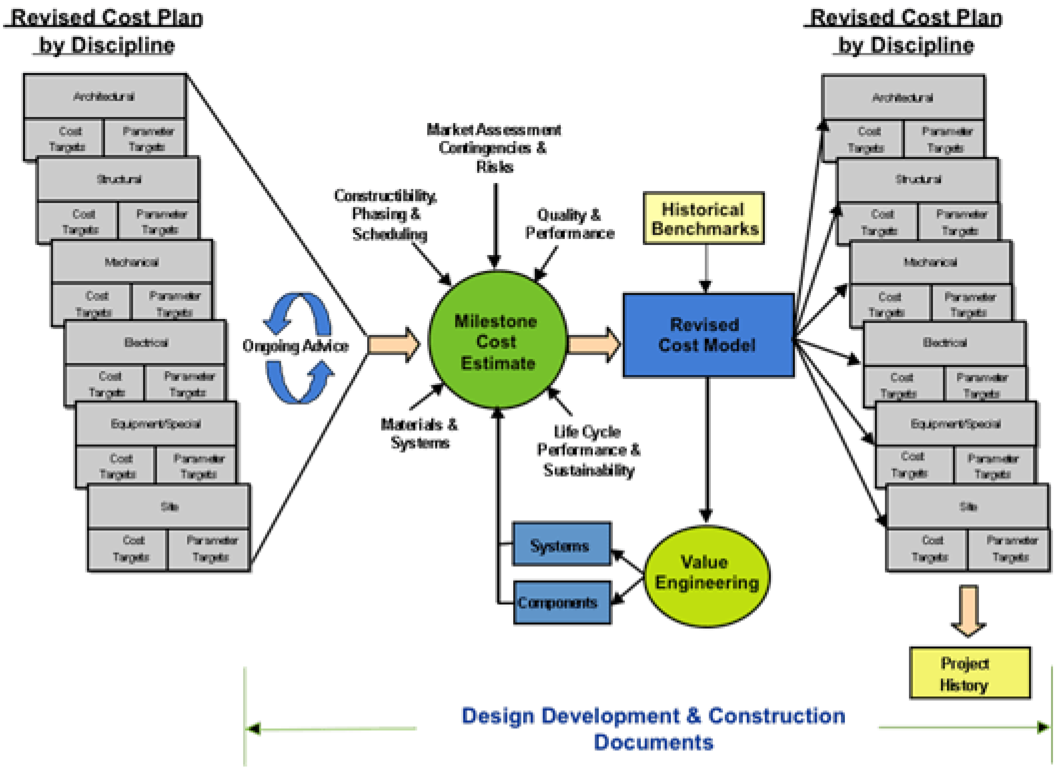
Design Phase

Chesapeake Bay Foundation Philip Merrill Environmental Center—Annapolis, MD

Once an initial budget has been established, the scope set and the quality expectations documented, it is important to monitor the estimated cost of the project by employing a series of increasingly precise cost estimating techniques that coincide with further development of design and construction details.



Intermediate estimates are employed at various stages of project design development as part of ongoing cost management, and as a means of evaluating competing alternative construction assemblies, systems, and materials. On large projects it is common practice for an owner to employ a construction manager or professional estimator to continually update project estimates and provide feedback on budget impacts of decisions on major design elements. The drawings and specifications should also go through a constructability review, wherein an independent review team analyzes the construction documents for completeness, coordination between disciplines, cost-effective design solutions, and general code compliance (as mentioned earlier this is where BIM and IPD bring significant benefits). The specifications should also be reviewed to ensure that the General Requirements included in division 1 are not overly restrictive (e.g. working hours, noise restrictions and so forth) and that throughout the specifications the use of proprietary materials is minimized. A market survey should have been carried out on sizable projects to determine where the bidders will come from—is the local market sufficiently large to accommodate the project, or will the major subcontractors be at capacity and therefore likely to bid high, if at all? It's often worth re-verifying the market survey if one was done much earlier in the process.



The estimates become much more refined in parallel with the refinement of the design, ultimately resulting in a pre-bid estimate that captures the entirety of the project.

Earned Value Analysis is a useful tool in cost management, in that costs for each component of the project (in a Work Breakdown Structure, or WBS) can be tracked against the initial budget, and adjustments made to ensure the overall budget is on track. Movements between components are common; however, without tracking where costs are changing, the budget is in danger of being exceeded leading to re-design or extensive value engineering. Similarly future cost planning can be improved by the use of Earned Value Analysis, by tracking where the money really goes in a project.

Procurement Phase

At the bid stage, the drawings should be 100% complete; however, in many instances this does not happen, leading to addenda being issued to clarify details, resolve conflicts or to complete the design. Often the estimate is not adjusted to account for these design changes, leading to a so-called final estimate that really does not represent the scope of work being bid. The estimate should therefore be adjusted during bidding to reflect the same information the bidders receive. Also a read of the market at bid stage is still useful, and can be included in a risk assessment to determine a range of bids expected. In a particularly volatile market, the use of bid options may allow the owner some flexibility in achieving the budget on bid day.

The preparation of the bidding documents is also crucial in an overall cost management strategy. Consideration should be given to contract clauses that govern changes in the work and how they will be valued (e.g. by reference to a published price book or trade manual); allowable mark-ups on changes by the various levels of contractors and sub-contractors; notice requirements for delays; the use of unit prices for changes and any other clauses that may affect the final cost of the project.

Construction Phase

During construction the focus shifts from predictive cost estimating to reactive cost management of any changes in the work. Changes arise from a number of different sources—unforeseen conditions, owner-generated changes, drawing errors and omissions, code issues or contractual claims. Also changes can arise from on-going proactive cost management, either generated by the design team or the general contractor, where one of the parties proposes a better-value substitution (sometimes known as Value Engineering Change Proposals or VECPs). For all reviews of changes the owner should first establish the ground rules as delineated in the contract documents, agree a format with the general contractor, and require the general contractor to first review change proposal from subcontractors before compiling and forwarding to the owner. Changes should also be reviewed by the design team for entitlement—is it really a change to the scope and are there any credits due? Then the agency Construction Manager or independent cost consultant should review the pricing against the contract and industry norms, leading to an independent government estimate for presentation to the general contractor. Wherever possible the value of the change should be agreed before the work is installed, otherwise the owner's leverage to agree a fair and reasonable price is greatly diminished.

Facility Performance Evaluation

To provide data for future cost management, an evaluation is often carried out to prepare a detailed cost analysis of the completed project and to develop lessons learned to inform future design decisions. The cost data captured should also be fed back in to the owner's database to better inform future estimates and budgets. Other areas to consider here include a review of energy performance of the building during occupancy, to ascertain if the data used as the basis for selection of the mechanical and electrical systems and components was accurate vis-a-vis the actual performance.

How to Do a Cost Analysis

A cost analysis (also called cost-benefit analysis, or CBA) is a detailed outline of the potential risks and gains of a projected venture. Many factors are involved, including some abstract considerations, making the creation of a CBA more of an art than a science, though a quantitative mindset is still a must-have. A CBA is useful for making many types of business and personal decisions, especially ones with a potential for profit (though this need not be the case). Although conducting a CBA can be a complex task, you do not need to be a business major to learn how to do so. Anyone who's willing to brainstorm, research, and analyze data can make a top-quality CBA.

EXPLANATION OF COST-BENEFIT ANALYSIS

Cost-benefit analysis (CBA) is a tool used to determine the worth of a project, programme or policy. It is used to assist in making judgments and appraising available options. CBA principles and practice are well established – as evidenced by the vast amounts of literature available from academics, CBA practitioners, and government agencies (both domestically and abroad). CBA is a quantitative analytical tool to aid decision-makers in the effi cient allocation of resources. It identifi es and attempts to quantify the costs and benefi ts of a programme or activity and converts available data into manageable information. The strength of the method is that it provides a framework for analysing data in a logical and consistent way. CBA helps managers answer questions such as:

1. Does the proposal provide a net benefi t to the community as a whole
2. Should the proposed project, programme or policy be undertaken?
3. Should the project or programme be continued?

4. Which of various alternative projects or programmes should be undertaken?

A CBA adds rigour to a programme evaluation because, among other things, it makes explicit the links between inputs and outcomes, clarifi es the underlying assumptions, and points to gaps in information. By endeavouring to express outcomes (benefi ts2) and inputs (costs) in dollar terms, it facilitates comparisons across different types of programmes as well as options within a particular programme.

A CBA is normally undertaken as one aspect of a more comprehensive assessment of a programme's appropriateness, effi ciency and effectiveness. A CBA is primarily designed to answer the question 'does the expenditure of public money on this particular programme provide a net benefi t to the Australian economy and the Australian public, bearing in mind that these resources could be applied in an alternative use?'

In principle, CBAs enable agencies to compare the relative merit of different (or alternative) programmes or projects in terms of their returns on the use of public resources. CBA may also be used to evaluate the social returns on the use of privately owned resources as in regulation reviews.

In practice, it is often diffi cult to provide a clear ranking of alternative demands on public funds. Another important stumbling block faced by economists in all evaluations is that the assessment depends on what would have happened without the project or programme, which has to be forecast. What is foregone when we undertake a project is known as the 'opportunity cost'. Section 5.1 discusses opportunity cost.

Types of evaluations

There are many ways to evaluate programmes and activities. However, there are three methods that have frequent relevance to Australian Government agencies. These methods are:

- CBA;
- fi nancial evaluation; and
- cost-effectiveness analysis.

Financial and cost-effectiveness analyses are alternative methods to CBA but share some common characteristics. These alternative methods are summarised below. Section C of this *Introduction to CBA* provides a more extensive discussion.

Cost-Benefit Analysis

CBA is a methodology for assessing the net benefits accruing to society as a whole as a result of a project, programme or policy. Most often a CBA is conducted from the point of view of the
local country or possibly the international community as well. It can, in principle, be conducted from the perspective of a state, a region, or even a local community, but such a restricted approach is less common. The appropriate time period over which a CBA should be conducted is generally the projected life of the project or programme.

The CBA method considers the fl ow of real resource costs and benefi ts, and excludes, for example, taxes and subsidies, which are regarded as transfer payments from one part of the economy to another. CBA attempts to measure the value of all costs and benefi ts that are expected to result from the activity. It includes estimating costs and benefi ts which are 'unpriced' and not the subject of normal market transactions but which nevertheless entail the use of real resources.

Financial Evaluation

A fi nancial evaluation (or 'investment evaluation') is generally conducted from the perspective of an individual fi rm or agency rather than from the vantage point of the community as a whole. It is essentially concerned with assessing the impact of a programme or project on the organisation's own fi nancial performance. A fi nancial evaluation can be used to answer the question of whether a proposal offers an acceptable return from an organisation's perspective. Financial evaluations can be used for other reasons – such as determining the lowest cost procurement method – but the *Introduction to CBA* is primarily focussed on evaluating programmes and projects.

In a fi nancial evaluation, only cash fl ows in and out of the organisation are considered; cash fl ows involving other parties are excluded, as are 'unpriced' costs and benefi ts. Unlike CBA, the relevant money values include the effects of taxes and subsidies on the relevant agency.

Cost-Effectiveness Analysis

Cost-effectiveness analysis (CEA) is aimed at determining the cost of achieving a specifi c physical target. Such studies may be undertaken from a national or local perspective. They differ from CBA in that benefi ts are expressed in physical units rather than in money units.

Costs, as in CBA, are expressed in money terms. In relaxing the approach towards benefi ts measurement, CEA is useful in areas such as health, accident safety and education where it is often easier to quantify benefi ts in physical terms than to value them in dollars.
CBA is generally the preferred method when markets or prices do not adequately refl ect all the costs and benefi ts of a proposal. When markets are competitive and most costs and benefi ts are refl ected in market prices, fi nancial evaluation can provide an adequate guide to the social viability of a proposal. Financial evaluation is also important when government as a whole or an agency of government has fi nancial objectives or responsibilities to fulfi l or when it is involved in a purely fi nancial decision such as a comparison of different procurement methods (e.g. traditional government ownership vs. outsourcing). CEA is useful most often when the benefi ts of a proposal are diffi cult to quantify in monetary terms but the government wishes to know which option will achieve social benefi ts or government objectives most cost effectively.

Programme evaluation and CBA

Programme evaluation is essentially an assessment of a programme, or part of it, in order to aid judgments about its appropriateness, effi ciency and effectiveness. Programme evaluations encompass policy/programme reviews, effi ciency (or process) and effectiveness (or impact) evaluations, post-implementation reviews, major enquiries and some audits.

The term ‘appropriateness’ refers here to the extent that the outcomes of the programme match Government policy and priorities and community needs. ‘Effi ciency’ is concerned with the net impact on community welfare and defi ned in terms of how well outputs are maximised for a given level of resource inputs, or resources minimised for a given level of output. ‘Effectiveness’ is concerned with the extent to which programme outcomes achieve stated objectives.
CBA is a useful tool in programme evaluation. It examines whether a particular use of resources generates net returns. A particular use of funds may be effective in terms of achieving the objectives of a programme, but may still generate a negative net return to the community if the benefi ts from these objectives are judged not to be worth the costs involved. Alternatively, an investment could achieve a positive return for the community but fall short of achieving the objectives of a particular programme.
It is important to note the distinction between outputs and outcomes in a government programme context. *Outputs* are physical deliverables over which managers have a high degree of control whereas *outcomes* refl ect the real programme impacts or benefi ts.

If outcomes cannot be quantified in money terms, it is not possible to undertake a formal CBA. However, there is an increasing volume of economic literature directed towards finding ways to attach dollar values to benefits so they can be measured on the same basis as costs, thus allowing comparisons to be made between alternative uses of public funds. For example, additional future earnings of trainees compared with what they would have gained otherwise may provide an indication of the benefit of a training programme. When valuing the cost of aircraft noise, the difference between house prices under aircraft flight paths and those not under them may provide a reasonable guide. However, while useful, the estimation of dollar values in such circumstances often involves a significant degree of judgment and imprecision. Another alternative is to quantify benefits as much as possible and determine ratios of the quantity of benefits per dollar spent, i.e. undertake a cost-effectiveness analysis. This approach may be useful when specific physical outcomes are compared but provides little policy guidance when comparing different outcomes, such as lives saved and children educated.

CBA in practice

In practice, CBA studies are diverse in terms of size, sector, approach and impact. Typical examples undertaken by Australian Government agencies include CBAs of infrastructure proposals (e.g. roads, dams, rail), agricultural, environmental, and scientific research, information technology and property sales/acquisitions. The assessment of costs and benefits is also undertaken in determining the impact of proposed regulation. The Office of Regulation