# ALTERNATIVE
# BUILDING TECHNOLOGIES

Demand for new buildings as well as the cost of building construction is growing at a steady pace. Bricks, cement, steel, timber, plastics, glass, etc. represent some of the commonly used conventional materials for the construction of buildings and other structures. Generally these materials are transported over great distances spending fossil fuel energy. Manufacture of such conventional materials requires expenditure of energy in various forms and many of these manufacturing processes are detrimental to the environment. On the other hand we have cost effective, labour intensive and energy efficient traditional building materials and techniques like mud walls, thatch roofs, etc. Some of these traditional building techniques like mud walls, thatch roofs require frequent repairs. Use of conventional materials alone to satisfy the demand for new buildings, can drain the available energy resources and cause environmental degradation/pollution. Also, such energy intensive building materials are expensive. This clearly indicates the need for energy efficient, environment friendly, economical alternative building materials and technologies.

Centre for ASTRA (**A**pplication of **S**cience and **T**echnology to **R**ural **A**reas) was formed in the Indian Institute of Science, Bangalore in 1974. Developing affordable, environment friendly, energy efficient, simple technologies utilising maximum local resources and skills was one of the main thrust areas of ASTRA's activities. R&D in alternative building technologies was immediately taken up by the Department of Civil Engineering at Indian Institute of Science as a part of ASTRA's activities. The emphasis in R&D into alternative building technologies was in looking at utilisation of local materials and reducing energy consumption to achieve cost reduction. ASTRA and Department of Civil Engineering have developed and disseminated several alternative building technologies over the past 2.5 decades. Brief details of some of these techniques and technologies are furnished below.

## STABILISED MUD BLOCKS (SMB)

### Concept/Process

Soil, sand, stabiliser (cement/lime) and water mixture is compacted into a high-density block using a machine. These blocks are cured and then used for wall construction.

### Type of soil

Soils containing predominantly non-expansive clay minerals are suited for cement stabilised blocks. For example, most of the red loamy soils are suitable with minor modifications. Expansive soils such as black cotton soils require addition of lime and the process of making SMB's is cumbersome using black cotton soil. Highly silty soils also pose problems of green strength and compaction. Soil with ~10% clay and >65% sand is ideal for SMB production using cement as a stabiliser. If some soils contain more clay fraction, then it is advisable to bring down the clay fraction by addition of sand or inert materials like stone quarry dust.

**Machines**

Mechanised as well as manually operated machines can be employed. Manually operated machines are ideal in rural areas for decentralised production. Mardini soil block press is one such manually operated machine.

**Block sizes**

Two blocks sizes (305 X 143 X 100mm and 230 X 190 X 100mm) have been standardised. These two sizes can be used to construct walls of thickness 305mm, 230mm, 190mm, 143mm or 100mm. These blocks are 2.5 to 2.8 times bigger in volume when compared with conventional bricks.

**Block strength**

Compressive strength of the block greatly depends upon the soil composition, density of the block and percentage of stabiliser (cement/ lime). Sandy soils with 7% cement can yield blocks having wet compressive strength of 3 - 4MPa. This kind of strength will be sufficient to construct 2 storey load-bearing buildings with spans in the range of 3 – 4m.

**Cost of SMB**

The cost of SMB depends on a number of factors such as: (1) machine depreciation cost, (2) cost of soil and sand, (3) cost of cement and (4) labour cost. Cost of one block of size: 230 X 190 X 100mm (2.5 to 2.8 times brick volume) will be in the range of Rs. 3 to Rs. 5 depending upon the above factors. Cost can be drastically reduced by the use of local materials and self-help labour.

**Advantages of SMB**

1. Energy efficient, ~70% savings when compared to burnt bricks
2. Economical (20 – 40% when compared to brick masonry)
3. Plastering to walls can be eliminated
4. Highly decentralised production
5. Better block finish and aesthetically pleasing appearance

Stabilised Mud block production using Mardini press

## FINE CONCRETE BLOCKS

The concept and process is similar to the one employed for SMB production except that the mix contains more sand and some fines. Inert fines like fly ash, polished stone waste, etc. or lower percentage of soil fraction (<25%), are mixed with either sand or quarry dust, along with cement and water. The mixture is then compacted into blocks using a machine (manual or mechanised) and then cured for 28 days. Inert fines (like fly ash, polished stone waste, etc.) in the range of 20% by weight of sand and 6 to 7% cement can result into a good quality block with wet strength >3MPa. In addition to inert fines about 10% red soil addition can result in some natural mud colour for the block.

The major advantage of fine concrete block is the utilisation of waste products like fly ash, polished stone waste, etc. which otherwise cause pollution and environmental degradation. Cost of the block will depend on several factors as mentioned for SMB cost.

## STEAM CURED BLOCKS

### Concept/process

Raw materials like lime are easily available. A mixture of lime, industrial waste products like fly ash/soil and sand can be compacted into a high-density block. Expansive soils like black cotton soil are also suitable. Lime reacts with fly ash/clay minerals forming water insoluble bonds imparting strength to the block. These reactions are slow at ambient temperatures (~30$^{o}$C) and hence steam curing for about 10 hours at 80$^{o}$C can accelerate these reactions leading to high strength for the block. The process involves:

1. Mixing of raw materials like lime, cement, fly ash or black cotton soil, sand and water in a mixer
2. Converting the mixture into a dense block using soilblock press
3. Stacking blocks in a steam chamber and steam curing for 10 – 12 hours

### Block sizes

Blocks of any convenient size can be manufactured. Experiments and field demonstration has been carried out using blocks of size: 305 X 143 X 100mm and 230 X 190 X 100mm. Bigger blocks have several advantages like higher masonry efficiency, lower labour cost, savings in mortar for wall construction, etc. It is difficult to produce the block sizes bigger than those suggested above using manually operated machines.

### Block strength

Compressive strength of the block depends upon the composition of the mix, density of the block and percentage of stabiliser (cement/lime). With a combination like 25% fly ash and 75% sand or quarry dust, and using 7% lime + 2% cement can yield blocks having wet compressive strength of >6MPa. This kind of strength will be sufficient to construct 3 storey load-bearing buildings with spans in the range of 3 – 4m. Blocks of higher strength can be easily achieved by adjusting the mix proportions.

**Cost of block**

Block cost depends on a number of factors such as: (1) machines depreciation cost, (2) cost of fly ash and sand, (3) cost of lime/cement and (4) labour cost. Cost of one block of size: 230 X 190 X 100mm (2.6 times brick volume) will be about Rs. 5-6 depending upon the above factors. It should be noted here that the block quality is much superior when compared to local bricks and SMB.

**Advantages**

1. Ideal process for a small-scale or cottage industry
2. Utilisation of industrial waste products like fly ash and problematic soils like black cotton soil and high clay soils
3. Energy efficient and environment friendly
4. Higher strength for the blocks
5. Better block finish and aesthetically pleasing appearance

Steam curing plant (capacity:1300 blocks per shift)

## MUD CONCRETE BLOCKS

This is a low cost concrete, which can be used for foundations, base course for floorings and building blocks. Its economic advantage can be fully utilised wherever stone boulders and irregular shape coarse aggregates are locally available. It is a mixture of soil-cement-sand and coarse aggregate. Two types of mud concrete blocks can be prepared depending upon the availability of the type of stone pieces.

a) Irregular shape stone pieces (coarse aggregate) of sizes ranging from 20 to 50mm are available, such stone pieces in combination with cement-soil-sand mixture can be utilised to make mud concrete blocks. Prepare a mixture of cement : soil : sand in the ratio of 1:4:4 by volume. If the soil is too clayey increase the sand proportion keeping the overall proportion the same. Now add this mixture to the coarse aggregate and convert into a workable concrete mix with adequate quantity of water. This concrete can now be poured into a wooden mould, compacted into a block and then cured. The proportion of cement-soil-sand mixture and coarse aggregate can be 1:1.5 by volume. Wet compressive strength in the rage of 3 – 5MPa can be achieved for the blocks of size 305 X 150 X 125mm. The block sizes can be easily manipulated by selecting a suitable mould size.

b) Irregular shaped stone boulder pieces of bigger sizes (>50mm) can also be utilised for producing mud concrete blocks. The process involves keeping the stones into the mould first and then packing the crevices between these stones by using a mortar of cement : soil : sand (in the ratio of 1:4: 4 by volume). This kind of block will have >60% of the block

Manufacture of mud concrete blocks

volume occupied by the bigger stone pieces there by saving the quantity of cement to be used for block production. Blocks of size 305 X 150 X 125mm or even bigger can be made using a suitable mould. In this case also wet compressive strength in the rage of 3 – 5MPa can be achieved.

Mud concrete block building

Mud concrete block boundary wall

## COMPOSITE MORTARS

Mortars play an important role in bonding the masonry units (bricks/blocks etc.) and imparting strength and stability to the masonry walls. Mortars should possess good workability, helping the mason in laying the bricks and develop good adhesion with the brick or block thereby providing good bond strength to masonry. Ordinary cement mortars are deficient in these two important characteristics. Composite mortars like cement-lime mortars and cement-soil mortars are superior to cement mortars in many aspects. Cement-lime mortars are more expensive than cement-soil mortars. Several investigations carried out at Indian Institute of Science reveal that composite mortars like cement-soil mortars are ideally suited for the construction of masonry using stabilised blocks or bricks. Mortar proportions like cement : soil : sand in the ratio of 1:2 – 3:6 – 8 by volume can be used for the construction of stabilised block masonry and plastering. It must be noted here that the soil should be sieved through a 5mm mesh and thoroughly mixed with cement and sand to produce a good quality mortar. Red loamy soils can be used for mortars. Presence of clay lumps and improper mixing of soil can lead to poor quality mortars. Experiments have shown that a properly made cement soil mortar of 1:2:6 proportion can result in 70 – 90% increase in bond strength for the masonry when compared to 1:6 cement mortar.

# ALTERNATIVE ROOFING SYSTEMS

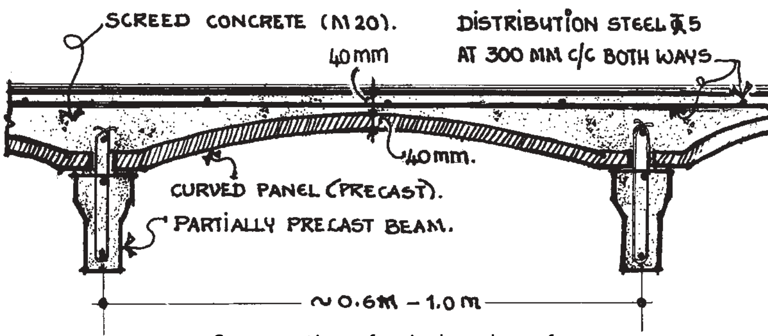
A number of roofing alternatives have been developed and disseminated. Brief details of some of these roofing systems are highlighted here.

## COMPOSITE BEAM AND PANEL ROOFS

This concept exploits the efficiency of beam and slab construction. The roofing system consists of partially precast or cast-in-situ ribs/beams at certain spacing covered with panels as shown in the following figure. The panels and beams are connected through shear connectors to achieve composite action. Varieties of options are available for the beams and panels as given in the Table below. The profile for the panels could be curved, folded plate or flat. Use of curved shape panels results in a composite jack-arch roof. The beam cross section can also be adjusted to minimise the material consumption. Partially precast beam of T-shaped or trapezoidal cross section can be easily generated in the field. The major advantages of the roofing system are: (a) possibility of prefabrication and quick erection (b) better quality assurance due to prefabrication (c) savings in volume of materials and hence cost effective (d) possibility of using hollow panels to increase thermal comfort. The cost of the roof greatly depends on the roof span, materials selected, labour cost, etc. Cost of composite beam and panel roof is compared with other type of roofs in the following sections.

## Materials/technologies for the beams and panels

| BEAM/RIB | PANEL |
|---|---|
| R.C. – CAST-IN-SITU<br>R.C. – PART PRECAST<br>STEEL (ROLLED SCTION)<br>STEEL (TRUSSED)<br>TIMBER<br>STEEL & R.C. COMPOSITE<br>TRUSSED TIMBER<br>TIMBER & STEEL COMPOSITE | R.C. - CAST-IN-SITU<br>R.C. – PRECAST<br>REINFORCED BRICKWORK<br>CUDDAPAH STONE<br>SHAHABAD STONE<br>HOLLOW HOURDI TILE<br>ARCHED BRICK/TILE<br>HOLLOW R.C. PANEL<br>SMB PANEL |




Cross-section of a jack-arch roof

Details of composite jack-arch panel roof

Composite jack-arch roof assembly

Composite beam panel roof building

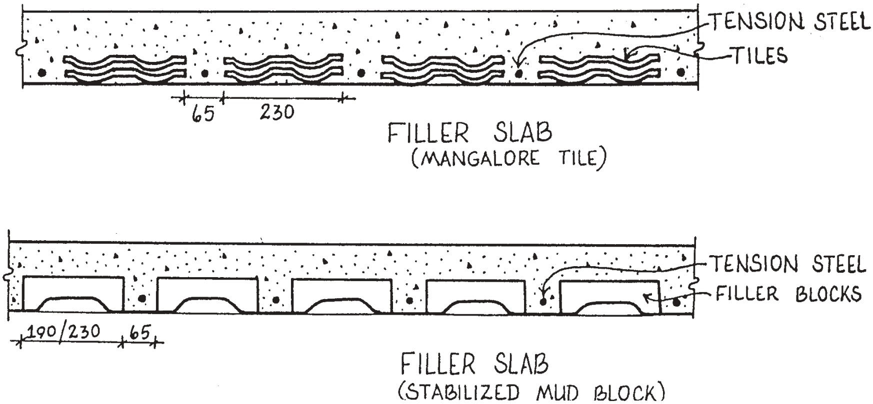
Reinforced tile-work jack-arch roof ceiling

Jack-arch panel roof with decorative clay tile ceiling

Reinforced brick-work flat panel roof

## 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 alternative 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. Typical cross-section showing the details of filler slab roof is shown in the figure below. 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 volume can be replaced by a material, which costs 1/3rd of the cost of concrete. This means that 15 – 20% of the cost of concrete can be saved by this operation. It must however be noted that this is not a prefabricated roof. Other versions of filler slabs are possible using lightweight concrete inserts.




Typical cross section of a filler slab roof

SMB filler blocks with reinforcement

Ceiling of SMB filler slab roof before finishes

Mangalore tile filler slab roof ceiling

**Cost analysis of roofing systems**

The following Table gives the cost analysis for the three types of roofing systems viz. R.C. slab, composite beam & panel roof and filler slab roof using SMB filler. The costs shown in the Table are based on the then prevailing market rates for materials and labour at Bangalore. The cost of the composite beam and panel roof is 26% less than that of R.C. solid slab, whereas SMB filler slab is 18% less than that of R.C. slab roof.

Cost analysis – per $m^2$ of roof area (2002)
LL: 200 $kg/m^2$, Two way slab size: 3.8m X 4.8m,

| Type of roof | Cost (Rs.) per $m^2$ | Savings in cost |
|---|---|---|
| R. C. Solid slab | 829. | —— |
| R. C. Filler slab (SMB filler blocks) | 680. | 18% |
| Composite beam-panel roof (curved/jack-arch panels) | 613. | 26% |

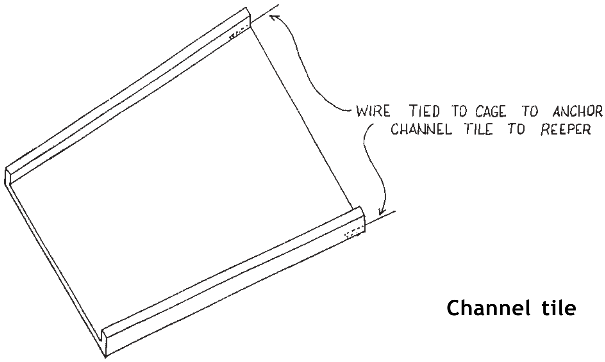
# FERROCONCRETE ROOF UNITS

Ferroconcrete is defined as concrete with smaller size coarse aggregate (<10mm) reinforced with thinner diameter (2 – 8mm) reinforcement bars. The mix proportion for such a concrete is generally of 1:2:2 (cement: sand: coarse aggregate), in order to achieve 20MPa strength for concrete using small size coarse aggregates. Thinner units (20–25mm thickness) for roofing application can be made using ferroconcrete. A number of precast products for various types of roofing systems can be made using ferroconcrete. Details of some of the roofing systems using ferroconcrete have been illustrated below.

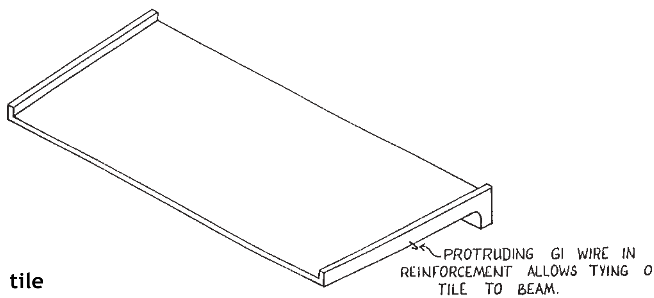
## FERROCONCRETE CHANNEL TILE & L-BEAM TILE ROOFS

These are thin ferroconcrete tile units used as alternative to traditional tiles like Manglaore tiles. Following figure shows the configuration of roofs using ferroconcrete tiles, viz. (a) channel tile and (b) L-beam tile. The thickness of these tiles is kept at 20mm. The channel tile requires the use of rafters and reepers as in Mangalore tiled roof. The L-beam tile rests directly on the rafters and the rib of the tile performs the function of a reeper thus eliminating the need of reepers.

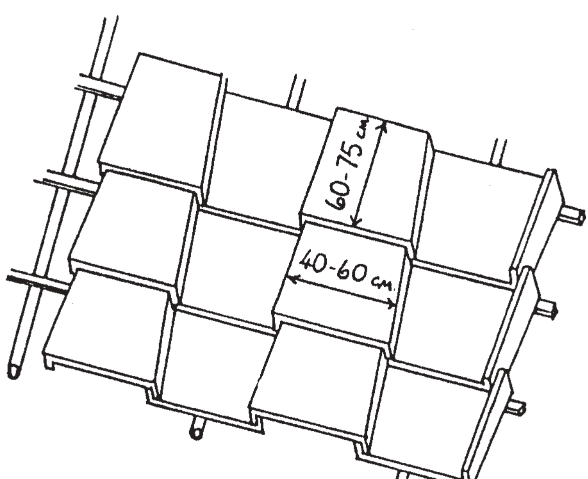
The channel tile size is about 0.6m X 0.75m. The size of L-beam tile is about 0.6m X 1.2m. These tiles when manufactured properly will have enough strength and permit a person to walk on the roof. Cost of the channel tile and L-beam tile roof will depend upon the type of supporting structure, labour costs, etc. Cost of typical channel tile is about Rs. 110 per $m^2$ of roof area, whereas it is Rs. 175 per $m^2$ for L-beam tile. Adding the cost of supporting structure will give the total cost of the roof.




**Channel tile**




**L-beam tile**

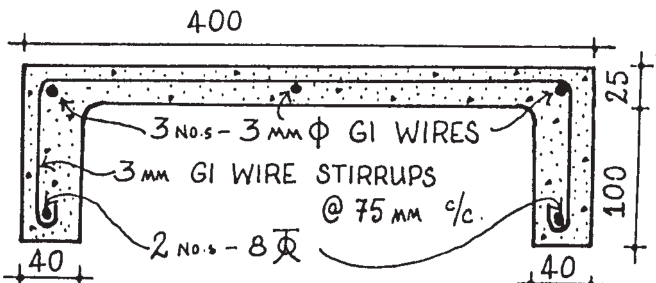



Channel tile roof

L-beam tile roof

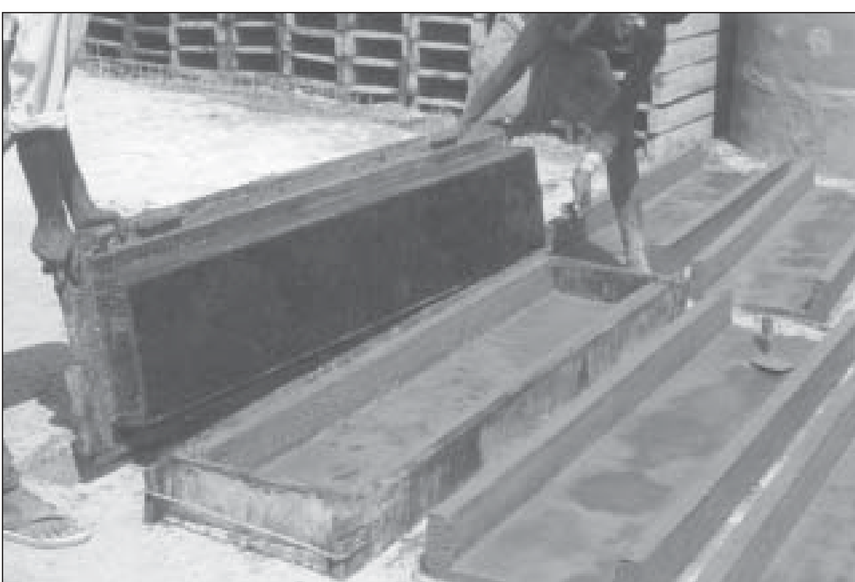
## FERROCONCRETE CHANNEL FLOOR UNIT

The cross section and reinforcement details of a typical floor unit designed for 2.5kN/m$^2$ live load spanning 1.7m are shown in the following figure. The depth of the channel unit and the steel quantity will mainly depend upon the span and the load. The elements can be cast on a level platform using wooden moulds. The channel units can be placed adjacent to each other spanning across the walls, beams or trusses. Then the top of the roof or floor can be finished with a screed concrete. A laboratory building was constructed at I.I.Sc., where the supporting members for the channels is a truss spanning 12m. The channel roof cost was Rs. 500 per m$^2$ in 1999.

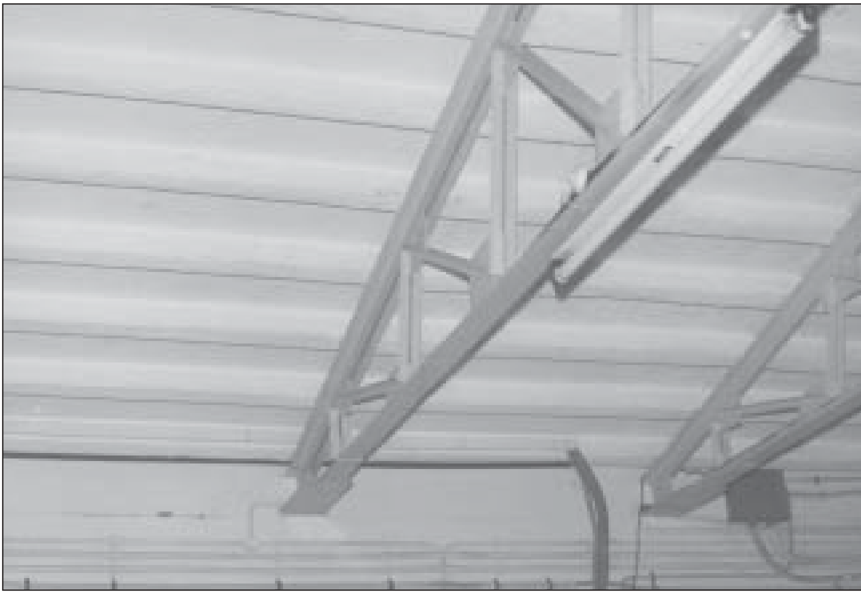



Cross-section of ferroconcrete channel floor unit

Casting of ferroconcrete channel floor units



Casting of ferroconcrete channel floor units



Ceiling of ferroconcrete channel roof

Casting of ferroconcrete T-beam floor unit and finished unit

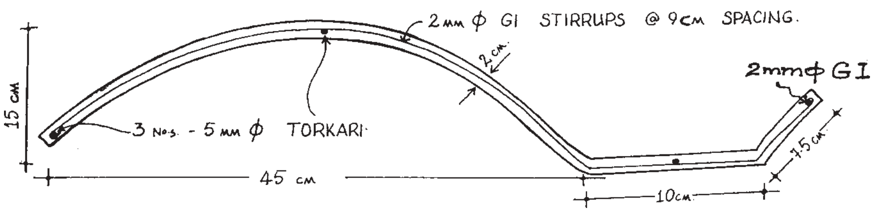
## T-BEAM FLOOR

Instead of a channel shape the roofing unit can also be made resembling a T shape. The depth of the T- beam unit and the steel quantity will mainly depend upon the span and loads. The elements can be cast on a level platform using minimal wooden moulds. Details of casting of T-beam units and the ceiling of finished T-beam floor unit are shown in the following figures. The cost of this floor is about Rs. 550 per $m^2$ (2000), where the span of the T-beam unit is 4m.

Ceiling of T-beam floor unit

## FERROCEMENT ROOFING UNITS

Ferrocement is a composite material consisting of rich cement mortar (1:2 or 1:3) (matrix) reinforced with layers of small diameter wire meshes. A skeleton of steel bars of requisite shape of the element is prepared and then wrapped with layers of small diameter wire meshes before applying the cement mortar. The wire mesh reinforcement is uniformly distributed across the thickness of the element, which helps in achieving improved mechanical properties like fracture and tensile strength as well as fatigue and impact resistance. It also helps to eliminate the formwork. Ferrocement elements are thin walled, where strength and rigidity are derived from the form and shape of the element. Ferrocement has wide range of applications like manufacture of boats, water tanks, silos, beams, lintels, chajjas, roofing elements, etc. Typical cross section of ferrocement channel unit for roofs is shown in the following figure. This kind of roofing channels can be designed for any span. The area of longitudinal steel reinforcement will depend upon the roof span and size and shape/profile of the roofing unit. For sloping roof with a clear span of 3.3m the tension steel area required will be 50mm$^2$ with 3mm G.I. wire stirrups for a channel width of 600mm. Roofing channel unit of size 0.6m width and 3.5 – 4m length will be convenient for lifting and assembling the roof without use of any machinery. The cost of ferrocement channel sloped roof for 3 – 3.5m span will be about Rs. 400 – 450 per m$^2$ of roof area.




Typical cross section of ferrocement roof unit

Ferrocement roof

## UNREINFORCED MASONRY VAULTED ROOFS

Vault and dome construction using unreinfroced masonry is known in India for more than six centuries. Due to the advent of steel and reinforced concrete these techniques were abandoned during British period. Because of the advantages like aesthetics, cost, durability and savings in energy, vaults and dome constructions have been revived. Recent work and expertise developed at I.I.Sc., has shown that unreinforced masonry vaults can be constructed using the concept of moving formwork. A metal formwork of about 1m width defining the vault shape can be repetitively used to construct such vaults. The following figures show this concept of roof construction. Various shapes can be adopted for the vaults. Catenary shaped vault is the most efficient. The thickness of the vault is dependent on the span of the vault. A vault thickness of about 100mm can be used for spans upto 4m. It is also possible to construct the intersecting vaults as well as hipped vaults.

Masonry vault construction under progress

Masonry vault roof

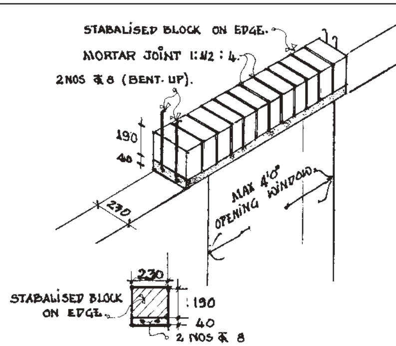
Intersecting vaults

## PRECAST LINTELS AND CHAJJAS

Openings in external walls are provided with lintels and chajjas. Generally, R.C. lintel and Chhajja is considered satisfactory from the point of view of performance. The cost of the lintel and chajja is a function of the opening size and length of the chajja. For smaller openings (<1.4m, where shear stresses are low) with at least 0.75m of masonry above the lintel, reinforced brickwork or reinforced block-work (R.B.) lintels are ideal alternatives for R.C. lintel beam. The R.B. lintels consist of a thin reinforced ferroconcrete layer (~40mm) in the tension zone and brickwork or block-work in the compression zone. Masonry is good for resisting compressive stresses and hence the reinforced masonry is ideally suited for such lintel beams. Obviously the cost of such lintel will be cheaper than R.C. lintel. R.C. Chajjas are generally provided with fascia and other such decorative elements for aesthetic reasons. Precast ferroconcrete brackets and chajja can provide the necessary cost reduction and gives enough scope for designing aesthetically pleasing brackets/chajjas. The cost of R.C. lintel – chajja and the R.B. lintel and precast chajja is given in the Table below. The cost of R.B. lintel and precast chajja is about half that of conventional R.C. lintel-chajja.

**Cost of Lintel – Chajja for 1.35m opening (2002)**

| Sl. No. | Details of lintel - chajja | Cost (Rs.) |
|---|---|---|
| 1. | **Precast chajja – bracket & RB lintel** | |
| | a) Reinforced block-work lintel | 88. |
| | b) Precast brackets – 2 Nos. | 149. |
| | c) Precast chajja | 118. |
| | d) Labour cost of erection | 50. |
| | Profit @ 15% | 60. |
| | **Total cost** | **465.** |
| 2. | **R.C. lintel beam and chajja** | |
| | a) R. C. lintel beam | 274. |
| | b) R. C. Chajja | 508. |
| | Profit @ 15% | 118. |
| | **Total cost** | **900.** |




Reinforced block-work Lintel

Precast brackets, Chajjas and
RB Lintel

## FUEL EFFICIENT KILNS

### a) Lime Kiln

Traditional lime kilns are often extremely small in size and have features, which lead to inefficient burning. ASTRA hence developed lime kiln designs to burn ½ ton and 1 ton limestone capacity per batch. Greater efficiency is achieved by controlling air flow. The smaller kiln uses 45% wood fuel while the bigger one can manage with about 35% wood fuel. The ½ ton kiln design has been disseminated by the TIDE (an NGO) in several locations. The cost of the ½ ton capacity kiln is about Rs. 10,000/-.

½ ton capacity lime kiln

### b) Pottery Kiln

Improved, fuel-efficient pottery kiln is important to upgrade and promote pottery activity in rural areas. A simple, up-draught pottery kiln has been designed and demonstrated in several locations. Uniform flow is achieved by using two layers of bricks with gaps to slow down movement of hot gases. The resistance to flow is also increased by having a narrow outlet at the top of the kiln. The field demonstrations have shown improved burning quality and reduced wastage.

Pottery kiln

**c) Pozzolana Kilns**

Two types of pozzolana kilns have been developed. The first one uses clay briquettes burnt by wood. This is similar to a lime kiln in operation. About 15% by weight of the clay is used as fuel while burning a ton of clay.

The second type of kiln is of the form of an annular cylinder with honeycomb brickwork. Alternate layers of rice husk and clay are used to load the kiln. The entire mass is set fire to from below. Rice husk to the tune of 40 – 45% of the weight of clay may be used.

The pozzolana, whether it is burnt clay or of burnt clay and rice husk ash is to be ground in a ball mill up to about 75micron size.

## LIME POZZOLANA CEMENT

This cement is made by mixing calcium hydroxide (lime) and pozzolana in the ratio of 1:1.5 or 1:2. If the lime is of poor quality the richer mix is to be used. Ideally calcium hydroxide and pozzolana have to be interground in a ball mill. But such mixtures have poor shelf life (about 15 days). The other technique uses site mixing of freshly slaked calcium hydroxide and pozzolana in the form of slurry in a concrete mixer. A few pieces of coarse aggregate could be added to provide better mixing. The aggregate may be removed subsequently and lime pozzolana (LP) slurry poured over sand to make mortar. Volume of proportion of 1:3 or 1:4 (LP cement : sand) may be used. Strength in the range of 1.0 – 3.0MPa may be expected from the mortar.

**Examples of alternative buildings**

**(1) Residential building of Prof. K. C. Patil**

Location: No. 440, 6th Main Road, JRD Tata Nagar, Kodigehalli, Bangalore-94, Year of completion: 2001

**Specifications:**

**Foundation**: Size stone masonry (in composite mortar) on a soft clayey soil (total height of foundation is 2.5m due to low-lying area) with R.C. plinth beam of 150mm thickness.

**Walls**: 230mm thick load bearing masonry walls using soil-cement blocks (7%cement) in 1:2:6 cement-soil-sand mortar. Partition walls are 100mm thick. Average wet compressive strength of the block is 4.7MPa (7% cement). External surfaces of walls have flush pointing in 1:1:3 composite mortar. Internal surfaces have plaster with 1:2:6 cement-soil-sand mortar.

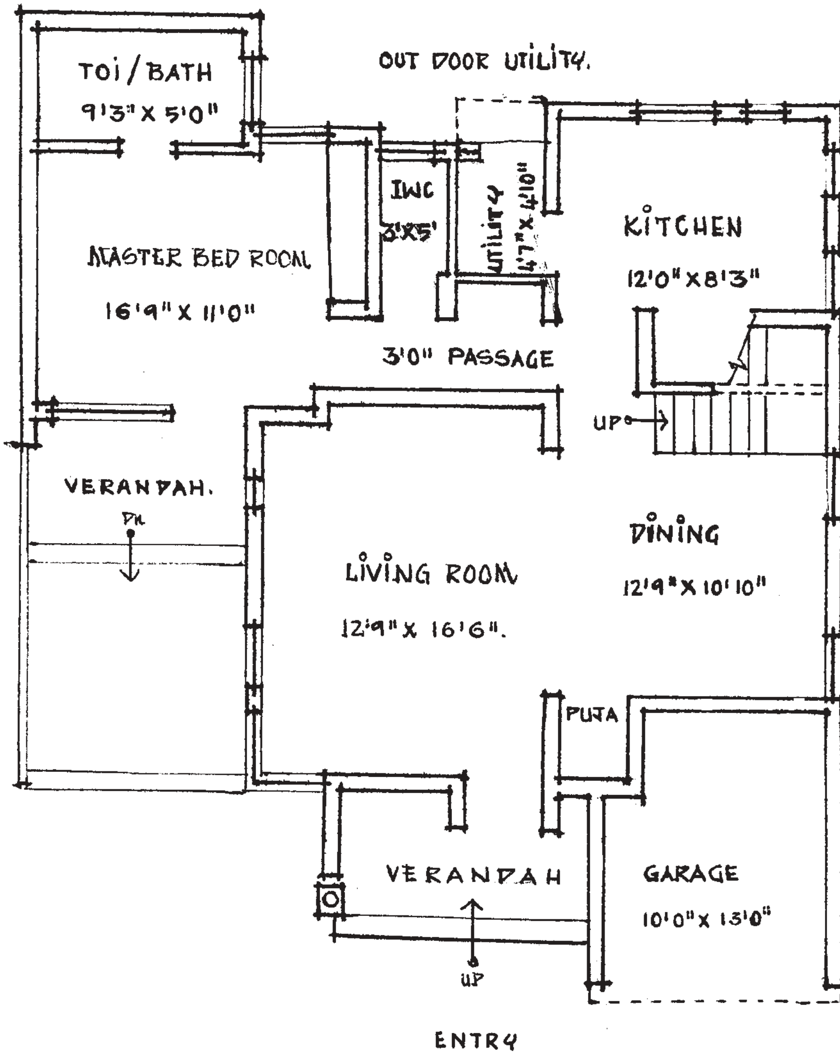
**Lintels & Chajjas**: Reinforced blockwork lintels for openings upto 1.25m and R.C. lintels for bigger openings. Mangalore tile chajjas supported on metal brackets.

**Doors & windows**: Teakwood and Padauk wood for frames. Teakwood, Padauk wood and block board for door shutters. Glazed window shutters. Steel doorframe and shutter for the garage.

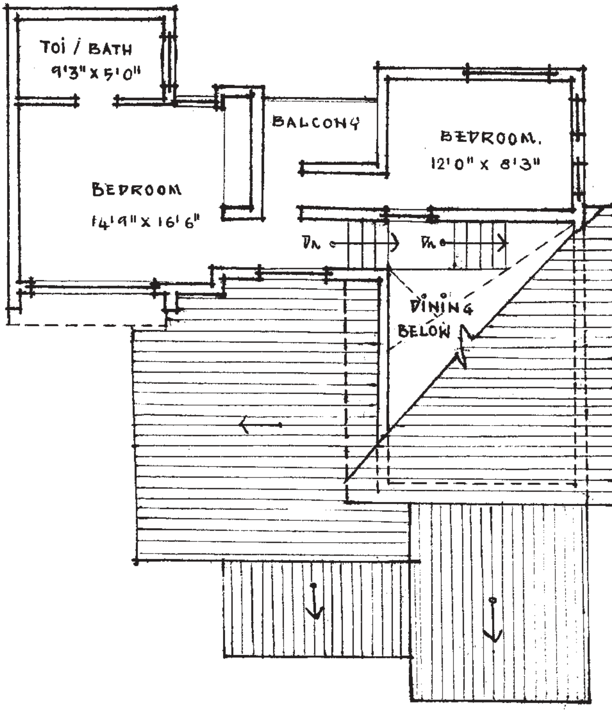
**Floor & Roof slabs**: R.C. precast composite jack-arch roof for living and dining and soil-cement block filler slab for the rest of the portion. The roof has Mangalore tile weatherproof course for sloping portions and Flat weatherproof tile for flat roof portions. Mangalore tiles (small size) supported on steel sections for the garage and jagali portion.

**Floor:** Kitchen has polished shahabad stone floor and grey mosaic tile floor finish in other places. Glazed tiling in bathrooms.

**Finishes:** Exposed external wall surfaces are coated with transparent silicone paint and internal wall surfaces with emulsion paint. Kitchen platforms have polished granite top and granite sink. Doors and windows have melamine polish.




Ground floor plan




First floor plan

Prof. Patil's residence

**Cost analysis**

Effective plinth area = 163.15 $m^2$, Carpet area = 117.69 $m^2$,
Cost of construction per $m^2$ of plinth area = Rs. 6976/ $m^2$ (Rs. 649/Sft)

| Component | Cost (Rs.) | % of total cost |
|---|---|---|
| 1. Structure | | |
| a) Foundation | 1,15,228.00 | 10.1 |
| b) Plinth | 12,502.75 | 1.1 |
| c) Walls/beams | 3,24,000.00 | 28.5 |
| d) Roof & floor slabs | | |
| Precast/ Filler slab | 85,080.00 | 7.5 |
| Mangalore tile roof | 40,890.00 | 3.6 |
| Sub-total | 5,77,700.00 | 50.8 |
| 2. Openings | | |
| a) Doors & Windows | 1,28,339.00 | 11.3 |
| b) Lintel & Chajjas | 15,355.00 | 1.3 |
| Sub-total | 1,43,649.00 | 12.6 |
| 3. Finishes | | |
| a) Flooring | 47,394.00 | 4.2 |
| b) Painting | 40,006.00 | 3.5 |
| Sub-total | 87,400.00 | 7.7 |
| 4. Services | | |
| a) Plumbing & Sanitary | 1,15,882.00 | 10.2 |
| b) Electrical | 43,053.00 | 3.7 |
| Sub-total | 1,58,935.00 | 13.9 |
| 5. Technical assistance | 1,30,400.00 | 11.5 |
| 6. Architect fee | 40,000.00 | 3.5 |
| Miscellaneous | 1,11,054.00 | |
| **Total cost** | **12,49,183.00** | |
| Labour cost in civil works | 2,55,298.80 | 22.4 |

**Materials used :**

a) Cement: 845 bags,
b) Steel: 1500Kgs (excluding steel used for fabrication of Mangalore tile roof).
1) Volume of bed concrete (1 : 4 : 8 ) : 14.74 $m^3$
2) Size stone masonry in foundation : 126 $m^3$
3) Plinth beam : a) concrete : 2.74 $m^3$, b) steel : 255 Kgs
4) Volume of masonry walls (load bearing) : 58.11 $m^3$

5) a) Concrete Roof/Floor area : 130.4 $m^2$, b) Floor area : 117.69 $m^2$
6) Roof/Floor slab : a) concrete : 18 $m^3$, b) steel : 912 Kgs
7) Area of : a) Doors : 16.75 $m^2$, b) Windows : 20.02 $m^2$

<u>**Miscellaneous items**</u>: a) Sump, b) Temporary shed, c) Gate, d) Paving, e) Solar water heater, f) Outside steel grill work, g) Boundary wall.

**(2) Residential building of Prof. Sudhakar M. Rao**

Location: No. 24, 2nd Main Road, JRD Tata Nagar, Kodigehalli, Bangalore 560 094
Year of completion: 2002

**Specifications:**

**Foundation**: Size stone masonry in composite mortar (total height of foundation is 1.75m due to low-lying area) with R.C. plinth beam of 150mm thickness.

**Walls**: 230mm thick load bearing masonry walls using soil-cement blocks (size: 230 X 190 X 88mm and 7.5%cement) in 1:2:6 cement-soil-sand mortar. Partition walls are 88mm thick. Average wet compressive strength of the block is 7.45MPa (7.5% cement). External surfaces of walls have flush pointing in 1:1:3 composite mortar. Internal surfaces have plaster with 1:2:6 cement-soil-sand mortar and recessed pointing in the entrance corridor and few other places.

**Lintels & Chajjas**: Reinforced blockwork lintels with ferroconcrete precast chajjas, supported on precast ferroconcrete brackets.

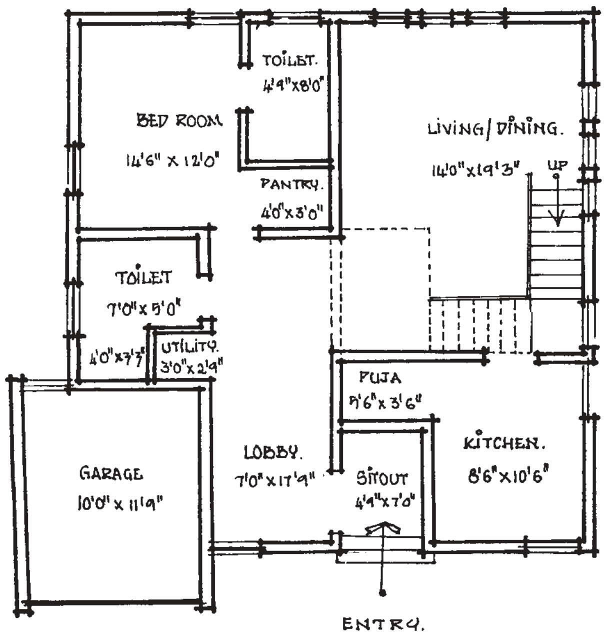
**Staircase:** Internal staircase constructed with precast ferroconcrete steps, cantilevered from the wall. Thickness of the step is 40mm.

**Doors & windows**: Padauk wood for frames for doors and windows. OST block board for door shutters except main door, which has padauk wood shutter. Glazed window shutters and rolling shutter for the garage.

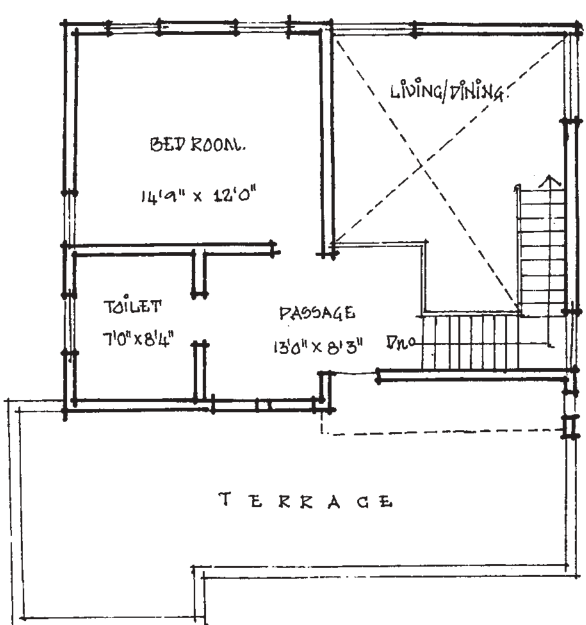
**Floor & Roof slabs**: R.C. precast composite jack-arch roof for living room and soil-cement block filler slab for the rest of the portion. The roof has weatherproof course using tiles.

**Floor:** Glazed ceramic tile flooring except in FF corridor. FF corridor has terracotta tile floor. Bathroom walls (up to 2.1m) and floor have been provided with ceramic glazed tiling.

**Finishes:** Exposed external wall surfaces and internal wall surfaces are plastered have paint. Kitchen platforms have polished granite top and stainless steel sink. Doors and windows have melamine polish.




Ground floor plan




First floor plan

**Cost analysis**

Effective plinth area = 163.04 $m^2$, Carpet area = 120.37 $m^2$,

Cost of construction per $m^2$ of plinth area = Rs. 6337/$m^2$ (Rs. 590/Sft)

| Component | Cost (Rs.) | % of total cost |
|---|---|---|
| 1. Structure | | |
| a) Foundation | 70,201.00 | 6.8 |
| b) Plinth | 11,218.00 | 1.1 |
| c) Walls/beams | 3,07,216.00 | 29.7 |
| d) Roof & floor slabs | 1,24,357.00 | 12.2 |
| Sub-total | 5,12,992.00 | 49.6 |
| 2. Openings | | |
| a) Doors & Windows | 1,36,583.00 | 13.2 |
| b) Lintel & Chajjas | 21,676.00 | 2.1 |
| Sub-total | 1,58,259.00 | 15.3 |
| 3. Finishes | | |
| a) Flooring | 75,295.00 | 7.3 |
| b) Painting | 54,344.00 | 5.3 |
| Sub-total | 1,29,639.00 | 12.6 |
| 4. Services | | |
| a) Plumbing & Sanitary | 60,340.00 | 5.8 |
| b) Electrical | 60,520.00 | 5.9 |
| Sub-total | 1,20,860.00 | 11.7 |
| 5. Technical assistance | 1,05,481.00 | 10.2 |
| Architect Fee | 6,000.00 | 0.6 |
| Miscellaneous | 1,52,176.00 | |
| **Total cost** | **11,85,407.00** | |
| Labour cost in civil works | 2,20,175.00 | 21.4 |

**Materials used :**

a) Cement: 831bags, b) Steel : 2.41MT
1) Volume of bed concrete (1 : 4 : 8 ) : 8.65 $m^3$
2) Size stone masonry in foundation : 55.32 $m^3$
3) Plinth beam : a) concrete : 2.95 $m^3$, b) steel : 288 Kgs
4) Volume of masonry walls (load bearing) : 63.3 $m^3$
5) a) Roof area : 188.37 $m^2$, b) Floor area : 120.37 $m^2$
6) Roof/Floor slab : a) concrete : 22.65 $m^3$, b) steel : 1.52 MT
7) Area of : a) Doors : 16.61 $m^2$, b) Windows : 23.91 $m^2$

**Miscellaneous items**:

a) Sump, b) Temporary shed, c) Gate, d) Bore well,
e) Hand pump, f) Steel grill work, g) Motor pump,
h) Boundary wall, I) Granite slabs.

Prof. Sudhakar M. Rao's residence

**(3) New ASTRA building**

Location: Centre for ASTRA, Indian Institute of Science, Bangalore 560 012
Year of completion: 1999

New ASTRA building

**Specifications:**

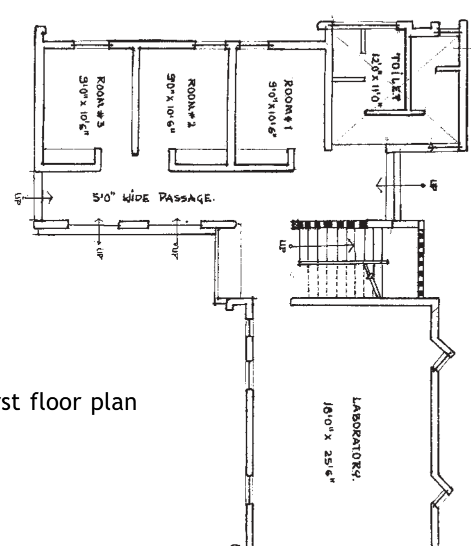
**Foundation**: Size stone masonry in composite mortar. 40mm thick R.C. plinth band provided 0.6m below the top of foundation.

**Walls**: 230mm thick load bearing masonry walls (designed for 3 floors) in 1:2:6 cement-soil-sand mortar, using steam cured stabilised blocks for the GF walls and soil-cement blocks (8% cement with wet strength of 5.4MPa) for the FF. Partition walls are 100mm thick. Average wet compressive strength of the steam cured blocks is 6.89MPa with a SD of 0.74MPa. External surfaces of walls have flush pointing in 1:1:3 composite mortar. Internal surfaces in corridors are exposed with recessed pointing and other internal walls have plaster with 1:2:6 cement-soil-sand mortar.

**Lintels & Chajjas**: Reinforced blockwork lintels and ferroconcrete precast chajjas are supported on precast ferrocement brackets. Soil-cement block arches have been provided in the corridors.
**Doors & windows**: Pressed metal sheet frames with block board shutters for doors. Pressed metal sheet frames and glazed shutters for windows.
**Floor & Roof slabs**: Soil-cement block filler slab for roof and floor. The roof has weatherproof course using tiles. Staircase headroom has precast ferroconcrete channel roof.

**Floor:** Cement mortar floor. In corridor the cement floor has some terracotta tile embedded in some portions. Glazed tiling in toilets.

**Finishes:** Exposed external wall surfaces are coated with transparent silicone paint and internal wall surfaces (except in corridors) with emulsion paint. Doors and windows are painted using enamel paint.




Ground floor plan & First floor plan

**Cost analysis**

Effective plinth area = 280 $m^2$, Carpet area = 223.64 $m^2$,
Cost of construction per $m^2$ of plinth area = Rs. 4247/ $m^2$ (Rs. 395/Sft)

| Component | Cost (Rs.) | % of total cost |
|---|---|---|
| 1. Structure | | |
| a) Foundation | 1,01,799.00 | 8.8 |
| b) Plinth | 6,797.00 | 0.59 |
| c) Walls/beams | 3,28,022.00 | 28.2 |
| d) Roof & Floor slabs | 1,88,811.00 | 16.3 |
| e) Staircase | 10,828.00 | 0.93 |
| Sub-total | 6,36,257.00 | 54.8 |
| 2. Openings | | |
| a) Doors & Windows | 1,08,720.00 | 9.4 |
| c) Lintel & Chajjas | 16,039.00 | 1.4 |
| Sub-total | 1,24,759.00 | 10.8 |
| 3. Finishes | | |
| a) Flooring | 38,233.00 | 3.3 |
| b) Painting | 32,377.00 | 2.8 |
| Sub-total | 70,610.00 | 6.1 |
| 4. Services | | |
| a) Plumbing & Sanitary | 1,40,861.00 | 12.1 |
| b) Electrical | 1,58,829.00 | 13.7 |
| Sub-total | 2,99,690.00 | 25.8 |
| 5. Architect fee | 30,000.00 | 2.5 |
| Miscellaneous | 27,942.00 | |
| **Total cost** | **11,89,258.00** | |

**Materials used:**

a) Cement: 842 bags b) Lime : 5.5 tonnes c) Steel: 2.661MT
1) Volume of bed concrete (1 : 4 : 8 ) : 9.86 $m^3$
2) Size stone masonry in foundation : 71.68 $m^3$
3) Plinth beam : a) concrete : 1.497 $m^3$, b) steel : 420 Kgs (Reinforced masonry)
4) Volume of masonry walls (load bearing) : 101.33 $m^3$
5) a) Roof area : 271.56 $m^2$, a) concrete: 34.03 $m^3$, b) Steel: 2.241MT
b) Floor area : 223.64 $m^2$
6) Area of : a) Doors : 24.80 $m^2$, b) Windows : 24.08 $m^2$

**Miscellaneous items:**

Jali works, Parapet.

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