Compendium of
BUILDING TECHNOLOGIES



CSIR- Central Building Research Institute, Roorkee
Ministry of Science and Technology, Government of India

Building Materials & Technology Promotion Council,
Ministry of Housing & Urban Affairs, Government of India

Compendium of
BUILDING TECHNOLOGIES

A joint publication of

CSIR- Central Building Research Institute, Roorkee
Ministry of Science and Technology
Government of India

and

Building Materials & Technology Promotion Council,
Ministry of Housing & Urban Affairs
Government of India

PREFACE

Housing for all by 75th year of our independence for urban as well as rural households in India triggered major construction technology transition to bring resource-efficient, climate-responsive, disaster-resilient, cost-effective sustainable building technologies. Through Pradhan Mantri Awas Yojna (Urban & Rural), sustainable building materials, local design & skills and innovative construction methodologies are being disseminated for their large-scale adoption to beneficiaries, state govts, professionals and artisans. The overall objective is to ensure sustainable, safe and affordable house to each household. Looking at the target of 11.2 million houses in urban areas & 10 million in next three years in rural area, it is well-nigh impossible to achieve it with traditional brick, mortar & cast-in-situ RCC construction. The age-old practices are no longer sustainable in the light of fast depletion of natural resources, climate change, green house gas emissions, energy scarcity. In addition, the prevalent construction practices are labor-intensive and time consuming. Therefore, it is prudent to bring in forefront alternative & innovative building materials & construction technologies in the construction sector.

The quest of mankind to have a shelter which can protect them from the vagaries of nature has been as old as our civilization. Earlier methods of construction employ locally available materials such as stone, soil, lime & wood. The use of sun-dried bricks as well as fired clay bricks also dates back to 3500 BC. The 19th century saw the biggest transformation in the history of construction when steel & cement were introduced as chief building materials. Today, the concrete is an ubiquitous material being used for small hamlets to skyscrapers to specialized structures. The reinforced concrete construction is versatile and time-tested; however, its sustainability is being questioned. The amount of green house gases (GHG) being emitted during production of cement, energy being consumed and natural resources being exploited in addition to the air/noise/land pollution puts the onus on Reinforced Concrete (RCC) Construction in its present form gradually untenable specially in fast growing economies such as India.

The majority of RCC construction is cast-in-situ and being performed manually to this day. It is time to bring industrialization in building construction by introducing off-site construction concepts. The mechanization/automation concepts have already been introduced in a few countries with success and India is also introducing them in mass housing projects. Form work systems, pre-engineered buildings, pre-cast concrete construction, dry wall construction are few such concepts which are now widely accepted by the construction fraternity in India. Govt. of India is also keen to introduce cutting edge technologies in the sector and have organized Global Housing Technology Challenge (GHTC) -India through Ministry of Housing & Urban Affairs in March 2019. In this process, 54 new construction systems have been identified which are clubbed into six broad categories namely (i) 3D precast volumetric concrete construction (ii) Precast concrete construction with precast building components (iii) Light Gauge steel structural system & pre-engineered steel structural system (iv) Prefabricated sandwich panel systems (v)Formwork systems (vi) Stay in Place form work systems. Now these systems are being showcased though construction of light house projects in different parts of India.

Nonetheless, these systems are ideally suited for mass housing and to take them to individual household level will not be feasible and therefore, a new set of building systems are required which not only take care of local aspiration, local materials, local skills but also offer sustainability, affordability and disaster resilience. Also, there is need to create synergy between traditional building techniques and the modern methods & knowledge. Both can learn from each other and blending both can produce cost-effective sustainable construction.

CSIR-CBRI being premier research institute in the area of building science & technology for more than 7 decades has developed many such building materials, components & technologies and BMTPC since its inception has been into technology transfer for field level applications. Both the organization joined hands to bring out this compendium on Building Technologies. The publication contains 66 existing technologies covering following broad components:

1. Floor/roof construction technologies
2. Roof construction technologies
3. Wall construction technologies
4. Foundation construction technologies
5. System level technologies
6. Services
7. Materials

Each system has been explained in detail along with technical specifications, tools & equipment, salient features, cost, sustainability & economic aspects, material requirements, limitations, market linkages, structural drawings/detailing and relevant standards & references. Also, the geo-climatic suitability of the technology region has been specified. These building technologies are time-tested and proven and the data presented is the outcome of the R & D done by scientists of CSIR-CBRI and their field level applications over the years. The document is ready to use and can be successfully used in the field for Beneficiary Led Construction for low-rise to mid-rise structures. The compendium will serve as a useful resource for construction of individual houses and can help State Governments to introduce these systems in their ongoing housing schemes.

The compendium is a stepping platform to create a technical databank of various existing alternate materials & construction technologies which are time-tested & proven and can readily be used in the field. However, more and more technologies will be added as and when developed and verified. In view of the clarion call given by Hon'ble PM for Atamnirbhar Bharat, it is opportune time to promote technology & innovations in housing especially for low to mid rise structures based on local materials, local skills & construction techniques amalgamated with updated knowledge to achieve affordability, sustainability, disaster resilience facilitating faster construction. The compendium is an attempt to bring together such indigenous innovations at a common platform and to take stock of alternate materials & technologies for field level applications.

(Dr. N. Gopalakrishnan)
Director, CSIR-CBRI

(Dr. Shailesh Kr. Agrawal)
Executive Director, BMTPC

ACKNOWLEDGEMENTS

The compendium on building technologies is the product of R & D efforts being put up by CSIR-CBRI over the years in the area of alternate cost-effective building materials, precast building components and housing technologies. The CSIR-CBRI being premier research Institute of India has been extending S & T support to Housing for All mission and is knowledge partner to Ministry of Housing & Urban Affair (MoHUA), Govt. of India & BMTPC. I gratefully acknowledge the help & support of CSIR-CBRI for the entire journey.

The idea of bringing out a publication on existing building materials & technologies germinated by Shri Durga Shankar Mishra, Secretary, MoHUA and the entire team show their gratitude towards him for his enlightened guidance & constant encouragement. Thanks are also due to Shri Amrit Abhijat, the then Joint Secretary & Mission Director, Housing for all, for reposing faith in us and giving us insights from time to time.

I would be failing in my duties, if I do not profusely thank Dr. N. Gopalakrishnan, Director, CSIR-CBRI who on my request immediately agreed to develop the publication in time bound manner without any financial support. His pro-active approach & technical advice for development of the compendium is duly acknowledged.

I would also like to place on record my deep appreciation to the entire team of scientists, technical officers & project assistants at CSIR-CBRI under the able guidance of Dr. S.K. Negi, Chief Scientist & Head, Development, Construction & Extension Group & Dr. Ajay Chourasia, Sr. Principal Scientist, Structural Engineering Division who untiringly have put best of their efforts for preparing & bringing out this compendium. The team members of CSIR-CBRI which are involved in the preparation of compendium are (i) Dr. N. Gopalakrishnan (Director) (ii) S.K. Negi (Chief Scientist & Head, Development, Construction & Extension Group) (iii) Ajay Chourasia, (Sr. Principal Scientist, Structural Engineering Division) (iv) H.K. Jain (Consultant, Development, Construction & Extension Group) (v) Ashish Pippal (Scientist & Head, Development, Construction & Extension Group) (vi) Nimisha Samadhiya (Project Assistant) (vii) Nitin Sahu (Project Assistant) (viii) Gaurav Sharma (Project Assistant) (ix) Ashutosh Singh (Project Assistant) (x) Sugam Kashyap (Technical Officer) (xi) Shubham Singhal (PhD. Scholar) (xii) Neelam Chauhan (Project Assistant). The help & support of other members of CSIR-CBRI who directly or indirectly helped in the publication are also duly acknowledged.

At last but not the least, the team at BMTPC specially Shri Sharad Kr. Gupta, Dy. Chief (TDE & IC) & Shri Dalip Kumar, Sr. Field Officer deserve special mention for reading & editing the publication and bringing it to printable form.

BMTPC wishes to express its deepest gratitude to Shri Hardeep Singh Puri, Hon'ble Minister of Housing & Urban Affairs & President, BMTPC for un-stinted support, constant encouragement & sincere advice. BMTPC is also indebted to HFA directorate & Housing division of MoHUA for supporting BMTPC's endeavors.

(Dr. Shailesh Kr. Agrawal)
Executive Director, BMTPC

CONTENTS

Floor/Roof Construction Technologies

Precast R.C. Plank and Partially Precast Joist System

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions

All regions except costal regions of the country

About the Technology

This is a precast flooring/roofing system for single and multi-storey buildings. It consists of precast R.C. planks supported over partially precast R.C.C. joists. The completed floor/roof (precast RC planks placed over partially precast RC joist) with 40 mm thick in-situ concrete filling forms the monolithic T-beam slab resting over walls .

Pre-cast RCC Planks are typically 300 mm wide x 1500 mm long, that are partly 30 mm and partly 60 mm thick with a 10 cm wide tapered concrete filling to strengthen the haunch portion against forces during handling and erection. The plank uses 3 nos. 6 mm dia. TMT reinforcement, and M20 grade concrete. One plank weighs about 50kg and can be easily handled manually.

Partially Pre-cast Joist is a RC beam partially precast with exposed top steel bars. The beam, together with the planks on both sides duly joined with concrete, form a monolithic T-beam. The width of the joist is equal to the required width of web of the T-beam (as per IS 13994:1994). The total depth is equal to the precast depth of the partially precast joist + the thickness of RC Plank as the flange. Typically for medium spans up to 4000 mm, a 150 mm x 150 mm section can be used for the joist with stirrups projecting out, so that the overall depth of the joist with RC plank and in-situ concrete becomes 210 mm. The length of the partially precast joist is equal to the span + bearing on walls.
For details refer CBRI BRN-4.

Material Requirements *(per unit)*

RC Plank Size 1500x300x60 mm	M20 Concrete- 0.02cum TMT Steel- 1.60 kg
Partially Precast joist Size 3300x150x150 mm	M20 Concrete- 0.075cum TMT Steel- 10 kg

Tools and Equipments

(a) Steel/timber moulds, (b) Plate vibrator, (c) concrete mixer (d) Mason's tools, (e) Light hoisting equipment, (f) Platform

Salient Features

1. Substantial reduction in construction time.
2. Cost-effective as it does not require shuttering.
3. Creates local employment in the production of precast components through micro level enterprises.
4. Pre- fabrication leads to better quality control.
5. Suggested size of components do not require mechanical handling and erection equipment.
6. Simple technology which can easily be adapted by semi-skilled labour.

Economic Aspects

1. This system results in saving 20% in overall cost, 25% in cement and 10% in steel as compared to conventional R.C. slab floor/roof.
2. Added savings in shuttering and construction time.

Sustainability Aspects

1. Saving in Embodied Energy: about 100 MJ /sq.m. over a 100 mm thick RCC roof.

Limitations

1. May not be suitable for rooms having large span more than 3.8m.
2. Not suitable in costal/aggressive environment.

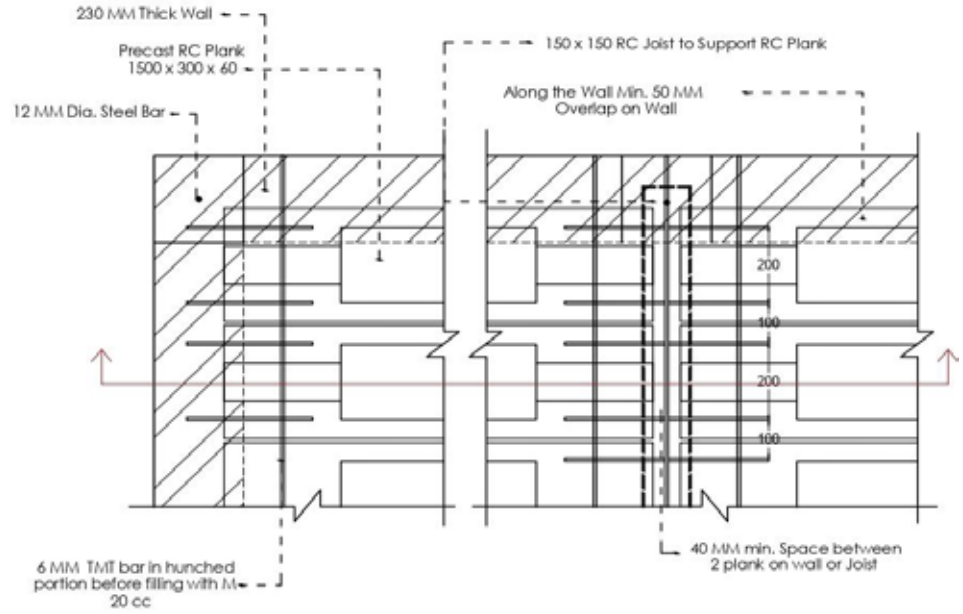
Market Linkages

1. The precast components can be locally cast near construction site.
2. It can also be produced by small entrepreneurs and supplied to consumers at State/ Block/ village level.

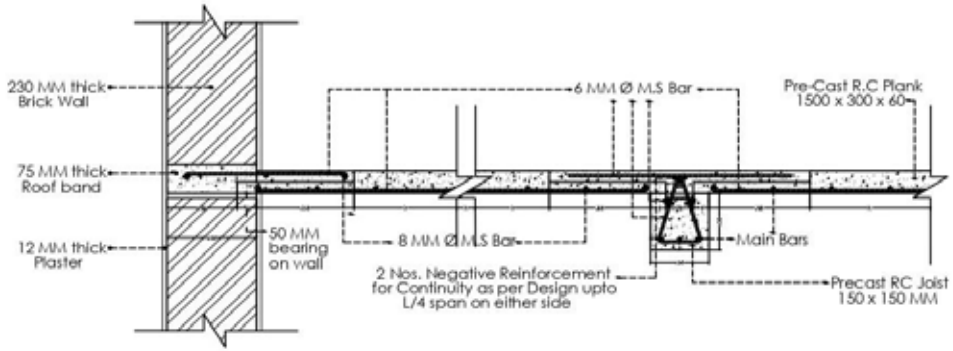
Cost

1. Savings in cost: about 15 to 25% over in-situ RC roof.

Floor/Roof system



Reinforcement detailing and arrangement of RC plank over RC joist in plan



Reinforcement detailing and arrangement of RC plank over RC joist in section

Specifications

Reinforced Concrete Plank *(Refer IS 456:2000)*	**Size** : Length up to 1.5 m, Width 300 mm ± 50 mm, Thickness partly 30 mm and partly 60mm **Concrete Mix** : M20 **Reinforcement** : 6 mm dia. TMT- 3 Nos. for main reinforcement and @200 mm c/c in transverse direction **Weight** : 50 kg
Partially Precast RC Joist *(Refer IS 13994:1994)*	**Size** : Length not more than 3.5 m, cross section 150 mm x 150 mm **Concrete Mix** : M20 **Reinforcement** : 6 mm dia., triangular TMT stirrups @ 130mm c/c Longitudinal 3 Nos. 8 to 12 mm dia. TMT bars as per design. **Weight** : 55 kg /meter length.
Plank and Joist Roof *(Refer CBRI BRN-4 and IS:875-1987)*	**In-situ concrete mix** : M20 with 12 mm and down well graded coarse aggregate **Overall depth :** 210 mm over the joist/web and 60mm at flange or RC Plank. Minimum 40 mm thick screed concrete with wire-mesh over planks for waterproofing of roof is preferred. **Bedding for joist** : Min. 300 x 230 x 75 mm block of cement concrete M20. **Design Load** : As per IS: 875 for residential buildings.

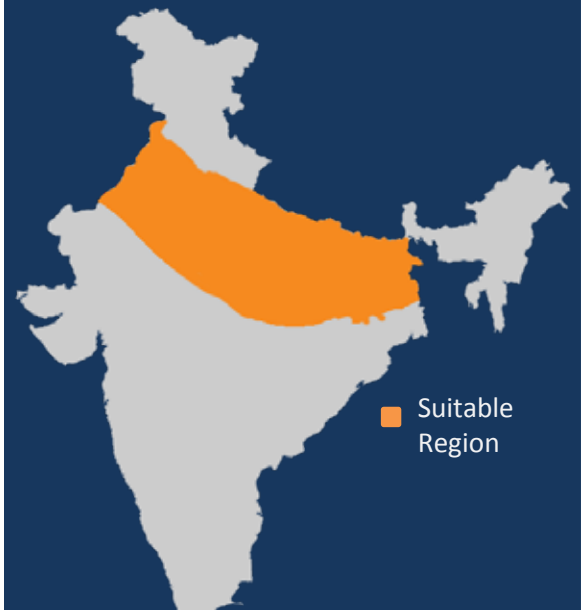
Relevant Standards and References

1. Precast R.C. Plank Flooring/Roofing Scheme, Revised 2004, Building Research Note-4, Central Building Research Institute, Roorkee.
2. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
3. IS 13994: 1994 Design and Construction of Floor and Roof with Precast Reinforced Concrete Planks and Joists - Code of Practice, Bureau of Indian Standards, New Delhi.
4. IS 875 (pt.1)-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Precast Brick Panel and Partially Precast Joist System

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions



States where brick is easily available.

About the Technology

This is a partially precast system where cement concrete is used in the compression zone, steel in the tension zone and bricks are used as filler materials in the tensile zone.

Steel reinforcement in Brick Panels is properly encased in M20 cement concrete along the longitudinal brick joints. The Brick panels are supported over and jointed to partially precast concrete joists with steel bars and M20 grade in-situ concrete to behave like T-beam floor/roof slab. The precast portion of the joist is designed to take self load and handling stresses only, so it should be propped at 1/3 of the span from both the end supports before placing panels and laying deck concrete.

Prefab Brick Panels are made of first class bricks and reinforced with two TMT bars of 6 mm dia. The joints are then filled with M20 concrete. The length of the brick panels varies from 900 mm to 1200 mm depending upon the room size, but the width is normally kept at 540 mm. Allow min 40 mm wide gap between the bricks to ensure proper cover to the steel bars placed in the gaps. The diameter of reinforcing bars should be increased according to structural requirement.

Partially Pre-cast Joist is min. 130 mm wide, and 125 mm deep. Their stirrups are kept projecting upward by 85 mm. The Brick panels supported over the partially precast joists are provided with 40 mm thick deck concrete with nominal reinforcement to form composite T-beam. The precast joists act as the web and the in-situ concrete over the panels acts as the flange.

Material Requirements *(per unit)*

Prefab Brick panel Size 1200x540x75 mm	Bricks- 18 nos. M20 concrete - 0.015 cum Steel - 0.6 kg
Partially Precast joist Size 3300x130x125mm	M20 concrete- 0.054cum Steel- 18kg
40 mm In-situ concrete/m²	M20 c concrete- 0.04cum Steel - 0.45 kg

Tools and Equipments

(a) Steel/timber moulds, (b) Plate vibrator, (c) concrete mixer, (d) mason's tools , (e) Light hoisting equipment

Salient Features

1. Use of pre-cast roof elements: faster execution, more productivity and economy in cost and time.
2. Does not require shuttering. Moulds can be used repetitively ,thereby reducing the cost of mould per unit.
3. Pre- fabrication leads to better quality control.
4. Moderate size of components that can be handled easily, without mechanical equipment.
5. Simple and sustainable building technology which can easily be adapted by semi- skilled labour.

Economic Aspects

1. This system is 30-35% cheaper compared to RCC slab in brick production areas of northern India
2. Savings in cement, steel and brick are 20-25%, 32-40% and 30-35% respectively.

Sustainability Aspects

1. Economically and socially more sustainable than RC slab roof in northern brick producing areas of India.
2. Bricks consume top fertile soil and have high embodied energy.

Limitations

1. Suitable where good quality burnt clay bricks are locally produced and sand and stone aggregate is costly.

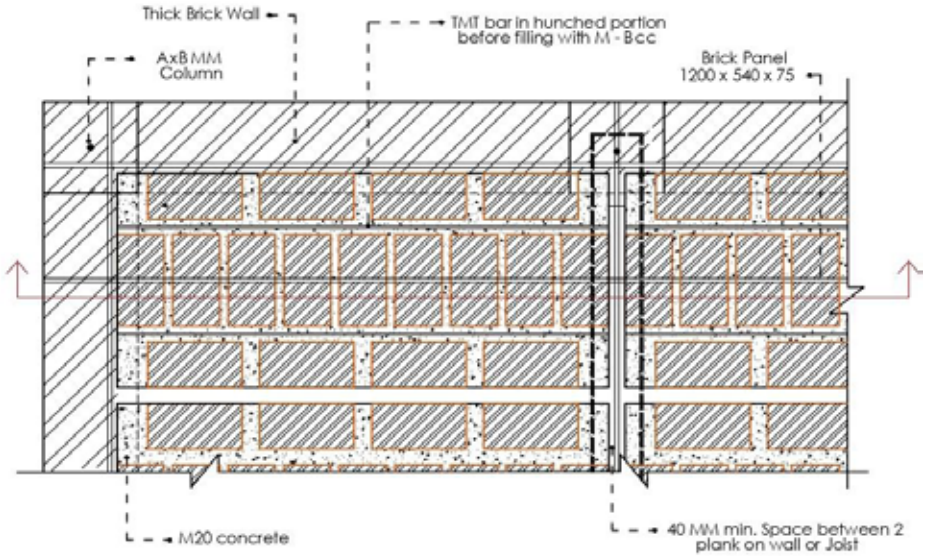
Market Linkages

1. The precast components can be cast at construction site.
2. The components can also be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.

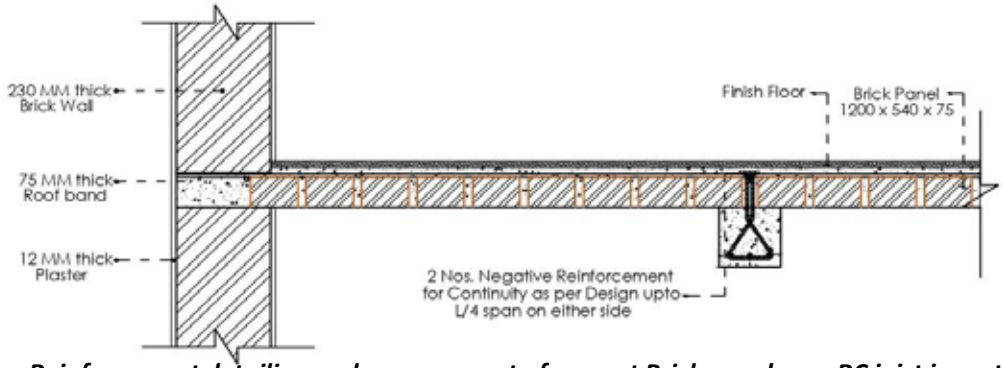
Cost

1. Overall about 25-35% savings compared to RC slab cost.

Floor/Roof system



Reinforcement detailing and arrangement of precast Brick panel over RC joist in plan



Reinforcement detailing and arrangement of precast Brick panel over RC joist in section

Specifications

Prefab Brick panel *(Refer IS 14142:1994 & 14143:1994)*	**Size** : Length max. Up to 1200m, Width 540 mm for conventional burnt clay bricks (230x110x75), thickness 75 mm **Longitudinal joints**: thickness to be 40 mm to accommodate 6 dia. rebar with adequate cover. **Transverse joints**: thickness to be 15-30 mm depending on the brick size. **Concrete Mix** : M20 **Reinforcement** : 6 mm dia. TMT- 2 Nos. for main reinforcement and @200 mm c/c in transverse direction **Weight** : 75 kg
Partially Precast RC Joist *(Refer IS 14142:1994 & 14143:1994)*	**Size** : Length not more than 3.3 m, cross section 150 mm x 150 mm **Concrete Mix** : M20 **Reinforcement** : 6 mm dia., TMT stirrups @ 130mm c/c Longitudinal 3 Nos. 8 to 12 mm dia. TMT bars as per design. **Weight** : 180 kg for 3.3m length.
Brick Panel and Joist Roof *(Refer CBRI BRN-79 and IS:875-1987)*	**In-situ concrete mix** : M20 with 12 mm and down well graded coarse aggregate **Overall depth :** min 220 mm over joist concrete and 75 mm at flange. About 40 mm thick screed concrete over brick panels with nominal steel. **Bedding for joist** : 300 x 230 x 75 mm block of cement concrete M20. **Design Load** : As per IS: 875 for residential buildings.

Relevant Standards and References

1. Prefab brick panel system for roofing flooring , Building Research Note- 79, Central Building Research Institute, Roorkee.
2. IS 14142: 1994, Design and Construction of Floors and Roofs with Prefabricated Brick Panel- Code of Practice, Bureau of Indian Standards, New Delhi.
3. IS 14143: 1994, Prefabricated Brick Panel and Partially Precast Concrete Joist for Flooring and Roofing Specification, Bureau of Indian Standards, New Delhi.
4. IS 875 :1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Precast Channel Unit

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions

All regions except costal regions of the country

About the Technology

This system is used for faster and economical construction of floors and roofs in single and multi-storey buildings. It consists of a full span trough shaped precast RCC unit which can be used for floors and roofs supported on suitable structures like brick/stone walls and RCC beams . The outer sides of the unit are corrugated and are grooved at the ends to provide shear key action between adjacent units. Nominal width of the unit varies from 300 mm to 600 mm, its depth from 130 mm to 200 mm and a minimum flange thickness of 30 mm. The length of the unit may be adjusted to suit the span to be covered, but the maximum length is restricted to 4200 mm for stiffness considerations. Horizontal corrugations are provided on the two longitudinal faces of the units so that the structural floor/roof acts monolithic after the concrete, grouted in the joints between the units, attains strength.

Main reinforcement of the channel units shall comprise two bars of required diameter as per the design placed at the bottom of two legs of channel unit. Two bars of TMT steel 6mm dia. shall be provided at top corners to support the stirrups. Stirrups of 3 mm dia. at the rate of 300 mm c/c along the length of the channel unit shall be provided.

The mould should be made from well seasoned good quality timber or steel. For economy in the long run in large projects, it is advantageous to have steel moulds or to line the surface of timber moulds coming in contact with concrete. by G.I. sheet.

Material Requirements *(per unit)*

Precast Channel unit Size 3300x 600 mm x 180 mm deep	M20 Concrete- 0.1 cum TMT Steel- 12 kg

Tools and Equipments

a) Steel/timber moulds b) Plate and electric vibrator
c) Light hoisting equipment d) mason's tools

Salient Features

1. Use of pre-cast roof elements saves construction time.
2. Shuttering is not needed which increases productivity.
3. Saves cement, steel, shuttering and construction time.
4. Pre- fabrication leads to better quality control.
5. 300 mm wide units can be handled manually, while 600 mm wide need mechanical equipment for handling and erection.
6. It's is a simple building technology which can easily be adapted by semi- skilled labour.

Economic Aspects

1. This system is 25-30% cheaper as compared to RCC slab due to savings in cement, steel, aggregate, shuttering & construction time.

Sustainability Aspects

1. Saves about 110 MJ of embodied energy against RC slab.

Limitations

1. Since the length is restricted to 4200 mm, this system may not be suitable for rooms with larger spans.
2. Special precautions are needed to bind the units together in high seismic areas (Zone IV and V).

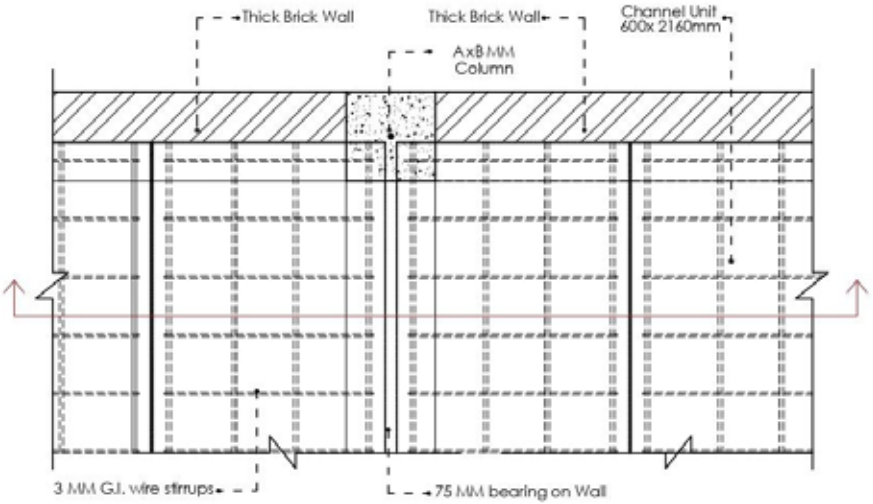
Market Linkages

- The precast components can be cast at construction site.
- The components can also be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.

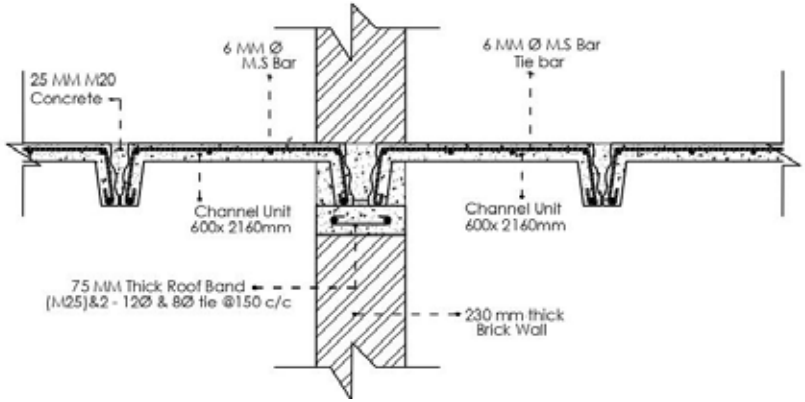
Cost

1. Approx. 25-35% savings are achieved against RC slab roof.

Floor/Roof system



Reinforcement detailing and arrangement of RC channel unit in plan



Reinforcement detailing and arrangement of RC channel unit in section

Specifications

Precast Channel unit *(Refer IS 14201: 1994, 14215: 1994 and IS 456:2000)*	**Size** : Length up to 4200mm (preferred up to 3500mm), Width 300 to 600 mm and depth 130 to 200mm. **Concrete Mix** : M20 concrete with 12 mm and down well graded aggregate **Reinforcement** : 8mm dia. TMT- 2 Nos. at top corners and Stirrups of 3 mm dia. @300 mm c/c along the length of the channel unit. 2 main reinforcement bars 10 to 14 mm at bottom legs as per span and design. **Weight** : 240 Kg for 3300x600x180 mm size **Design load:** As per IS 875-1987 and 456-2000 for residential buildings.
In-situ concrete *(Refer CBRI BRN-52)*	**In-situ concrete mix** : M20 with 10 mm and down well graded coarse aggregate. All concrete work to be well compacted using electric vibrator.

Relevant Standards and References

1. Precast channel unit for floor/ roof , Building Research Note- 52, Central Building Research Institute, Roorkee.
2. IS 14201 : 1994, Precast Reinforced Concrete Channel Units for Construction of Floors and Roofs – Specification, Bureau of Indian Standards, New Delhi.
3. IS 14215 : 1994, Design and Construction of Floors and Roofs with Precast Reinforced Concrete Channel Units- Code of Practice, Bureau of Indian Standards, New Delhi.
4. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
5. IS 875 :1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Precast R.C. Waffle Unit

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions

All regions except costal regions of the country

About the Technology

This scheme is suitable for floors/roofs spanning in two directions, having a span of 9m or above in either direction. It consists of nominally reinforced precast concrete units, called waffle units, laid in a grid pattern and cast-in-situ concrete in the joints between them, together with the required amount of reinforcement. No deck concrete is provided over the units. The finished slab has a pleasant grid pattern in the soffit.

The units are in the shape of inverted trough, square or rectangular in plan, having lateral dimensions up to 1200mm. Reinforcement is provided in the flange in the form of steel wire fabric having 3mm dia. Wires at 150 mm centre to centre distance both ways.

The mid span sections are designed as tee sections with precast flange taking the compression and main reinforcement at the bottom of in –situ concrete taking the tension. The support sections are designed as doubly reinforced rectangular beams with a width equal to the sum of the thickness of the precast webs and width of in-situ concrete joint.

The mould consists, mainly, of two parts- peripheral frame which forms the sides of the units and a inside box which forms the trough, together with two angle iron lifting handles by which the box is removed. The top of the units is formed by casting platform itself.

Material Requirements *(per unit)*

Precast R.C. Waffle unit Size 1200mm x1200 mm x450 mm deep	M20 Concrete- 0.018 cum TMT Steel- 4.5 kg

Tools and Equipments

a) Steel/timber moulds b) Plate vibrator c) Light hoisting equipment d) mason's tools e) casting platform d) Plain centering and shuttering

Salient Features

1. Preferred in construction of two-way slabs of large span (above 9 m).
2. Use of pre-cast roof elements saves construction time.
3. Only flat Shuttering or propping is needed which increases the productivity thereby making it a cost-effective construction technique for RC grid slab.
4. Pre- fabrication leads to better quality control.
5. The size of components is such that they can easily be handled manually if mechanical handling/erection equipment is not available.
6. Can be easily cast and assembled by semi- skilled labour.

Economic Aspects

1. This scheme is 30% cheaper compared to RCC slab; savings in cement and steel are 16% and 12.5% respectively. Also, 16% savings in aggregates and formwork.

Sustainability Aspects

1. Precast waffle slab has lower carbon foot-print and lower embodied energy as compared to conventional RCC slab.

Limitations

1. Suitable for large span 2 way grid slabs. Not economical for small houses with small spans.

Market Linkages

1. The precast components can be cast at construction site.
2. The components can also be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.

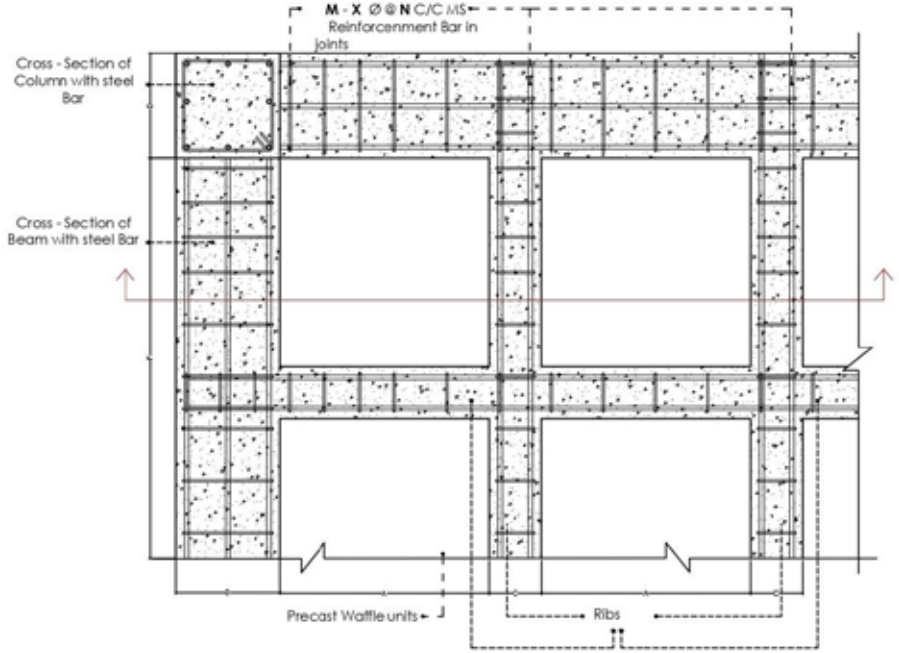
Cost

1. Approx. 20-30% savings over RC grid slab roof/floor.

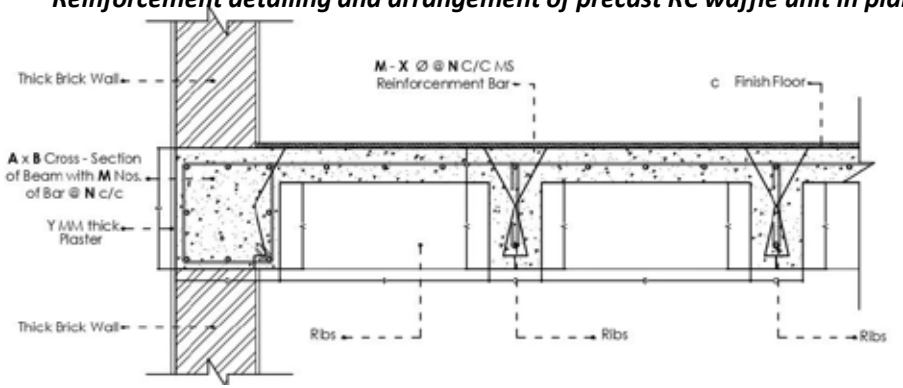




Floor/Roof system



Reinforcement detailing and arrangement of precast RC waffle unit in plan



Reinforcement detailing and arrangement of precast RC waffle unit in section

Specifications

Precast R.C. Waffle unit *(Refer IS 10505:1983 and IS 456:2000)*	**Size** : to be designed as per loads and span. **Concrete Mix** : M20 concrete with 10 mm and down well graded aggregate **Reinforcement** : As per design **Weight** : 70 to 150 kg as per size **Design:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete	**In-situ concrete mix** : M20 with 10 mm and down well graded coarse aggregate with required steel in the gaps between the waffle units.

Relevant Standards and References

1. IS 10505-1983 code of practice for construction of floors and roofs using precast concrete waffle units, Bureau Of Indian Standards, New Delhi.
2. IS 456-2000, code of practice for plain and reinforced concrete (reaffirmed 2016), Bureau Of Indian Standards, New Delhi.
3. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Precast Cored Unit

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions

All regions except costal regions of the country

About the Technology

The cored unit is full span self supporting precast RCC structural component. A one-way slab is made over walls/beams with this system. As concrete near the neutral axis does not contribute to its structural strength, it is removed to get a lighter unit. The cored units have the advantage of lighter dead load, better insulation due to hollow core and saving in material & shuttering cost.

Precast Cored Unit It is a precast RCC structural component for roof/floor. The unit is structurally complete and does not require any temporary support or propping during construction. It provides a flush ceiling. The nominal width of the unit is varies from 300 mm to 600 mm with the actual as 295 mm and 595 mm respectively. Though the depth (thickness) of the unit will depend upon the span and loading conditions, a depth of 130 mm can be taken for normal spans up to 3300 mm. The weight of such a unit will be 46 kg per running metre. If mechanical handling facilities are available, units having nominal widths of 600 mm can also be used. The top and bottom of the units are flush while the sides are corrugated with shear keys towards the end. The corrugations on the sides of the units, when filled with in-situ concrete develop monolithicity and help in transferring the loads transversely and also provide space for negative reinforcement over supports.

The mould consists of two longitudinal members, two end pieces, two G.I. pipes and clamps for making the cores. For casting very large number of units, the timber mould shall be stiffened with steel members or may be made entirely of steel.

Material Requirements *(per unit)*

Precast Cored unit Size 3300 mm x 600 mm X 180 mm deep	M20 Concrete- 0.13 cum TMT Steel- 12 kg

Tools and Equipments

a) Steel/timber moulds b) Plate vibrator c) Light hoisting equipment

Salient Features

1. This system has lower self weight and heavy weight capacity and can be used in structures with large spans or loading.
2. Use of pre-cast roof elements leads saves construction time.
3. Shuttering or propping is not needed which increases the productivity thereby making it a cost-effective construction technique.
4. Pre- fabrication leads to better quality control.
5. The size of components is such which can easily be handled manually without heavy mechanical handling and erection equipment.
6. Can be easily be adapted by semi- skilled labour.

Economic Aspects

1. Saves construction cost by about 15% over RCC slab.
2. Saves construction time by about 50% over in-situ RCC.

Sustainability Aspects

1. Embodied Energy 690 MJ /sq.m as compared to 750 MJ/sq.m for a 100 mm thick RCC roof.

Limitations

1. Difficult to transport and assemble in remote/hilly regions

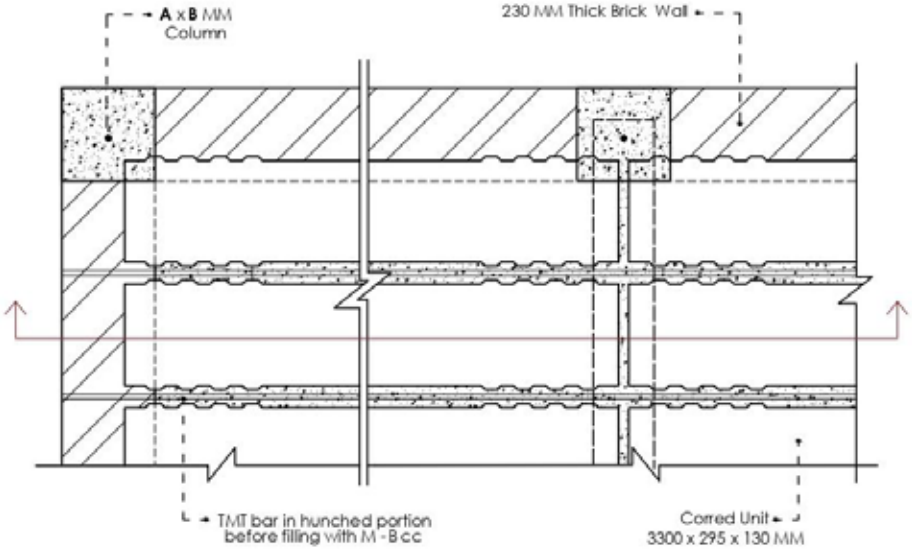
Market Linkages

1. The precast components can be cast at construction site.
2. The components can also be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.

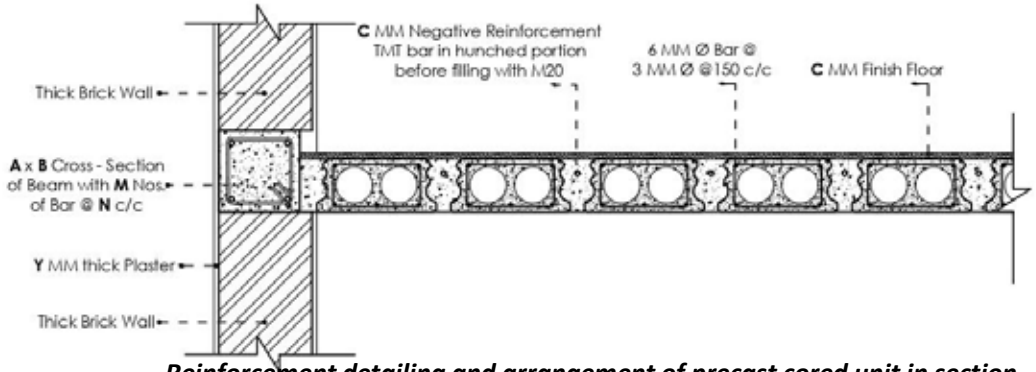
Cost

1. Approx. 15-20% savings over RCC slab.

Floor/Roof system



Reinforcement detailing and arrangement of precast cored unit in plan



Reinforcement detailing and arrangement of precast cored unit in section

Specifications

Precast Cored unit *(Refer IS 10297:1982)*	**Size** : to be designed as per loads and span. **Concrete Mix** : M20 concrete with 10 mm and down well graded aggregate. **Reinforcement** : Main bars of 6 mm dia. TMT- 5 Nos. and Stirrups of 3 mm dia. G.I. Wire @150 mm c/c along the length of the channel unit. **Weight** : 46 kg/ metre length. **Design load:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete *(Refer CBRI BRN-97)*	**In-situ concrete mix** : M20 with 10 mm and down graded coarse aggregate

Relevant Standards and References

1. Precast Cored Unit For Floor/ Roof, Building Research Note- 97, Central Building Research Institute, Roorkee.
2. IS 10297:1982, Code of Practice For Design and Construction of Floors and Roofs Using Precast Reinforced Pre-stressed Concrete Ribbed or Cored Slab Units, Bureau Of Indian Standards, New Delhi.
3. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Precast L-Panel

(alternate of conventional cast-in-situ RCC roof)

Suitable Regions

Only hilly regions and NE part of the country

About the Technology

Prefabricated L-Pan roofing mainly consists of full span R.C.C. L-shaped components. Sheeting and purlins/battens, normally used for a conventional sloping roof, are monolithically composed into single components in this scheme. The precast panel has its section as 'L' . Its smaller leg functions as rib of an L-beam and the wider leg (flange) as sheeting. The length of components depends upon the width of the room and can be up to 4000 mm, though lower size is preferable for ease in handling and erection. Thickness of the flange also varies from 30 to 40 mm mainly on the basis of climatic conditions. In coastal areas and in aggressive environment the reinforcement should be protected against corrosion by suitable treatments. Overlap between two adjacent components also varies from 80 to 150 mm depending upon the climatic conditions.

The precast L-panels can be supported over sloping masonry gable walls, trusses, portal frames or sloping beams. Anchorage rods , if needed, can be inserted through the mortar joints of the top courses in case of walls. In case of rafters with projected stirrups at the top, the in-situ slanting ridge concrete may act structurally in composition, resulting in more economic design of such structures.

The mould should be made of well seasoned good quality timber. For mass production a steel mould may be used. The mould is quite simple and consists of two parts. Outer frame of the L-pan mould is composed of 4 separate pieces and the inner one is a single piece.

Material Requirements *(per unit)*

Precast Cored unit Size 3100 mm x 450 mm x 40 mm	M20 Concrete- 0.07 cum TMT Steel- 7 kg

Tools and Equipments

a) Steel/timber moulds b) Plate vibrator c) Light hoisting equipment

Salient Features

1. Provision of a sloping roof avoids waterproofing courses and reduces both live and dead load resulting in an economic design.
2. Use of pre-cast roof elements leads saves construction time.
3. Shuttering or propping is not needed which increases the productivity thereby making it a cost-effective construction technique.
4. Pre- fabrication leads to better quality control.
5. The size of components is such which can easily be handled manually without heavy mechanical handling and erection equipment.
6. Can be easily be adapted by semi- skilled labour.

Economic Aspects

1. This scheme results in saving approx. 15-20% in overall cost when compared with A.C. sheet roof and about 20 to 30% in comparison to conventional R.C. Slab roof.

Sustainability Aspects

1. Precast L panels are reusable and can be used for temporary constructions or re-construction of a roof.

Limitations

1. it is suitable only in hilly regions and north east region of the country.

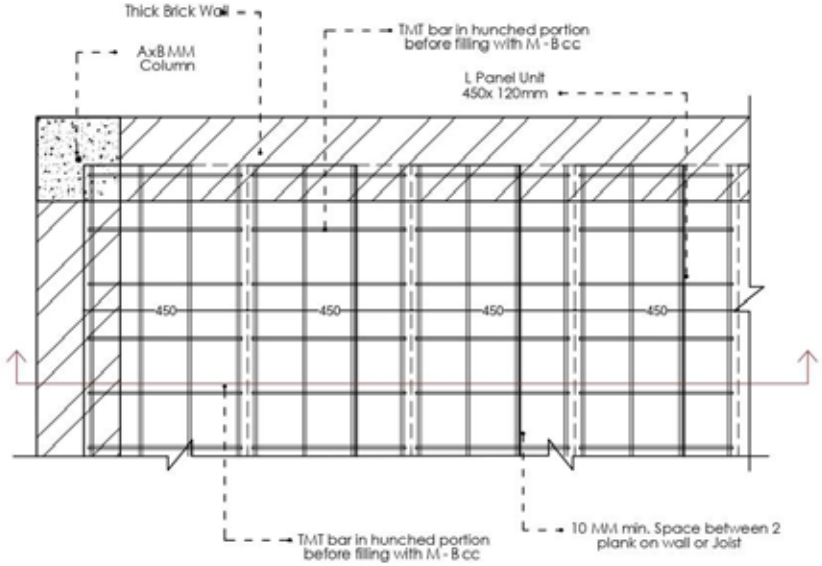
Market Linkages

1. The precast components can be cast at construction site.
2. The components can also be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.

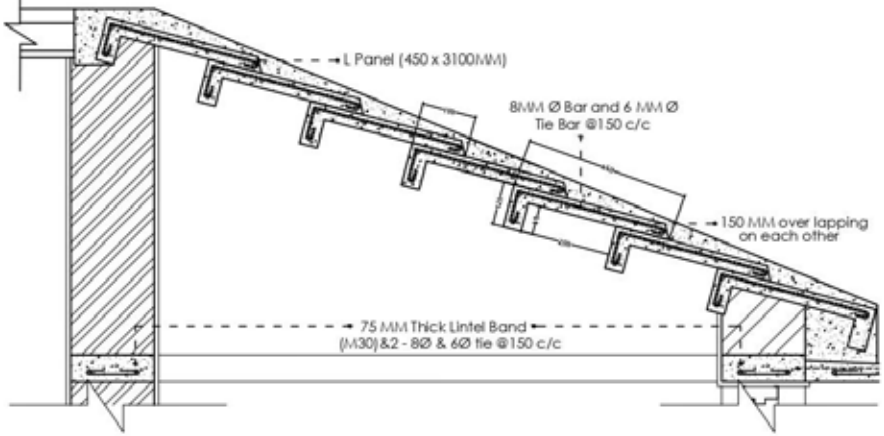
Cost

1. Approx. 25-30% savings of total slab concrete cost.

Floor/Roof system



Reinforcement detailing and arrangement of precast L-panel unit in plan



Reinforcement detailing and arrangement of precast L-panel unit in section

Specifications

Precast L-panel unit *(Refer IS 14241:1994 and 14242:1994)*	**Size** : Length up to 4000 mm, width 450 mm and thickness 30 mm to 40 mm. **Concrete Mix** : M20 **Reinforcement** : Main bars of 8 mm dia. TMT- 5 Nos. And 6 mm dia. Tie bars @150 mm c/c along the length of the unit. **Weight** : 144 Kg for size 3100 mm x 450 mm x 40 mm. **Design load:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete *(Refer CBRI BRN-61)*	**In-situ concrete mix** : M20 with 12 mm and down well graded coarse aggregate.

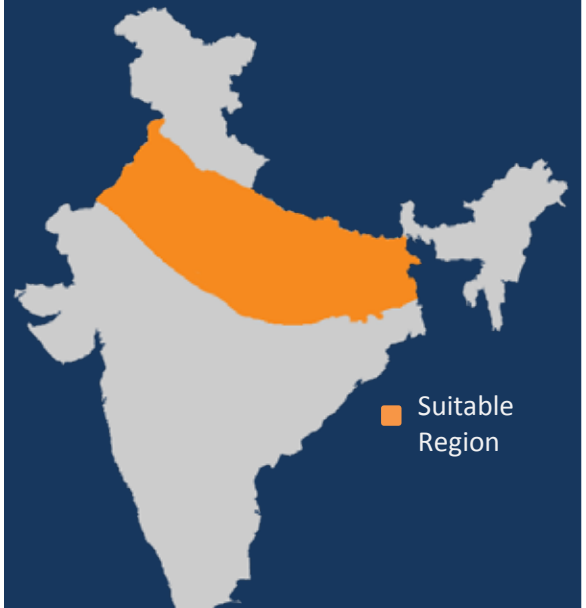
Relevant Standards and References

1. L-Pan Roofing, Building Research Note- 61, Central Building Research Institute, Roorkee.
2. IS 14241:1994 , Precast Reinforced Concrete L-panel for Roofing- Specification, Bureau Of Indian Standards, New Delhi.
3. IS 14242:1994 , Code of practice for design and construction of roof with L-Panel units, Bureau Of Indian Standards, New Delhi.
4. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Reinforced Brick Concrete (RBC) Slabs

(alternate of conventional cast-in-situ RCC roof)

Suitable Regions



States where brick is easily available.

About the Technology

Reinforced brick (RB) and Reinforced Brick Concrete (RBC) floors and roofs are widely adopted, particularly in the Northern parts of the country where good quality of bricks are available and stone chips for concreting are costly.

RBC construction has been found to be strong, durable and it also facilitates quick construction. However, if the bars happen to come in contact with bricks , corrosion of bars may start. Therefore, care must be taken to ensure that the rebars are properly encased in concrete .

This type of construction method consists of laying high strength bricks directly over the formwork with reinforcements in between the joints and filling up the joints with concrete.

The bricks are laid flat on the formwork with at least 25mm gaps to accommodate steel bars. This spacing can be increased up to 60 mm to prevent corrosion. Reinforcement bars are then laid in these gaps. Proper cover is ensured all round the reinforcement for protection against corrosion. M20 Concrete is then poured in the gaps to fill the joints with clear cover to the reinforcing bars. At least 40 mm M20 concrete layer is provided on the bricks to give a 110 mm thick RBC slab. Any floor finish can be provided in case of intermediate floors and waterproofing treatment of lime concrete or mud phuska with tiles .in case of roof.

Material Requirements *(per cubic meter)*

Reinforced Brick Concrete slab	Bricks- 260 M20 Concrete- 0.48 cum TMT Steel- 32 kg

Tools and Equipments

a) Centering & shuttering b) Concrete mixer c) Plate vibrator d) Bar cutting tools e) general mason's tools

Salient Features

1. RBC slabs are cheaper than RCC slabs where good clay bricks are locally available and stone is transported from a distance.
2. Bricks only act as filler material in the tensile zone.
3. Self load of the RBC slab is less than RCC slab.

Economic Aspects

1. RBC slabs are 24-30% cheaper as compare to RCC slabs where good clay bricks are locally available.

Sustainability Aspects

1. RBC slabs have Embodied Energy almost equal to RCC slabs. Use of local bricks reduces transportation.

Limitations

1. Brick, being a porous material, absorbs moisture from the air which may lead to corrosion of reinforcement bars if these are not properly encased in concrete.
2. Suitable only where good quality burnt clay bricks are locally produced.

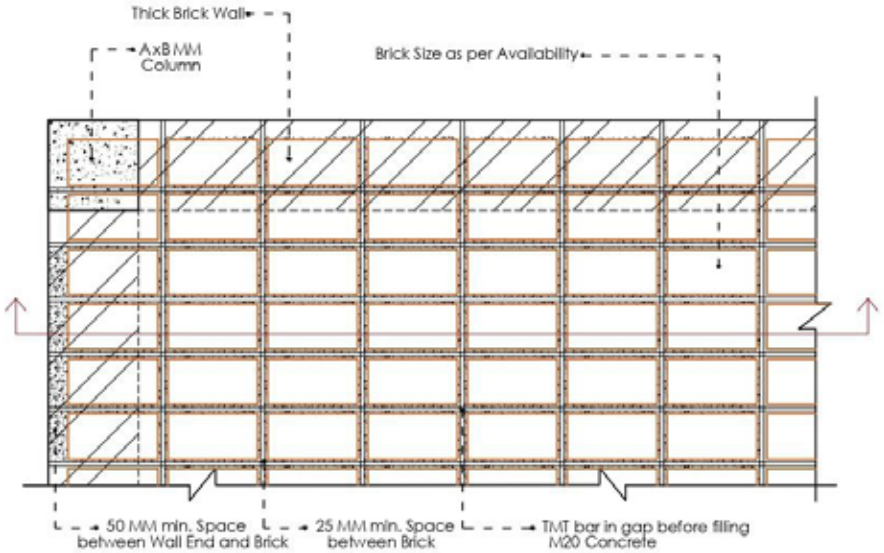
Market Linkages

1. Can be cast by locally available masons/ contractors.

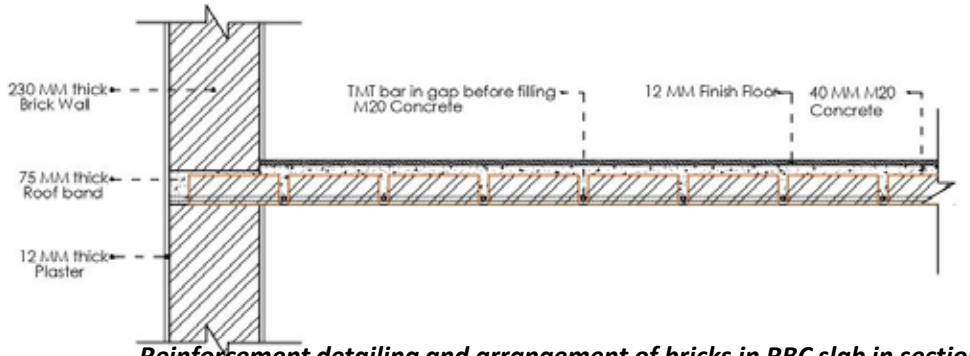
Cost

1. Approx. 25-30% savings over RCC slab.

Floor/Roof system



Reinforcement detailing and arrangement of bricks in RBC slab in plan



Reinforcement detailing and arrangement of bricks in RBC slab in section

Specifications

Reinforced Brick Concrete slab *(Refer IS 10440:1983, IS 456:2000 and IS 875:1987)*	**Size** : to be designed as per loads and span. **Concrete Mix** : M20 **Reinforcement** : As per IS 456:2000. The horizontal distance between two parallel main reinforcement shall not be more than three times the effective depth of the slab or 450 mm whichever is smaller. The pitch of the distribution bars shall not be more than five times the effective depth or 450 mm whichever is smaller. **Design:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete *(Refer IS 456:2000)*	**In-situ concrete mix** : M20 with 12 mm and down well graded coarse aggregate.

Relevant Standards and References

1. IS 10440:1983, Code Of Practice For Construction Of RB And RBC Floors And Roofs, Bureau Of Indian Standards, New Delhi.
2. IS 456:2000, Plain and Reinforced Concrete - Code of Practice, Bureau Of Indian Standards, New Delhi.
3. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Reinforced Cement Concrete Slabs

(conventional system for floor/roof)

Suitable Regions

All regions of the country

About the Technology

Cement Concrete is a hardened mass obtained from a mixture of cement, sand, gravel and water in definite proportions. These ingredients are mixed together to form a plastic mass which is poured into desired shape moulds. Cement concrete has very low tensile strength. To improve the tensile strength of concrete, steel reinforcement is needed which can take up the tensile stresses developed in the structure. The most common type of reinforcement is in the form of steel bars which are quite strong in tension.

The steel reinforcement, generally in the form of steel bars, are placed in the tensile zone of the cement concrete, bearing the tensile stresses and the concrete is called as reinforced cement concrete (R.C.C.).

R.C.C. is a versatile construction material which is strong in compression as well as in tension. The use of reinforcement in concrete not only increase its strength but also helps in preventing the temperature and shrinkage stresses. RCC slabs with varying thickness from 100mm to 150mm are generally used for construction of floors and roofs.

Material Requirements *(per cubic meter)*

Reinforced Cement Concrete slab (100 to 150mm thick)	M20 Concrete- 1 cum - Cement = 350 kg - Sand= 700 kg - Aggregate= 1200 kg - Water= 150 Litres. TMT Steel- as per design

Tools and Equipments

a) Centering & shuttering b) Concrete mixer c) Plate and needle vibrator d) Bar cutting tools

Salient Features

1. R.C.C. has very good strength in tension as well as compression.
2. R.C.C. elements are durable if designed and cast properly.
3. R.C.C. sections can be given any shape easily by properly designing the formwork. Thus, it is more suitable for architectural requirements
4. R.C.C. structures are more fire resistant than other commonly used construction materials like steel and wood.

Economic Aspects

1. RCC construction work is costly with high labour cost, material cost and machinery cost.

Sustainability Aspects

1. Have Embodied Energy 750 MJ/sq.m for a 100 mm thick RCC roof.

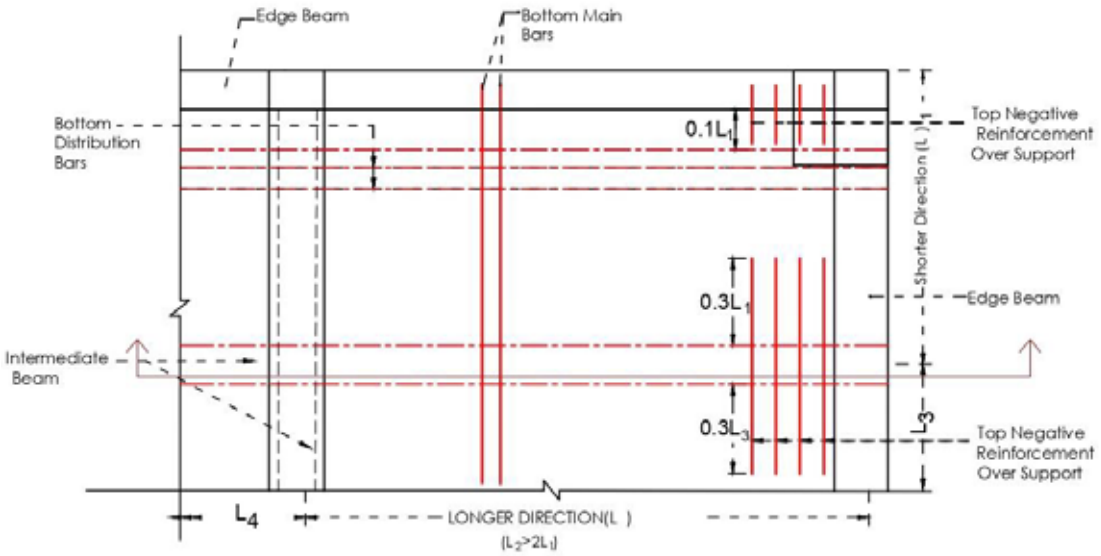
Limitations

1. R.C.C. structures are heavier than structures of other materials.
2. R.C.C. needs form-work, centering and shuttering to be fixed, thus requires site space and skilled labour.
3. Concrete takes time to attain its full strength. Thus, R.C.C. structures can't be used immediately after construction unlike steel structures

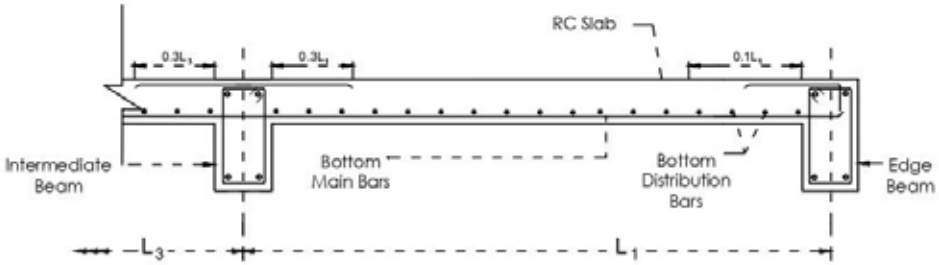
Market Linkages

1. Can be cast by locally available contractors.

Floor/Roof system



Reinforcement arrangement in RCC slab in plan



Reinforcement arrangement in RCC slab in section

Specifications

Reinforced Cement Concrete slab *(Refer IS 456:2000 and IS 875:1987)*	**Size** : to be designed as per loads and span. **Concrete Mix** : M20 **Reinforcement** : As per IS 456:2000. The spacing of bars shall not exceed 2 times the slab thickness, except where a slab is of cellular or ribbed construction. **Design load:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete *(Refer IS 456:2000)*	**In-situ concrete mix** : 1:1.5:3 for M20.

Relevant Standards and References

1. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
2. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Filler Slabs

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions

Preferred in the southern region of the country

About the Technology

Filler slab technology is a simple and cost effective technology. In this technology, concrete is partially replaced with light weight and low cost filler material.

The filler materials are so placed that the structural strength, stability and durability is not compromised, resulting in replacing ineffective and non-functional tension concrete. This results in economy in consumption of high energy incentive material, cost savings and decreased dead load of the slab.

An internal cavity can be provided between the filler material which adds an extra advantage of improved thermal comfort for the interiors.

Light weight, inert and inexpensive materials such as low grade Mangalore tiles, Thermopolis Burnt Clay Bricks, Hollow Concrete blocks, Stabilized Mud blocks/ Hollow Mud blocks, Clay pots, Coconut shells, AAC blocks and so can be used as filler materials. These materials are laid in the grids of steel reinforcement and concrete topping is done over them.

Material Requirements *(per unit)*

Filler slab Size 2540 mm × 386 0 mm x 100 mm thick	Cement- 342.35 kg Sand- 0.39 cum Aggregate- 0.78 cum TMT Steel- 17.48 kg
Mangalore tile (filler material) Size 420 mm x 250 mm	No. Of tiles= 93.4

Tools and Equipments

a) Centering & shuttering b) Concrete mixer c) Plate and needle vibrator d) Bar cutting tools

Salient Features

1. It is cost effective, provides thermal effectiveness to the roofing technology and substantial reduction in the dead load.
2. Filler slabs can be kept exposed (with proper workmanship) to create aesthetically pleasing ceiling with a view of filler material from below and thus the cost of plastering and/or painting also can be avoided.
3. Reduction in concrete quantity compared to conventional slab construction, adds this technology to the list of sustainable and environment friendly technologies, incorporating green building features.

Economic Aspects

1. This technology results in 15-20% saving in overall cost; 19% in cement and 38% in steel as compared to conventional RCC slab floor / roof.

Sustainability Aspects

1. The total embodied energy can be significantly reduced by about 15% when compared with solid RCC slab.

Limitations

1. Proper bond between the filler material and overcast concrete needs to be ensured.
2. It demands dense concrete overlay to avert water ingress.

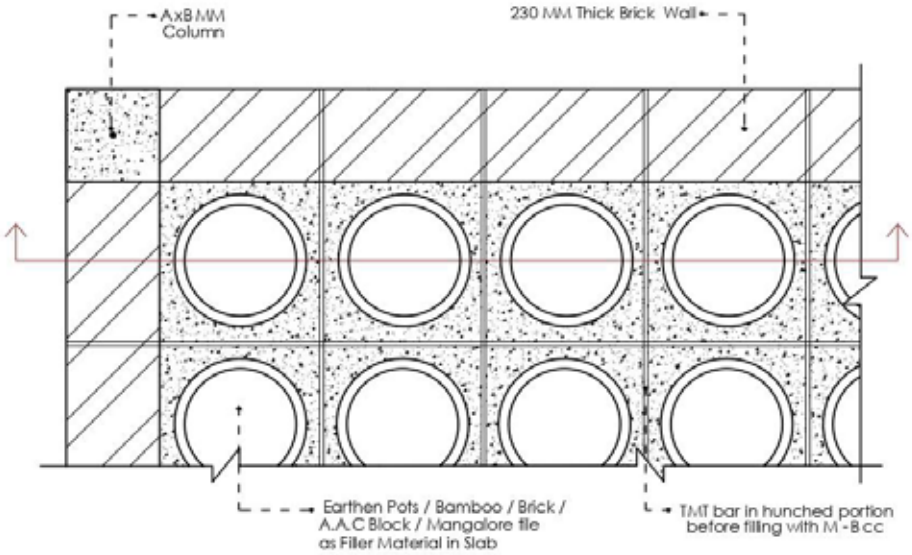
Market Linkages

1. Regional level agencies.

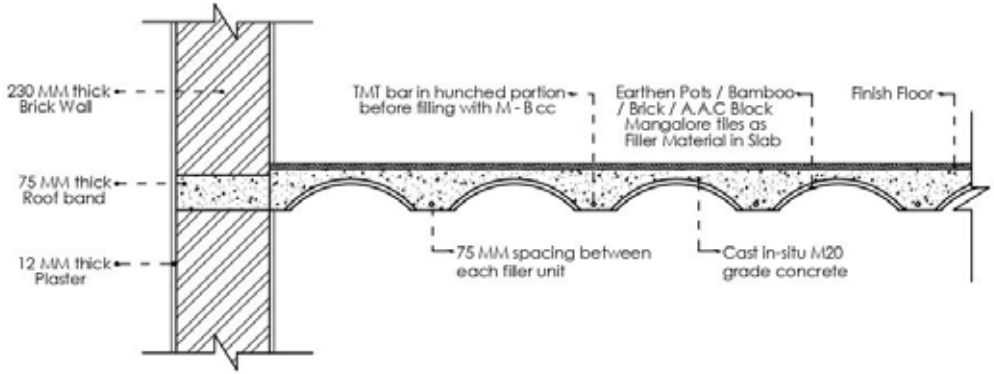
Cost

1. Approx. 25-30% savings in cost as compared to conventional RC slab.

Floor/Roof system



Arrangement of filler material and reinforcement in Filler slab in plan



Arrangement of filler material and reinforcement in Filler slab in section

Specifications

Filler slab *(Refer IS 456:2000 and IS 875:1987)*	**Size** : To be designed as per loads and span. Minimum thickness of the slab should be 100 mm. **Concrete Mix** : M20 For a 200 sq.m house slab- Cement- 6847 kg Course aggregate- 15.51 cum Fine aggregate- 7.76 cum **Reinforcement** : As per IS 456:2000. The distance between two parallel main reinforcement shall not be more than three times the effective depth of the slab or 450 mm whichever is smaller. The pitch of the distribution bars shall not be more than five times the effective depth or 450 mm whichever is smaller. For a 200 sq.m house slab- Steel- 349.58 kg **Filler material:** The distance between each unit of filler unit should be 75mm. For a 200 sq.m house slab with Mangalore tiles as filler material- Number of tiles- 1468.73 **Design load:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete *(Refer IS 456:2000)*	**In-situ concrete mix** : M20 with 12 mm and down well graded coarse aggregate.

Relevant Standards and References

1. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
2. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Ribbed Slabs

(alternate of conventional cast-in-situ RCC floor/roof)

Suitable Regions

Preferred in hilly regions & earthquake prone areas

About the Technology

Thin Reinforced Concrete ribbed slab consists of precast R.C. ribs 110 x 200 mm spaced at 1200 mm c/c with 50 mm thick cast-in-situ R.C. flange above. It can be used for flat as well as sloping floor/roof in residential and other lightly loaded buildings. In case of heavily loaded floors and roofs, the size and reinforcement of the ribs and flanges shall have to be increased appropriately. Conventional floor/roof finish has to be used above the ribbed slab, as the case may be. Ceiling plaster can be omitted in low cost constructions. In situations, where very good finish is called for, ceiling should be plastered.

The ribs are designed as rectangular RC beams to support the weight of concrete in the flange, the shuttering and the live load of workmen and equipments during construction. They act as T-beams for full design loads, after the concrete in the flanges has attained strength. The flange is designed as a continuous slab spanning the ribs . To keep the deflections within permissible limits, the span/depth ratios for the flange and the rib have been kept as per relevant provisions of IS : 456-2000. To ensure monolithic action of precast ribs with cast in-situ flange, stirrups in the ribs are projected into the cast-in-situ concrete of the flange.

The ribs are precast, preferably in steel moulds over a casting platform. To provide holes in the ribs, 25mm square, MS hollow box sections are inserted through square holes in the longitudinal members of the mould. At least 20 reuses can be expected from G.I. sheet lined shuttering for casting the flange portion. Alternately, steel shuttering panels may be used to increase the number of reuses.

Material Requirements *(per unit)*

Precasting of Rib (1 no.) Size 110mm X 200mm and 3600mm	M20 Concrete- 0.0792 cum TMT Steel- 10 kg

Tools and Equipments

a) Steel/timber mould b) Needle & Plate vibrator c) Light hoisting equipment d) Centering & shuttering

Salient Features

1. Long slab spans can be constructed up to 4000mm through ribbed slabs.
2. In this type of roof system, chances of leakage and seepage is less.
3. This roofing system is a combination of precast R.C. Ribs and cast in-situ R.C. Flange.

Economic Aspects

1. This scheme is 30% cheaper as compared to RCC slab; savings of 47% in cement and 14% of steel in case of 140mm thick RCC slab.

Sustainability Aspects

1. Due to reduction in cement and steel consumption, less carbon footprint is expected in this technology.

Limitations

1. For spans smaller than 1500mm , this technology is not viable.

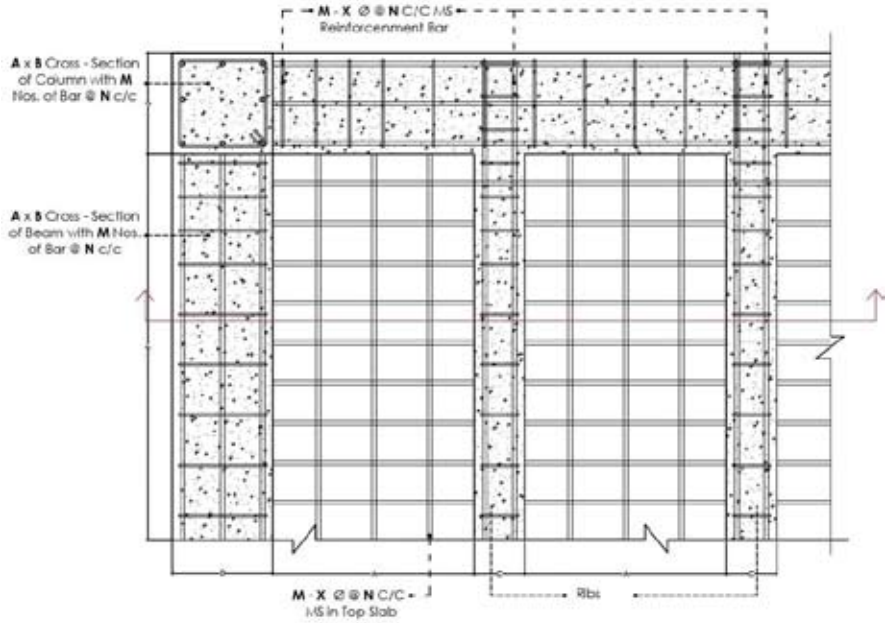
Market Linkages

1. It can be locally cast at the construction site.

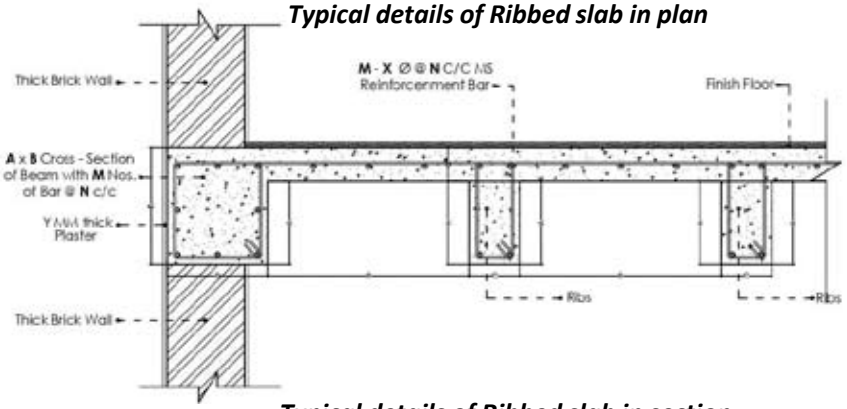
Cost

1. Approx. 25-35% in slab cost as compared to conventional concrete slab.

Floor/Roof system



Typical details of Ribbed slab in plan



Typical details of Ribbed slab in section

Specifications

Ribbed slab *(Refer CBRI BRN-5, IS 456:2000 and IS 875:1987)*	**Size** : To be designed as per loads and span. **Concrete Mix** : M20 with 20 mm an d down, graded coarse aggregate, thoroughly compacted by plate vibrator. **Reinforcement** : 6 mm dia. bars for main reinforcement @ 150 mm c/c longitudinally and @ 100 mm c/c in transverse direction. **Design load:** As per IS 456:2000 and loading for residential buildings as per IS 875:1987.
In-situ concrete *(Refer CBRI BRN-5)*	**In-situ concrete mix** : M20 with 12 mm and down, graded coarse aggregate is then laid over the shuttering and ribs and compacted to a thickness of 50 mm by a plate vibrator.

Relevant Standards and References

1. Thin R.C. Ribbed Slab For Floors And Roofs , Building Research Note- 5, Central Building Research Institute, Roorkee.
2. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
3. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Roof Construction Technologies

Timber Roof Truss

(alternate of conventional cast-in-situ sloppy roof)

Suitable Regions

All regions of the country where timber is available.

About the Technology

Timber roof truss (also known as pitched roof) is a structural framework made up of wooden members designed to bridge the space above a room, thus providing support for a roof sheet. Trusses usually occur at regular intervals, linked by longitudinal timbers elements known as purlins. A roof truss is cross-braced into a stable and rigid unit. Ideally, it balances all of the lateral forces against each other, and thrusts directly downwards on the supporting walls. Adequate anchorage of truss is ensured by base plate.

Pre-fabricated wood trusses offer advantages in building construction through machine-made accuracy and tend to use less timber. The earliest wooden truss connections consisted of mortise-and-tenon joints and were most likely crafted at the construction site with the posts. A truss connector plate or a Gusset plate is a thick galvanized steel-sheet that is now being used for connections at the joints; it is fastened to a RC beam with bolts. Plates can help support heavier structural loads than timber alone, which allows for wide-spanned trusses. It can also be used to provide shear resistance and other types of force.

Material Requirements *(per unit)*

Timber Roof truss	- Timber as per design - Nails and plates

Tools and Equipments

a) Carpentry tools

Salient Features

1. Timber trusses are light in weight and can be easily handled and lifted into place.
2. The high strength-to-weight ratios of timber trusses permit long spans, offer greater flexibility in floor plan layout and can be moulded into almost any shape and size.
3. Accurate fabrication and constant quality control assure trusses are uniform in size and shape and provide required structural integrity to a building.
4. They have excellent thermal properties, especially when compared with other framing materials such as steel.
5. It also provides good appearance from the ceiling.

Economic Aspects

1. Saving in cost by 60% in comparison to RC sloppy roof making it a very cost effective roof system.

Sustainability Aspects

1. Timber frame with roof cladding have Embodied Energy 188 MJ/sq.m as compared to 750 MJ/sq.m for a 100mm thick RCC roof.

Limitations

1. Timber trusses are exposed to warping and bowing problems, which can cause structural damage to the rest of the building.
2. Timber trusses are more likely to get damaged in extreme weather conditions.

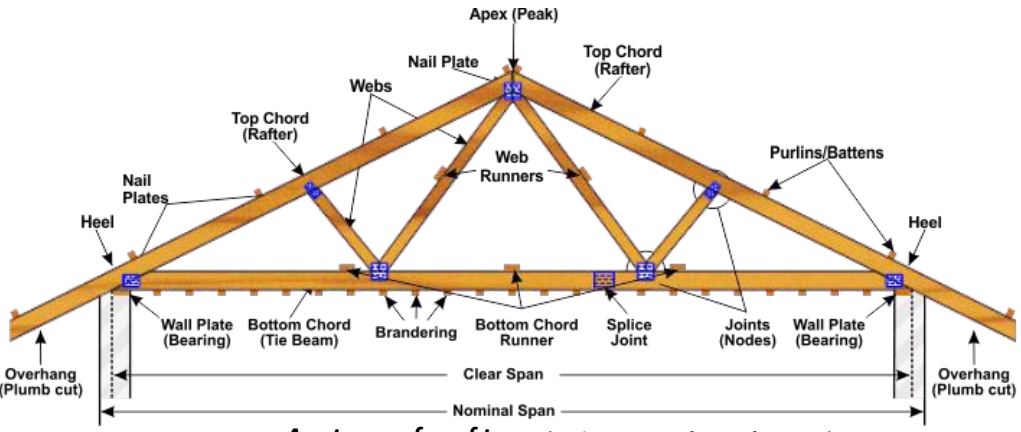
Market Linkages

1. Can be constructed by local contractors and labour skilled in carpentry.

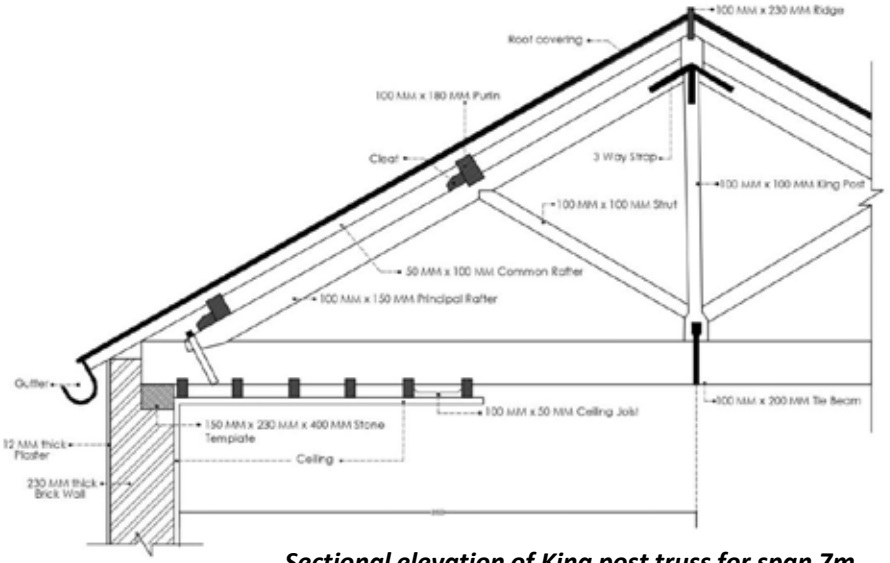
Cost

1. Approx. 60% savings of total slab concrete cost.

Roofing system



Anatomy of roof truss *(Technistrut Roof Manufacturers)*



Sectional elevation of King post truss for span 7m

Specifications

Timber frame *(Refer IS 883:2016, 2366:1983 and IS 875:1987)*	**Size** : suitable for spans up to 18m. **Design load:** As per IS 875:1987 for residential buildings.

Types

Type of Timber roof truss
Collar roof: consists of a collar beam (tie) which is fixed near the middle of the rafters.
Scissor roof: similar to collar roof, the tie beam is fixed in the shape of scissor.
King post truss: framework consist of 2 principal rafters, 1 tie beam, 2 struts and a king post. The trusses are spaced not more that 3m and are connected through purlins.
Queen post truss: consist of 2 principal rafters, a straining beam & sill, 2 inclined struts and 2 queen post.

Relevant Standards and References

1. IS 883 : 2016, Design of Structural Timber in Buildings - Code of Practice (Fifth Revision), Bureau of Indian Standards, New Delhi.
2. IS 2366 : 1983, Code of practice for nail-jointed timber construction, Bureau of Indian Standards, New Delhi.
3. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
4. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Steel Roof Truss

(alternate of conventional cast-in-situ sloppy roof)

Suitable Regions

All regions of the country

About the Technology

In this roofing system, timber is replaced by steel which are used to cover large clear spans. A truss consists of an assembly of rigid but elastic members joined in the form of triangle to act as a beam. The safe working tensile stress of mild steel is about 20 times that of structural timber. Thus, steel trusses work out to be economical, specially for larger spans.

Steel truss is widely used due to its lightweight nature, reduced deflection and the ability to carry heavy loads. Prefabricated steel trusses offer a highly durable roof system that can be installed quickly.

Steel truss can be made of tubular section, MS section and hollow box section. In case of tubular and hollow box section, joints are fully welded to achieve clean appearance. However it is likely that joints with shear members in the truss will require external strengthening to prevent failure of the thin wall. MS or open sections are utilitarian and give more scope for bolted forms of connection. Vertical webs with gusset plates welded on centreline result in a planar element through which forces can flow from member to member which may not require any strengthening.

Depending upon the span of the structure, there are different types of steel trusses, for example, Fink truss for spans up to 10m, Mansard truss for 20-30m, Pratt and Howe truss for 6-30m and Warren truss is used for spans 20-100m. Steel truss is ideal for airport terminals, auditoriums, stadiums and so since complex roof designs can be achieved easily.

Material Requirements *(per unit)*

Steel truss	•Steel members (hollow in case of tubular truss) •Bolts and base plate •Roof coverings

Tools and Equipments

a) Welding tools b) Light hoisting equipment

Salient Features

1. Steel trusses are stronger than timber trusses.
2. Steel sections are light in weight and can be fabricated in any desired pattern and length as per requirement.
3. Resistant to fire as well as rotting of material.
4. Steel sections are easy to handle and install. Hence the construction time is less.

Economic Aspects

1. Steel truss system is about 70% cheaper than RC sloppy roof and 40% savings can be achieved in contrast to wooden truss.

Sustainability Aspects

1. Steel frame with roof cladding have Embodied Energy 460 MJ/sq.m as compared to 750 MJ/sq.m for a 100 mm thick RCC roof.

Limitations

1. Adequate connections and bracing should be ensured.
2. In case of hollow sections, fixing of bolts needs proper attention.

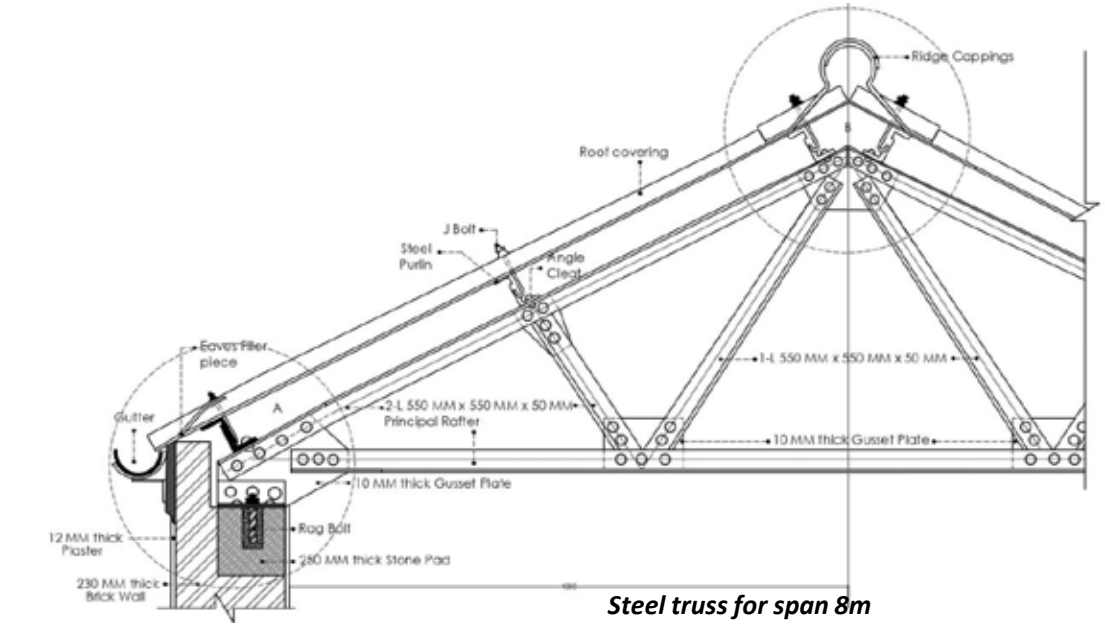
Market Linkages

1. Locally available contractors can fabricate at the construction site.

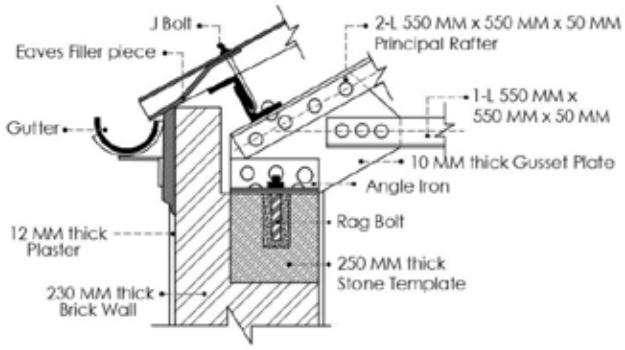
Cost

1. Approx. 60% savings of total slab concrete cost.

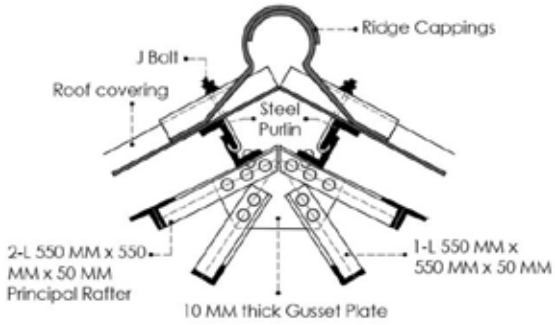
Roofing system



Steel truss for span 8m



Detail at A



Detail at B

Specifications

Steel frame *(Refer IS 806:1968, IS 875:1987 AND SP 38:1987)*	**Size** : To be designed as per load and span. **Design load:** for loading for residential buildings as per IS 875:1987.

Types

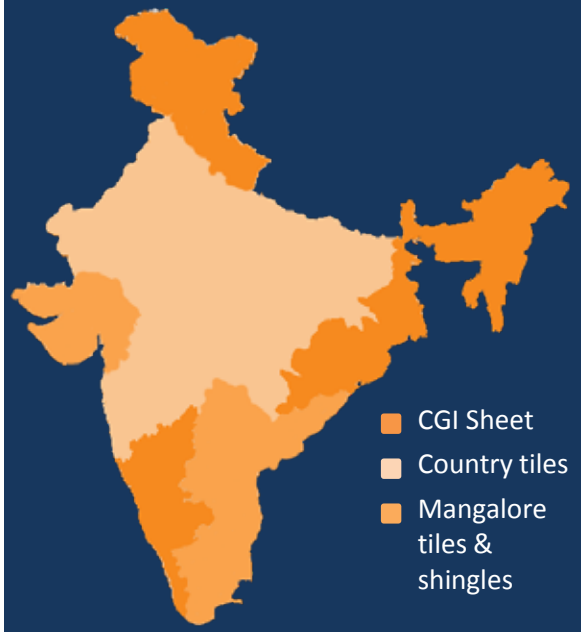
Type of Timber roof truss
Raised chord, Cambered fink and Scissor truss
King post truss and variation of Scissor truss and Cambered fink truss
Simple fink, Fan fink truss, Howe truss and Compound fink
Pratt truss, variations of Fink truss and Howe truss
Camel back truss, Crescent truss, Mansard truss and Bow string truss
Warren truss

Relevant Standards and References

1. IS 800:2007, General Construction In Steel - Code of Practice, Bureau of Indian Standards, New Delhi.
2. IS 806:1968 (Reaffirmed 2008), Code Of Practice For Use Of Steel Tubes In General Building Construction, Bureau of Indian Standards, New Delhi.
3. SP 38 (1987): Handbook of Typified Designs for Structures with Steel Roof Trusses (With and Without CRANES) (Based On IS Codes), Bureau of Indian Standards, New Delhi.
4. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
5. IS 875-1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.

Roof Coverings

Suitable Regions



About the Technology

The selection of roof covering material depends upon various factors such as availability of material, cost, appearance, durability, climate and so.

Mangalore tiles, or corrugated tiles, are the oldest and the most popular tiles since ages. The conventional size of Mangalore tiles is 420mm x 250mm but are available in different sizes to suit different requirements. The tiles can be single or double grooved at the edges and are interlocked while laying.

Country tiles, or curved pan/half round tiles, are attached with nails to the wooden sheathing or the common rafters of the pitched roof spaced 300mm apart. The tiles are 330mm to 380mm long and 230mm to 280mm wide and are laid with sufficient overlap over each other.

Concrete tiles are made of mixture of sand, cement and water, moulded under heat and high pressure. The exposed surface of a tile may be finished with a paint like material. They have additional water locks, or interlocking ribs on the edges that prevent water infiltration. They are resistant to hail, wind, and fire, making them a very safe roofing material when properly installed.

Shingle should only be used on roofs with enough pitch to shed water into the gutter system by gravity alone. Asphalt is the most common type of shingle as it is inexpensive, easy to install, come in a variety of colors and laid in a similar manner as tiles.

Corrugated galvanised iron (CGI) sheets are a lightweight roofing material made of thin sheets, stiffened by corrugations. These sheets shall be properly anchored to each purlin/batten that supports them. Corrugations, such as waves, considerably increase the strength and stiffness of the lightweight material.

Slates, one of the most durable roofing materials, is obtained from sedimentary rocks of limestone or sandstone that is mined and cut to become a form of shingle. Synthetic slate roofing options, like rubber slates, are becoming popular that look identical to the real stone, but cost at least 50-60% less. Compared to stone, these are also lightweight and highly durable.

Tools and Equipments

a) Moulds b) Welding tools c) Carpentry tools

Salient Features

1. Clay tiles are durable, resistant to fire and insect damage. They stand up to extreme weather offering insulating properties.
2. Unlike clay tiles, concrete tiles are not as susceptible to damage due to freezing temperatures, and therefore can be used in almost any climate.
3. Asphalt shingles possess a greater ease of installation and require less maintenance than concrete tiles.
4. GI sheets are low cost, maintenance free and last longer in rural, urban and coastal environments.
5. Rubber slate is extremely durable, extreme weather resistant and completely waterproof.

Economic Aspects

1. The clay tiles can last over 100 years and its total life cycle cost is less as compared to other roof coverings materials as it is made of natural material which makes it maintenance free.

Sustainability Aspects

1. Clay tiles are environmentally friendly & can be recycled.
2. Shingles are recyclable at the end of their useful life & widely used in paving.
3. CGI sheet is a sustainable and recyclable product.
4. Rubber slates are eco-friendly, made from recycled tires, sawdust, and slate dust.

Limitations

1. Clay roof tiles can be heavy, so extra roof support may be necessary before installation, making it costly.
2. Asphalt shingles are susceptible to high wind damage.

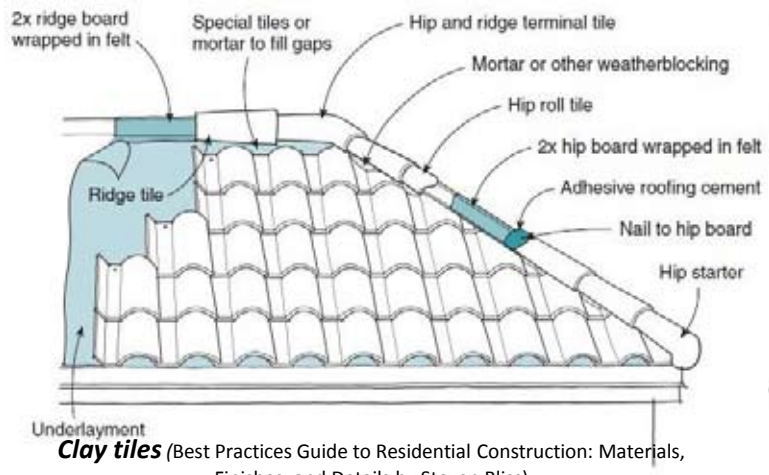
Market Linkages

1. Can be constructed by local contractors and labour skilled in carpentry.

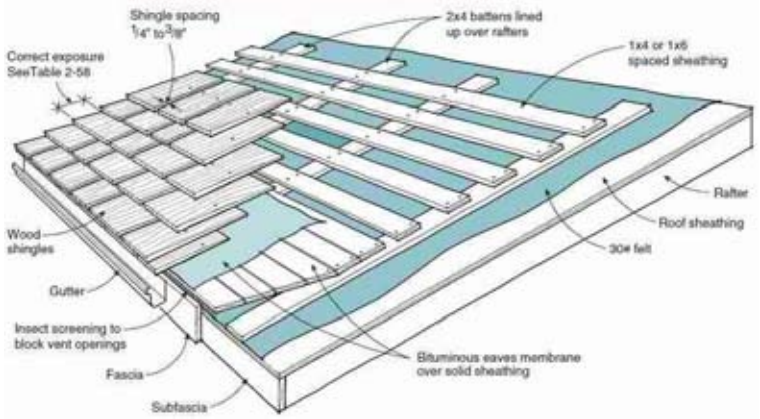
Cost

1. Approx. 25-30% savings of total slab concrete cost.

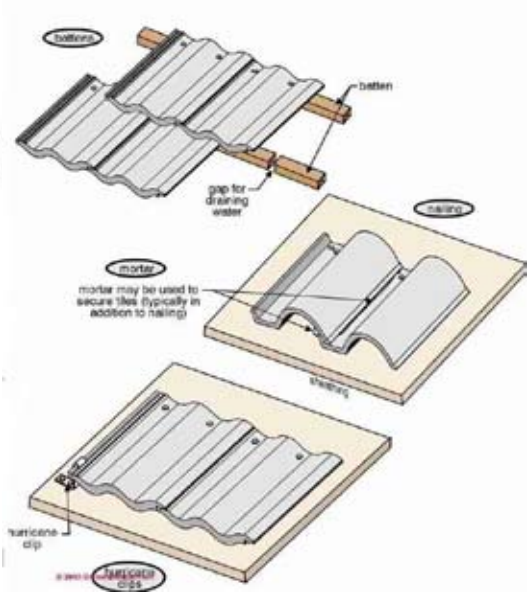
Roofing system



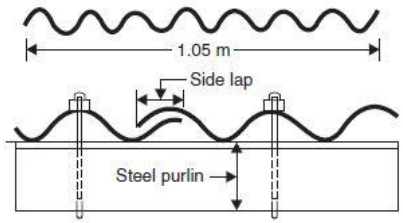
Clay tiles (Best Practices Guide to Residential Construction: Materials, Finishes, and Details by Steven Bliss)



Shingles (Best Practices Guide to Residential Construction: Materials, Finishes, and Details by Steven Bliss)



Concrete tiles *(source: carson dunlop)*



Fixing of CGI sheet

Specifications

Mangalore tiles *(Refer IS 654:1992)*	**Size** : 420mm x 250mm **Weight** : 2.75 kg **Requirement:** 15 Nos./Sq.m
Country tiles *(Refer IS 13317:1992)*	**Size** : 450 mm x 200 mm / 160 mm **Weight** : 1.85 kg **Requirement:** 25Nos./Sq.m
Concrete tiles *(Refer Elabana website)*	**Size** : 420mm x 330 mm **Weight** : 4.4 kg **Requirement:** 9.7 Nos./Sq.m
Asphalt shingle *(Refer IKO website)*	**Size** : 305mm x 915mm (29 shingles in a bundle) **Weight** : 23 to 36 kg per bundle **Requirement:** 3 bundles per square
CGI sheet *(Refer IS 277:2003)*	**Length** :1800, 2200, 2500, 2800, 3000 and 3050 mm. **Width**: as per IS 277:2003. **Thickness**: as per IS 277:2003. **Weight** : varies as per thickness from 2.25 kg to 9.25 kg per square meter.
Rubber slate *(Refer Euroshield website)*	**Size** : 600mm x900 mm x 22 mm **Weight** : 2.26 kg to 3.62 kg **Requirement:** 40 to 48 per 100 sq.ft. depending on profile

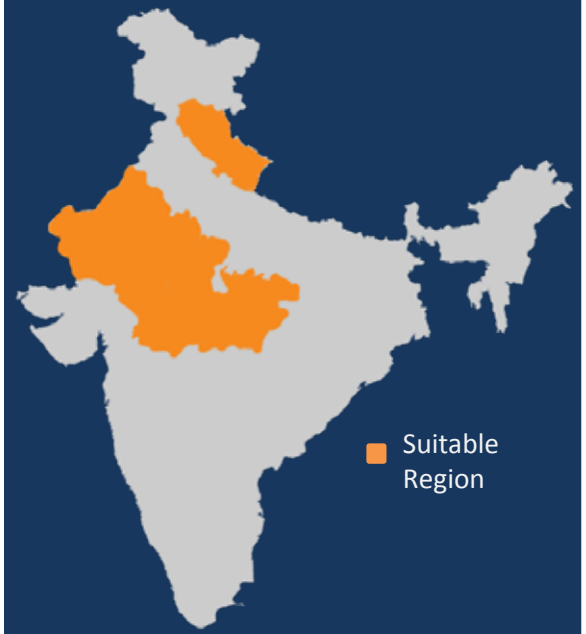
Relevant Standards and References

1. IS 654:1992, Clay Roofing Tiles, Mangalore Pattern-Specification (Reaffirmed 2002), Bureau of Indian Standards, New Delhi.
2. IS 13317:1992, Clay roofing country tiles, half round and flat tiles –Specification (Reaffirmed 2002), Bureau of Indian Standards, New Delhi.
3. IS 277: 2003, Galvanized Steel Sheets (Plain And Corrugated)- Specification, Bureau of Indian Standards, New Delhi.
4. IKO, https://www.iko.com/na/pro/building-professional-tools/roofing-101/iko-shingle-dimensions/
5. Euroshield Roofing Technical Information, http://www.euroshieldroofing.com/technical/
6. Elabana Concrete Roof Tiles, https://www.btiles.com/roofing-tiles/roofing-tiles-concrete.html

Stone coated Steel Roofing

(alternate of conventional cast-in-situ sloppy roof)

Suitable Regions



Suitable in M.P., Rajasthan, H.P. & Uttarakhand.

About the Technology

A stone coated metal roof consists of tiles made from steel or other metal which are coated with stone chips with an acrylic film. The goal is to obtain a durable roof that still retains the aesthetic advantages of a traditional roofing material.

This roofing type boasts of stone coated steel/metal roofs that are fastened to a batten system, a series of vertical and horizontal wood planks that are connected to a roof decking, and in some cases, even through an existing roofing material. The core of stone coated steel roofing panels is structural-grade steel**.** It has the right combination of tensile strength to withstand loads and enough elasticity to allow for stamping into shingle, shake and tile profiles without cracking.

This type of roofing can have the appearance of traditional shingles while delivering the durability and strength of metal. It can be made of 24 or 26 gauge rolled steel sheets with a rust-preventing coating. Stone-coated steel roofing is finished with a thick layer of stone that permanently adheres to the surface and provides the decorative look. Stone-coated steel roof offer comparable performance, but without the added weight of clay or concrete. The manufacturing process of Steel coated metal roof tile involves following steps:

1. Cutting and shaping of metal sheet;
2. First gluing of stone ships;
3. Sanding;
4. First baking of tiles;
5. Second gluing;
6. Final baking and coating.

Metal roofs are known to last a long time if installed properly. Their life span ranges from 40–70 years, compared to asphalt shingles that need to be replaced approximately every 20 years. Steel can withstand gusting winds, heavy rain or hail, and many other adverse weather conditions. Metal roofing actually reflects heat from the sun, rather than absorbing it like a dark asphalt material would. This cuts down on the energy cost to keep your home cool, and it also protects from ultraviolet rays.

Material Requirements *(per unit)*

Stone coated roof tile Size 1340 mm x 420 mm x 0.4mm	Steel sheets Acrylic Priming System Basecoat Ceramic Coated Stone Granules Adhesives Over glaze

Tools and Equipments

(a) Metal cutting & shaping machines, (b) Self threading screws and other carpentry tools

Salient Features

1. Easy and quick to install over existing roofs.
2. The interlocked individual panels can also resist high wind pressures over 120 mph.
3. Low maintenance. The frequency of steel coated metal roof cleaning is less than its counterparts, and even if it reaches its end of life, the materials can still be recycled.
4. Excellent resistance to hail, fire and earthquakes.
5. Pleasing appearance of roof.

Economic Aspects

1. This type of roofing system is 60% cheaper than RCC roofing system.

Sustainability Aspects

1. Steel roofing systems can be recycled an infinite number of times without degradation.
2. Minimum use of natural resources.
3. About 45% energy savings over traditional roofing materials.

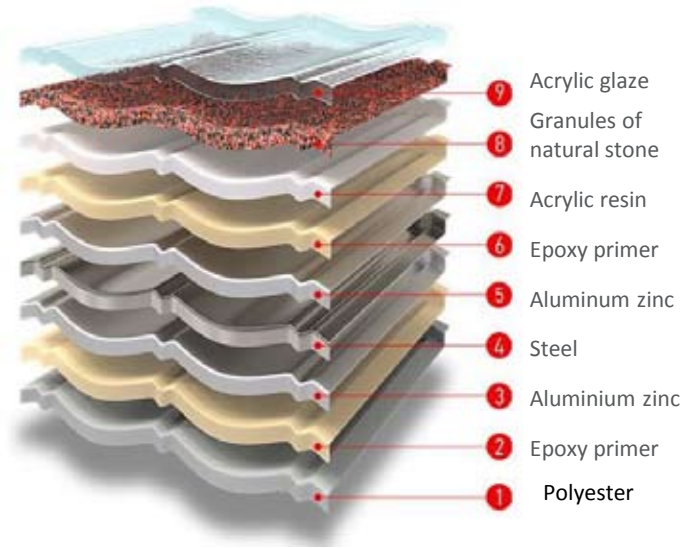
Limitations

1. Skilled manpower is required in fixing of roof tiles.
2. Slightly uncomfortable in very hot climate.

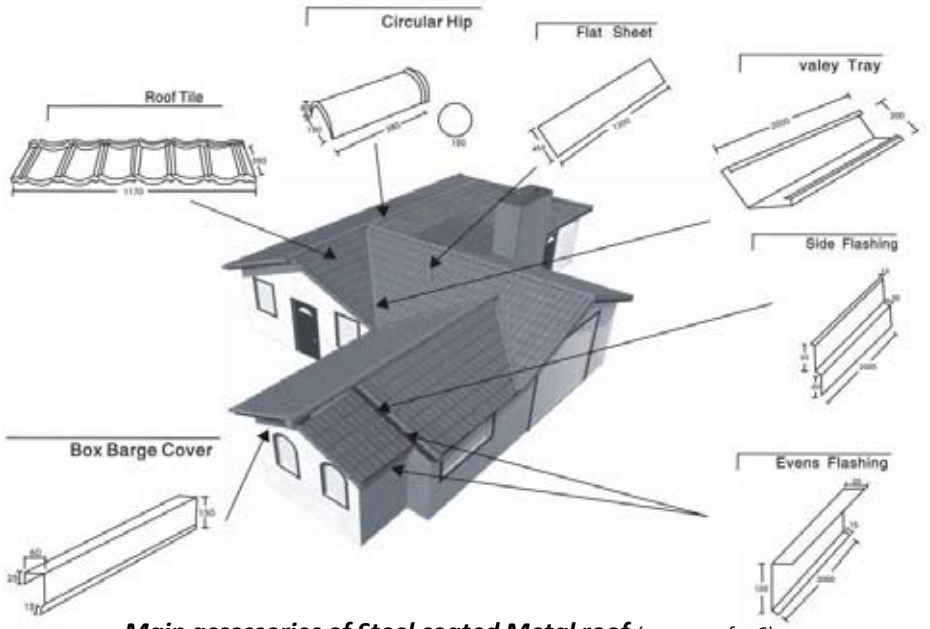
Market Linkages

1. The roof tiles are commercially available and can be installed by skilled labour.

Roofing system



Product Structure *(source: refer 6)*



Main accessories of Steel coated Metal roof *(source: refer 6)*

1	Anti-finger pressing
2	Enhance corrosion resistance and scratch resistance
3	Galvalume-Maximize corrosion resistance of steel
4	Base board
5	Galvalume-Maximize corrosion resistance of steel
6	Enhance Corrosion resistance and adhesion
7	A tough opaque acrylic resin base coat containing additive restraint to biological growths such as algae and lichen
8	Provide excellent surface coverage and protection in a wide range of attractive colours
9	Clear acrylic resin coating in a semi gloss finish

Specifications

Stone coated Steel roof tiles *(Refer Decra and CERTEG website)*	**Size**: 1340 mm x 420mm. Thickness varies from 0.4 mm to 0.5 mm. **Weight**: 3 kg **Requirement:** 2.16 pieces/Sq.m

Relevant Standards and References

1. Hedrick construction blog, https://www.hedrickconstructioninc.com/blog/the-pros-and-cons-of-stone-coated-steel-roofing.
2. Decra Metal roofing, https://www.decra.com/.
3. Metal Roofing Systems, https://www.metalroofing.systems/stone-coated-steel-roof-cost/.
4. Dads roofing, https://dads-roofing.com/your-guide-to-stone-coated-metal-roofing/.
5. CERTEG, https://www.alibaba.com/product-detail/Color-Stone-Coated-Metal-Roof-Tiles_60477895258.html.
6. San-gobuild, http://www.sangobuild.com/stone-coated-roof/.

Funicular shell Roof

(alternate of conventional cast-in-situ RCC roof)

Suitable Regions

All regions of the country

About the Technology

A Funicular Shell is a 3 dimensional catenary on a rectilinear base. The roofing system consists of doubly curved shells made with materials of good compressive strength such as waste stone pieces and brick tiles and supported on reinforced concrete edge beams. A series of these shells in variable geometric configurations supported on a grid of concrete beams, identical to a coffer slab, provides an attractive roof for small to medium spans.

Edge Beam is a reinforced concrete beam which supports and distributes the horizontal thrust of the funicular shell. The beam can be conventionally cast along with the funicular shell. As per the span, the beam is designed for a coffer slab or a grid of beams. Alternatively, the beam can be partially precast, in which case a pre-welded reinforcement cage is placed along the grid and cast half. The cage is fabricated as a truss girder (see overleaf for details) which improves the load bearing capacity of beam considerably, while simultaneously reducing the beam section.

Funicular Shell The entire area to be roofed is divided into a grid depending on the size of the funicular shell required or the size / shape of moulds available. The rise to span ratio is 1:6, thus the optimal span of the shell is 3 m though it can span up to 15 m. The mould is supported between the edge beams. Timber planks are used to bridge the gap between the edge of the mould and the edge beam. The shell comprises of the materials – bricks, stone waste – laid in the funicular profile topped with cement-sand mortar and concrete screed.

Concrete In-fill After the shells have been cast, the valley spaces which are formed between the shells can be filled with light-weight material like brick jelly lime concrete and finished flat. The infill will enable the construction of an intermediate floor which can be used to build above.

Tools and Equipments

a) Steel/masonry moulds b) Table vibrator c) Light hoisting equipment

Material Requirements *(per unit)*

Funicular shell roof Size as per architectural and structural design	•M20 Concrete •TMT Steel •Full Bricks

Salient Features

1. Allows ample flexibility in design- funicular shells can take any shape – square, rectangular, triangular or trapezoidal.
2. For construction above the intermediate floor, the funicular roof provides greater flexibility for locating walls since the load distribution is uniform because of arch action of the shell.
3. Design of the funicular roof can be very well adapted to seismic design requirements.
4. Simple technology which can easily be adapted by semi-skilled labour with minimum supervision.

Economic Aspects

1. Compared to RCC roof, Funicular Shell roof offers savings in Steel (60%) and cement (35%).

Sustainability Aspects

1. Uses locally available waste stone, normally available from stone cutting and polishing units.

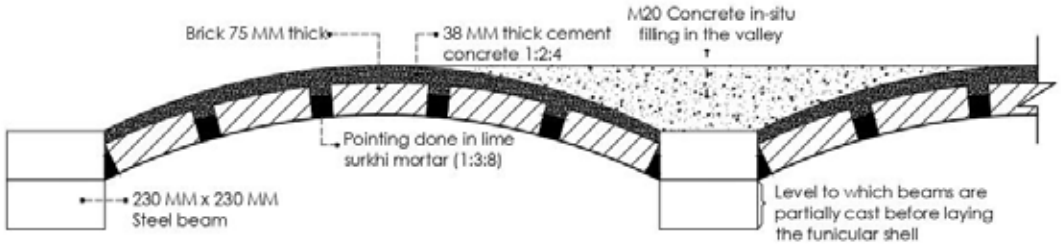
Limitations

1. Adequate care in jointing edge is required for leak proof elements.

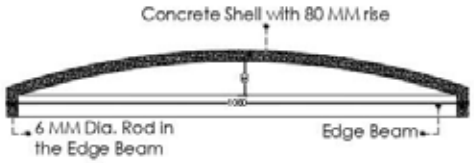
Market Linkages

1. Roof components can be locally produced and delivered through micro level enterprise.
2. The roof can be cast in-situ or precast as per designs suggested by CSIR-SERC and CSIR-CBRI.

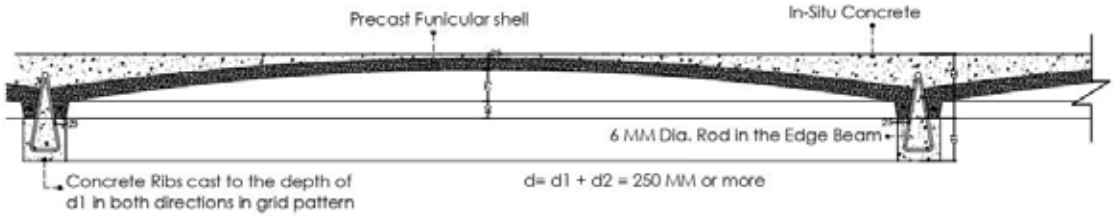
Roofing system



In-Situ Funicular shell roof in in section



Precast Funicular shell roof in in section



Precast Funicular shell roof in in section

Specifications

In-situ Funicular Shell roof (doubly curved) *(Refer IS 6332:1984)*	**Clear span** : 1m to 3m (nominal span). Bigger spans up to 12 m are also possible, as per structural design. **Shape** : A variety of shapes are possible- square, rectangular, triangular as per dimensions of the floor/roof. **Rise at centre** : One sixth of the clear span. 150 mm to 450 mm(for nominal spans). **Shell material :** Broken stone pieces of 25 mm to 50 mm thickness (for a masonry shell). Brick tiles (40 mm to 50 mm) of at least 5 Mpa compressive strength. **Reinforcement :** less **Topping mortar :** Rich cement-sand mortar of 1:2 ratio over the masonry shell.
Precast Funicular Shell roof *(Refer CBRI-BRN)*	**Clear span** : 0.75 m to 1.2 m with 20 mm thickness **Shape** : A variety of shapes are possible- square, rectangular, triangular as per dimensions of the floor/roof. **Rise at centre** : 75 mm **Shell material :** M20 concrete/masonry **Reinforcement :** 6 mm dia. Steel rod all around in the 40 mm thick edge beam. **Weight:** for 1 m x 1 m shell, 65 kg.

Relevant Standards and references

1. IS 6332:1984, Code of practice for construction of floor and roofs using precast doubly-curved shell units (Reaffirmed 2000), Bureau of Indian Standards, New Delhi.
2. IS 875 -1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.
3. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
4. Precast Concrete Funicular Shells for roofs and floors by CSIR- Central Building Research Institute, Roorkee.

Ferro-Cement Roofing Channels

(alternate of conventional cast-in-situ RCC roof)

Suitable Regions

In the plains of the country

About the Technology

The roofing system uses pre-cast Ferro-cement roofing channels of a segmental arch profile which are placed adjacent to each other and spanning over two supports. After partly filling the valley between channels with concrete, the channels form an idealized T-beam and are able to carry the load of a roof/floor. Ferro-cement comprises of a uniform distribution of reinforcement by use of chicken wire mesh and welded mesh encapsulated in rich cement mortar, thereby achieving significant reduction in both steel reinforcement and dead weight of roof. This composition provides a more uniform distribution of strength as compared to RCC.

Pre-cast Ferro-cement Channels are pre-cast shell units made with rich cement mortar (1:2 to 1:3) and reinforcement consisting of a continuous layer of chicken mesh with steel bars provided at two edges of the channel. These shell units are cast either manually on a masonry mould or mechanically on steel moulds mounted on table vibrator. The channels are supported on ends either on load bearing masonry or on a frame structure (RCC or steel).

Restraining Beams are provided in order to balance the channel movement at ends, to prevent differential movement of FC roof in case of any instability in the support structure. The restraining beam will be a part of RCC bands required for structural strengthening, specially in disaster prone areas.

Concrete Filling of at least M20 grade laid to a 150 mm thickness is used to join the Channels after placing them side by side. This concrete completes the T-beam structural action of the FC Channels and creates a basic roof. In case of an intermediate floor, the remaining portion of the valley can be filled the with lean concrete, brick jelly lime concrete or light-weight material and finished with a floor.

Material Requirements *(per unit)*

Precast Ferro-cement channel Size 750 mm (inner); 840 mm (outer); 25 mm thickness; length as per design	M20 Concrete- 0.29 cum TMT Steel- according to length

Tools and Equipments

a) Steel/masonry moulds b)Table vibrator c) Light hoisting equipment

Salient Features

1. Ferro-cement channel roof provides light weight roofing – 60% reduction in dead weight as compare to RCC.
2. Pre-casting of roof leads to substantial reduction in construction time.
3. Much better quality control can be maintained during pre-fabrication.
4. Versatile technology – with respect to profiles of roofing channels (subject to structural design).

Economic Aspects

1. Compared to RCC roofing, the Ferro-cement roofing channels offer savings in steel (30%) and cement (35%).

Sustainability Aspects

1. Has a embodied energy of 620 MJ/sq.m as compared to 750 MJ/sq.m for a 10cm thick RCC roof

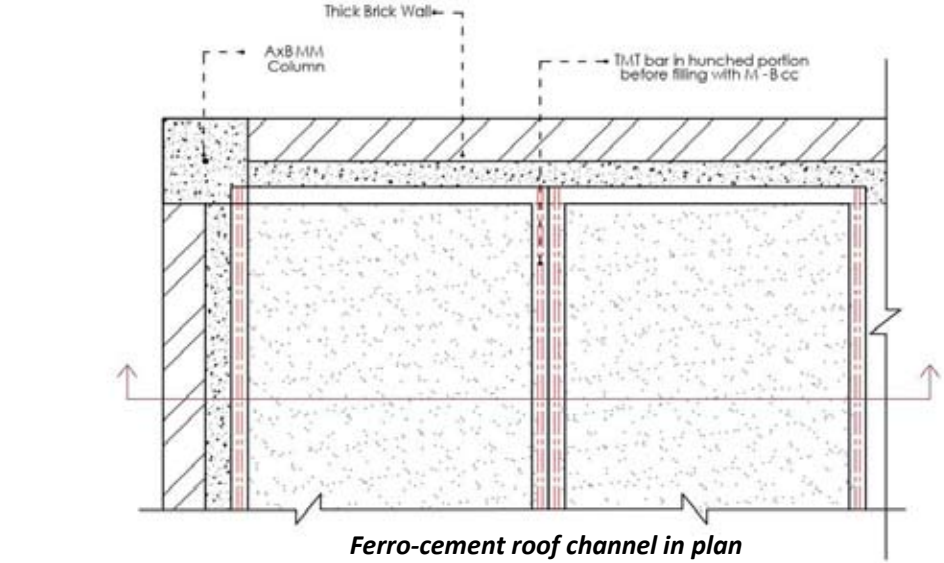
Limitations

1. If not maintained properly or improper slopes, leakage of water maybe an issue.

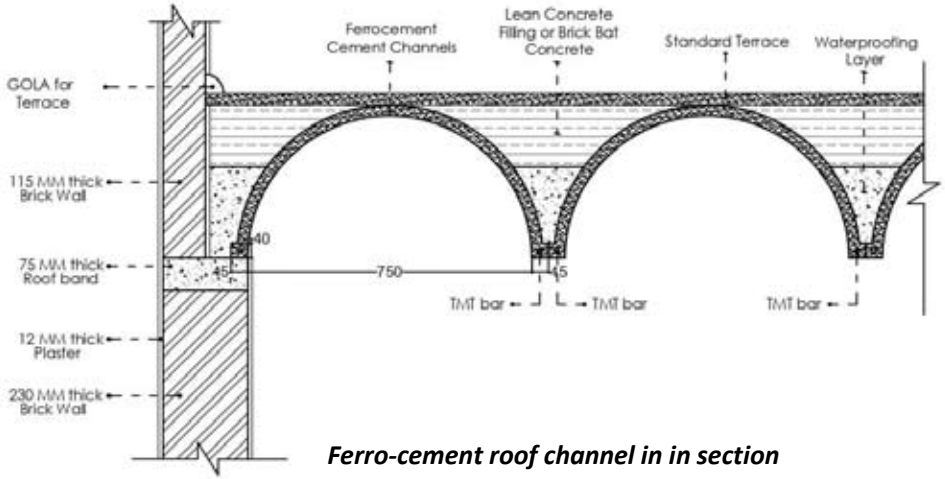
Market Linkages

1. Roof components can be locally produced and delivered through micro level enterprise.

Roofing system



Ferro-cement roof channel in plan



Ferro-cement roof channel in in section

Specifications

Precast Ferro-Cement channel *(Refer IS 383:1970)*	**Clear bay length** : 750 mm (Outer dimension 840 mm, including two 40 x 45 mm nibs at bottom) **Rise of arch** : 290 mm **Shell thickness** : 25 mm **Unit weight** : 50 kg per meter length **Length** : Up to 4 m **Design mix :** Cement: Fine Aggregate 1:2 to 1:3 by weight, M25 grade Water: Cement ratio 0.45 to 0.55. Fine Aggregate should be coarse sand confirming to grading Zone II as per IS 383-1970. **Mesh reinforcement :** 200 mm strip of MS weld mesh of 12 gauge, 25 mm square opening along crown of channel GI wire chicken mesh of hexagonal 12 mm opening, 22 gauge, throughout the shell and double layer of 1 m length at both ends of channel. **Nib reinforcement :** Roof application: from 6 mm for 3 m span to (1 no. In both nibs)12 mm for 5.4 m span. Floor application: from 8 mm for 3 m span to 16 mm for 5.4 m span. **Design load :** As per IS 875:1987 Load carrying capacity of FC Channel roof varies from 650 kg/sq.m to 1200 kg/sq.m depending on the reinforcement.
Valley filling *(Refer IS 456:2000)*	M20 Plain cement concrete up to 125 mm thickness and light weight local material for the remaining depth.

Relevant Standards and References

1. IS 383-1970, Specification For Coarse And Fine Aggregates From Natural Sources For Concrete, Bureau of Indian Standards, New Delhi.
2. IS 875 -1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.
3. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Brick Pyramidal Roof

(Roofing system resistant to cyclones, marine corrosion and high rainfall)

Suitable Regions

Only in the costal regions of the country

About the Technology

A pyramid shaped roof cast at site using locally available burnt clay bricks and cement mortar/ M20 concrete. In coastal regions steel reinforced cement concrete slabs or CGI sheets fixed over steel rafters/purlins get badly corroded by salt bearing marine winds. Coastal areas are also prone to high winds, rainfall and cyclones. Keeping these conditions in view a Pyramid shaped roofing system has been developed using only red burnt clay bricks, and cement sand mortar or M20 cement concrete resting over walls confined within a RCC ring beam at the roof level. No steel bars are used in the roof – so no corrosion.

Pyramidal Brick roofs are shaped with equal pitch on both sides and tend to have good aerodynamic features, giving them the ability to withstand strong winds compared to the normal gable roofs. They are therefore ideal for use in the coastal regions where tough winds and storms are common occurrences. Roof slope is maintained at about 16^{o} to minimize wind forces. The centre of the roof may also be anchored to the ground using an under-reamed pile and an anchor column to resist low air pressure at the eye of a cyclone.

Good sloping sides of the roof help in quick drainage of rain water reducing chances of leakage or seepage. This type of roof is usually constructed for houses that have a square or a rectangular plan. The RCC ring beam is cast over walls in dense M20 cement concrete with 40 to 50mm clear cover to check corrosion of steel bars. In multi-storey buildings the intermediate roof/floors can be in normal RCC while only the top roof can be Brick Pyramidal Type.

Material Requirements *(per 25 square meter)*

Pyramid roof 25 sq.m area	Bricks: 1400 Cement: 8 bags Sand: 0.7 cum Stone aggregate: 1.1cum Steel in ring beam: 125Kg

Tools and Equipments

a) Normal mason's tools b) Construction T&P c) centering and shuttering d) Scaffolding e) concrete mixer

Salient Features

1. Brick Pyramidal roofs have no steel reinforcement that are prone to corrosion by salt bearing marine winds in the slab portion.
2. About 16^{o} slopes are wind resistant, hence these are ideal for coastal regions.
3. Have efficient drainage capabilities as they have equal slopes with no flat surfaces.
4. Brick Pyramidal roof is cost effective, more stable and durable.

Economic Aspects

1. Cost is almost equal to RCC slab roof, but it is more durable and safer in cyclone prone coastal areas.

Sustainability Aspects

1. Uses locally available burnt clay bricks.
2. No steel reinforcement required in the pyramidal roof.

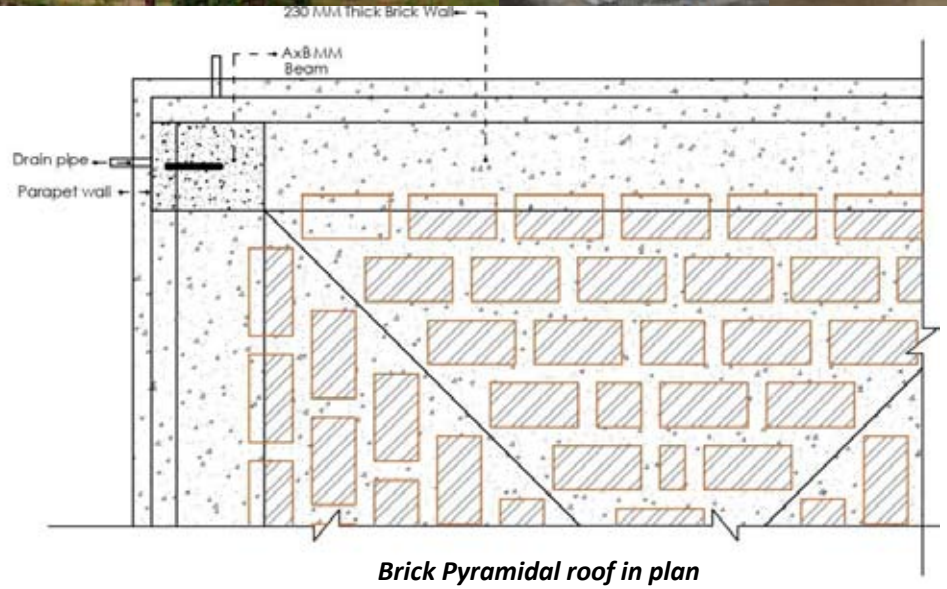
Limitations

1. Due to pyramidal shape of roof, vertical expansion is not possible
2. Not recommended in highly earthquake prone areas (Zone IV and V) without proper EQ safety measures.
3. Building plans are restricted to square or rectangular.

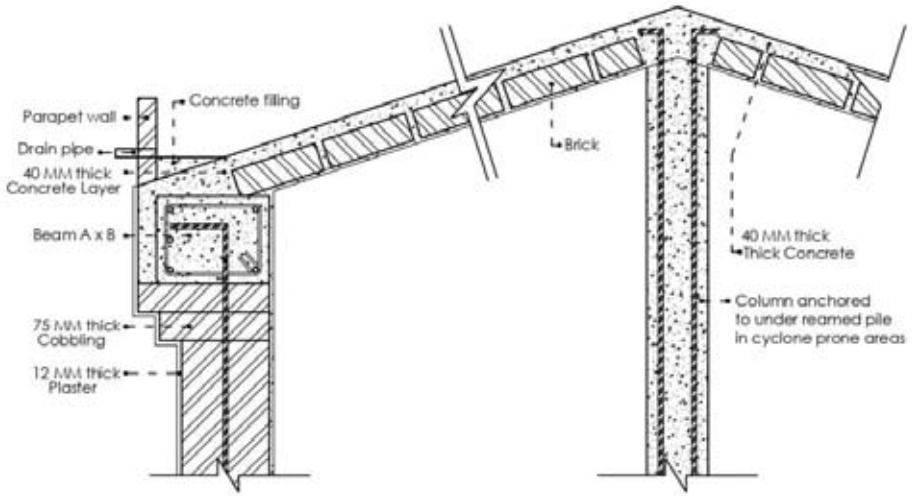
Market Linkages

1. Onsite construction by trained masons / contractors using conventional materials.

Roofing system



Brick Pyramidal roof in plan



Brick Pyramidal roof in section

Brick Pyramidal roof	**Cast in situ brick concrete slab in the shape of a pyramid over walls at roof level. The edges of the brick pyramid are bound by a RCC ring beam.** **Bricks:** 1st Class, 7.5 or higher grade well burnt clay bricks. Excessive Salt Peter in bricks is not recommended **Binder:** M 20 cement concrete using 10mm stone aggregate **Steel in Ring Beam:** 415 grade TMT as per design. Vertical corner bars from walls to be bent 50D into the Ring beam.

Relevant Standards and References

1. IS 875 -1987, Code of practice for design loads (other than earthquake) for buildings and structures : Part 1 Dead loads, Bureau of Indian Standards, New Delhi.
2. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Green Roofs

(alternate of conventional cast-in-situ RCC roof)

Suitable Regions

All regions of the country

About the Technology

A green roof system is an extension of the existing roof which involves, at a minimum, high quality water-proofing, root repellent system, drainage system, filter cloth, a lightweight growing medium, and plants.

Green roof systems may be modular, with drainage layers, filter cloth, growing media, and plants already prepared in movable, often interlocking grids, or loose laid/built-up whereby each component of the system may be installed separately. Green roof development involves the creation of "contained" green space on top of a human-made structure.

Green roofs are also known as vegetative or eco–roofs. They fall into three main categories—*extensive*, *intensive*, and *semi–intensive*. Although there are no precise definitions of them, an extensive green roof has a shallow growing medium—usually less than six inches—with a modest roof load, limited plant diversity, minimal watering requirements, and is often not accessible. Intensive green roofs have more soil and a deeper growing medium—sometimes several feet—that can support a more diverse plant selection, including small trees. Thus, they have more substantial structural loads and need more frequent maintenance and watering. They are usually accessible. Semi–intensive green roofs include features of both types. The appropriate depth of any green roof depends on the roof structure, the plants chosen, annual rainfall, and storm water performance requirements.

All three types of roofs require specific layers of roofing materials not found on regular roofs. The basic anatomy of a green roof consists of vegetation, growing medium, filter membrane, drainage layer, waterproof/root repellent layer, roofing membrane support for plantings above, thermal insulation, vapour control layer, and structural roof support. Each of these layers performs a specific function to keep the plants alive and to protect the structure beneath.

Material Requirements *(per square meter)*

Screed	Waterproof layer	Root barrier	Drainage layer
Geotextile fabric	Gravel & pebbles	Soil	Plants

Tools and Equipments

a) Carpentry tools b) Gardening tools

Salient Features

1. The longevity of these roofs are no less than three to five decades and sometimes even more.
2. On a wider scale, green roofs improve air quality and help reduce the Urban Heat Island Effect.
3. Reduces energy costs with natural insulation.

Economic Aspects

1. Long-term energy benefits outweigh the start-up costs.

Sustainability Aspects

1. Green roofs are capable of reducing electromagnetic radiation penetration by 99.4%.
2. The temperature moderating effects of green roofs can reduce demand on power plants, and potentially decrease the amount of CO2 and other polluting by-products being released into the air.
3. Plants on vertical and horizontal surfaces are able to cool cities during hot summer months and reduce the Urban Heat Island (UHI) effect.

Limitations

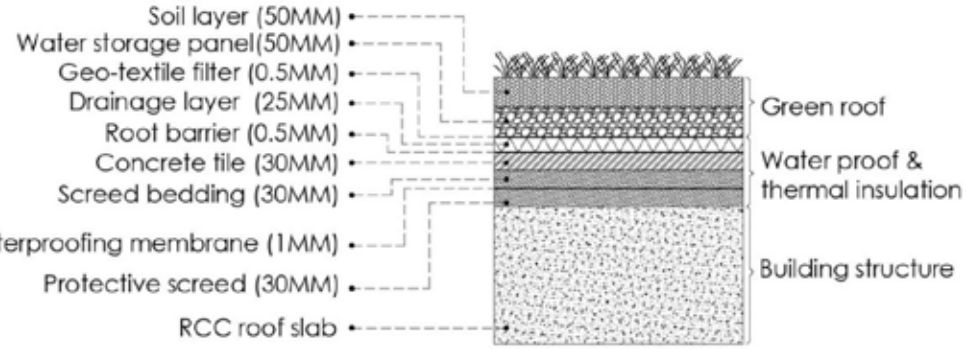
1. When soil erodes, especially during harsh weather conditions, the slope can get damaged.
2. Skilled manpower is required in fixing of green roofs.

Market Linkages

1. Green roofs are commercially available and can be installed by skilled labour.

Roofing system

Green roof vs. Traditional roof *(source: refer 6)*



Different layers of Green roof in section

Specifications

Extensive ***Green roof*** *(Refer 5)*	**Features**: • Build-up height 50 –-150mm • Suitable for large areas • Lightweight & Easy to install • Self-sustaining plant community • Less irrigation • No / low maintenance **Application:** • Lightweight roof decks • Inaccessible roofs • Flat or sloping roofs • Reducing water run-off **Vegetation:** • Moss and sedum • Moss and sedum and herbs • Sedum and grass and herbs • Grasses and herbs
Intensive ***Green roof*** *(Refer 5)*	**Features**: • Build-up height 150 – 1500mm • Wide range of plants and trees • Regular irrigation & Regular maintenance • Often indistinguishable from natural gardens • Usually a mixture of hard and soft landscaping • Good insulation properties **Application:** • Natural gardens • Recreation and sport • Growing food **Vegetation:** • Lawn (Shrubs & Edible plants) • Generalist perennials and grasses • Small deciduous trees and conifers

Relevant Standards and References

1. Technical Preservation Services, https://www.nps.gov/tps/sustainability/new-technology/green-roofs/define.htm
2. Green roofs, https://greenroofs.org/about-green-roofs
3. https://science.howstuffworks.com/environmental/green-science/green-rooftop.htm
4. Strata, http://www.strataindia.com/green_roof_casestudy.html
5. Greenspec, http://www.greenspec.co.uk/building-design/green-roofs-1/
6. https://commons.bcit.ca/greenroof/faq/why-green-roofs-benefits/

Integrated Solar Roof

(alternate of conventional solar panels + PPGI sheets)

Suitable Regions

All regions of the country

About the Technology

This is a UNIQUE roof sheet which generates power using solar energy (ATUM). The usage of the ATUM depends upon various factors such as availability of material, cost, appearance, durability, climate etc. It is generally compared with the market available solar panels use and their cost.

Traditional/conventional Solar Panels: Market available PV solar panels/modules are majorly of 210-350Wp configuration. They are generally placed directly on roof slab or on the ground (soil) using G.I. framing system. This will consume lot of floor space of the ground if placed on ground, if used on terrace of a house / apartment, terrace space will be occupied and cannot be used for any other purposes. If anyone wants to use solar panels as roofing, then a Corrugated Galvanised Iron (CGI) sheets or PPGI (Pre-painted G.I.) sheets or Clay tiles are used as a base roof material and on top these roofing sheets, the conventional solar panels will be laid with necessary walkways to clean the solar panels. As a thumb rule, 10 sq.m of roof area is required to generate 1KW solar power.

ATUM: The integrated solar roofing panels which generates power, are first of its kind in India which is a patented technology developed by M/s. Visaka Industries Limited. ATUM is available in standard size of 1010 x 1980 x 14mm thick, 320Wp with 72 cells. The base is a special cement board developed to sandwich the PV cells with tempered glass. ATUM acts like a roofing sheet doesn't require any roof sheet support like traditional solar panels.

Tools and Equipments

a) Screw Driving Machine b) PU sealant application Gun
c) Vacuum suction cups to move the ATUM panels
d) Safety belts & tools.

Salient Features

1. ATUM has dual purpose viz. generates solar energy and act as roof integrated solar roof panel on a steel structure of trusses, rafters, and purlins (1mx1m grid to support panel).
2. Roof can generate minimum 20% extra power due to the end to end covering of roof with more number of panels on roof compared to conventional system and creates an extra room space for multiple uses.
3. Return on Investment is 5-6 years and power generation till 25 years with 80% efficiency.
4. Life of the roof is more than 45 years and can withstand 200 KMPH wind load as well as 150 Kg point load.
5. Fire-resistant solar panels and 100% water leakages proof.
6. Low thermal conductivity due to its special cement board base.
7. A hybrid roof can be easily done with combination of ATUM, PPGI, shingles, clay tiles etc.

Economic Aspects

1. More economical than the conventional solar panels + PPGI sheets (2 times in 25 years incl. material and labour for laying).
2. Lasts more than 45 years with guaranteed power generation for 25 years as per market standard.

Sustainability Aspects

1. ATUM solar panels are sustainable material which goes as a roof sheet in place of RCC.

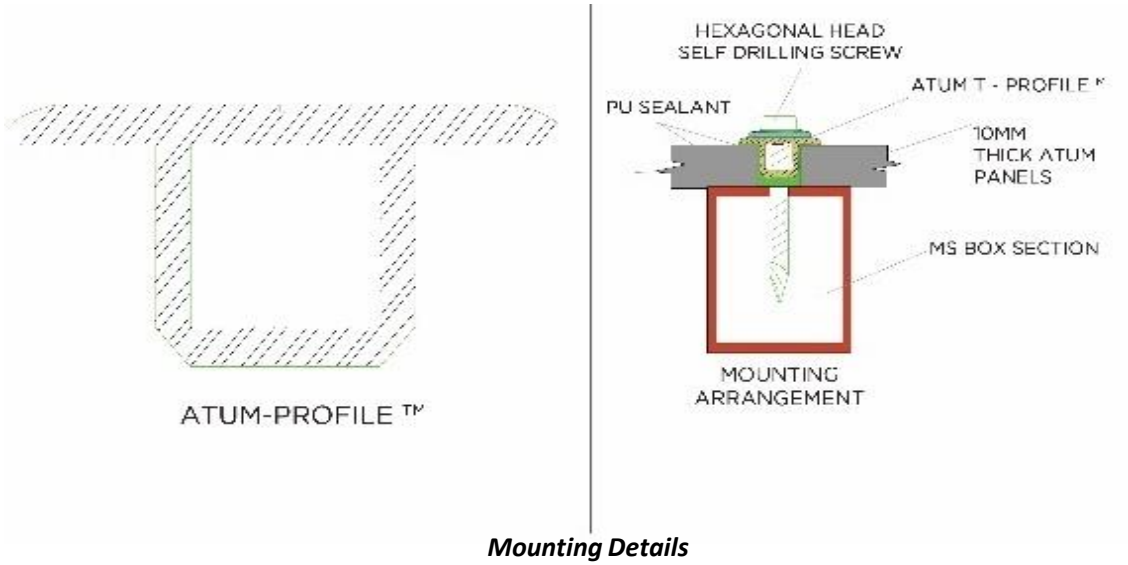
Limitations

1. ATUM solar roof panels are heavier than the traditional solar panels + PPGI combined by 5 Kg/sq m.

Market Linkages

1. ATUM solar roof panels can be installed by local contractors and labour skilled in roofing works with the help of Installation guide and videos.
2. Manufacturers: Visaka Industries Ltd.

Roofing system



Mounting Details

Roof Frame Work with 1m x 1m grid spacing

ATUM panels roof completed

ATUM panels installation in progress

Specifications

Module	Type VIL 320P
Maximum Power (Pmpp)	320 Wp
Positive Power Tolerance	0-2.5
Open Circuit Voltage (Voc)	4.18
Short Circuit Current (Isc)	9.06
Maximum Power (Voltage Vmpp)	37.2
Maximum Power Current (Impp)	8.61
Module Efficiency	16% - 1 7%
Dimensions	1980 x 1010 x 10mm (Board Thickness)
Weight	45 .0 KG

BIS Certified	IS 14286: 2010/IEC 61215: 2005, IS/IEC 61730 (Part 1): 2004 & IS/61730 (Part 2): 2004)
PID free	IEC 62804
Lean Maestro for winds speed	Up to 200 kmph
Leak proof- JNTU Test Report	ASTM E 2410-01;
Class A (or 1) fire rating	BS 476
UL Certified	IEC 61215-series:2016, IEC 61730-1:2016, IEC 61730-2:2016

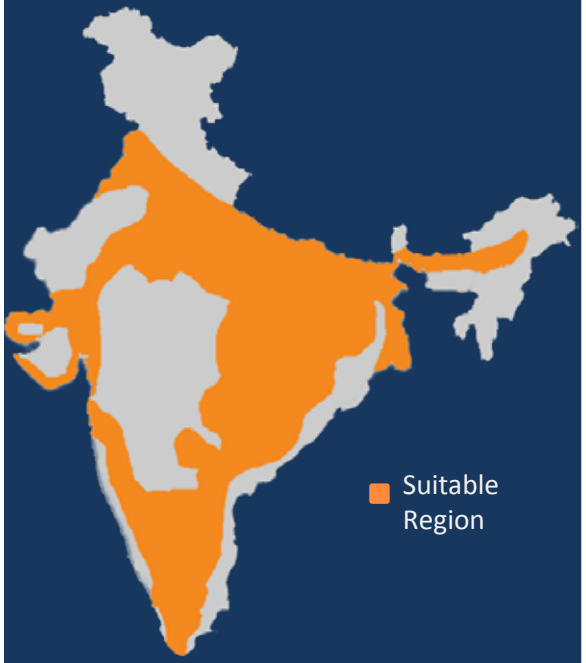
Relevant Standards and References

1. Visaka Industries Limited.

Wall Construction Technologies

Brick Masonry
(Conventional Scheme for Walls)

Suitable Regions



Predominantly in Alluvial soil region and Deccan plateau with relatively low strength bricks.

About the Technology

The success of brick masonry is mainly due to its durability, excellent fire resistance, acoustic and thermal characteristics and relative simple in realisation and cost. Masonry is a composite material, comprising brocks as building units and mortar as joining material. Metric size of brick is 190X90X90 mm with an indent called frog of 10-20 mm deep. The most popular size is 230 x115 x 75 mm. BIS has classified the bricks on the basis of compressive strength. According to IS: 3495-1992 (Part III) the water absorption shall not be more than 20 % by weight up to class 125 of burnt solid clay bricks and 15% for rest higher class. As per IS:1077-1992, common building brick shall have minimum compressive strength of 3.5 N/mm^2.

A good mortar should be able to develop good adhesion with building units and capable of resisting design stresses. It should not allow water penetration and should be durable. IS : 2250-1981 & IS : 3466 – 1988 can be referred for more details on masonry mortar. The arrangement of bricks in courses should be such that individual units are well bonded and vertical joints of the successive courses are not continuous in same vertical line. Bricks should be of uniform size. Vertical joints in the alternate courses should be along the same perpendicular.

Brick masonry walls are popular in the alluvial soil regions, with or without external plaster. Brick Masonry wall strength depends upon quality of bricks. Various tests to be performed includes size, shape, compressive strength, water absorption, efflorescence etc.

Material Requirements *(per cubic meter)*

230 mm thick Brick wall	Mortar- 0.25 cum Bricks- 480 nos.

Tools and Equipments

a) Masonry Hammer b) Trowel c) Masonry Square
d) Mason's Level e) Straight Edges e) Plumb bob
f) Mixing Tools g) Mason's Line h) Measuring tape

Salient Features

1. Bricks are available in alluvial soil regions where they are less costly in comparison to stone masonry.
2. Excellent Acoustic, thermal insulation.
3. Locally available skills required for construction.
4. Walls of different thickness i.e. ½ , 1, 1½ bricks can be constructed.

Economic Aspects

1. Brick Masonry is most economic walling solution in the alluvial soil region. Up to 4 storey load bearing structures can be constructed.

Sustainability Aspects

1. Removal of top soil for brick manufacture and coal consumption in kilns is harmful to environment.

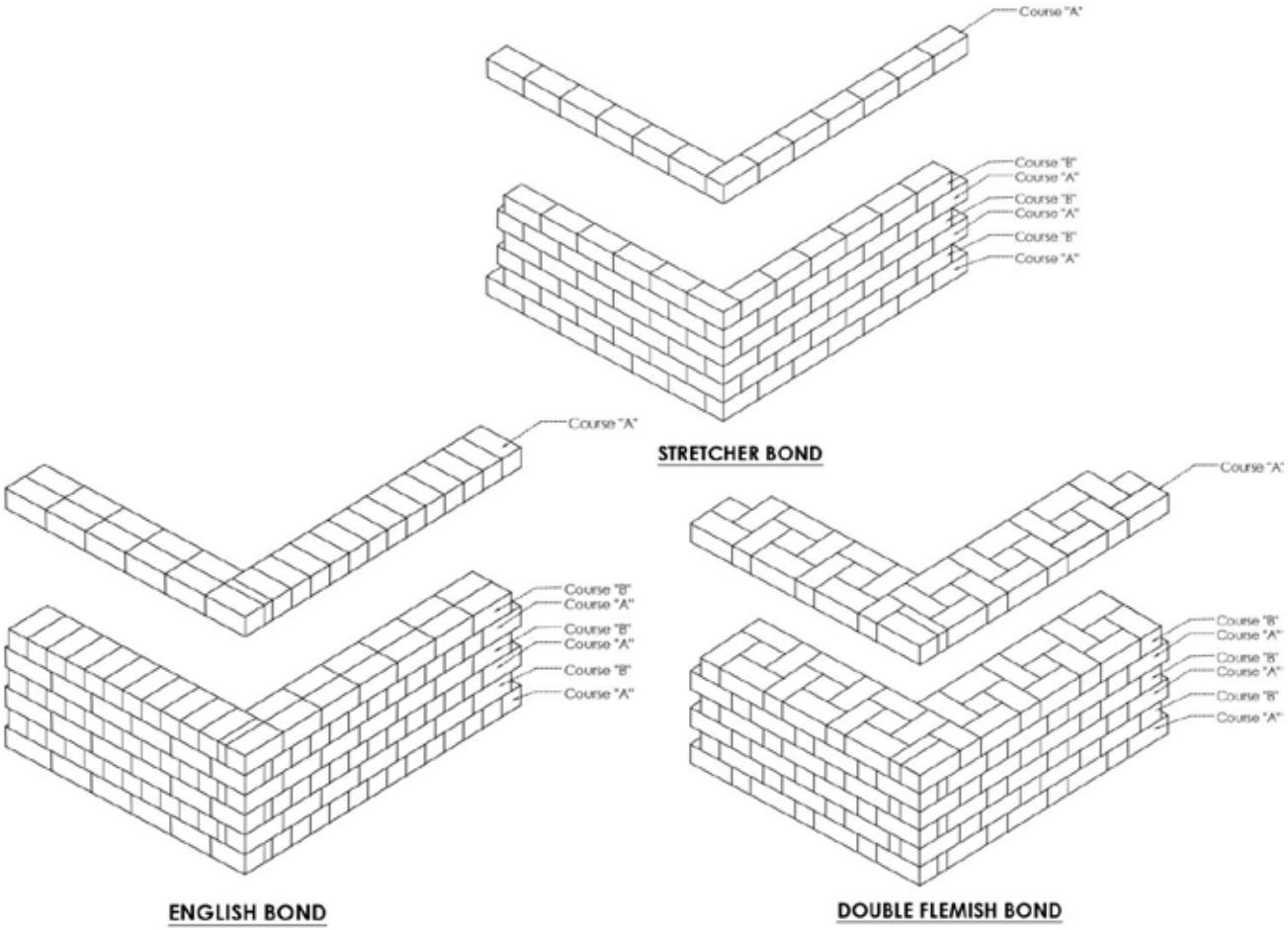
Limitations

1. Masonry is heterogeneous material, which is very weak in tension and vulnerable in lateral loads.
2. Un-economical in hilly and rocky region due to high transportation cost.
3. Along Deccan plateau region, bricks are of very low compressive strength i.e. less than 3.5 N/mm^2.
4. Brick masonry needs plastering to finish, which can raise construction costs.
5. Brick absorbs water which causes dampness and efflorescence with time.

Market Linkages

1. Can be locally manufactured in alluvial soil region.

Walling system



Brick masonry bonds for wall construction

Specifications

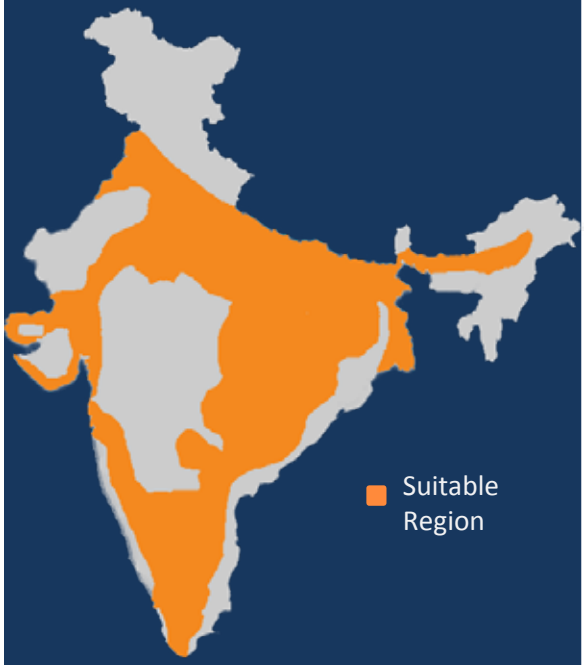
Stretcher Bond	Stretcher bond or stretching bond is one in which all the bricks are laid as stretchers on the faces of the walls. It is used only for partition walls, sleeper walls, division walls or chimney stacks.
English Bond	This is most commonly used bond, for all wall thickness and considered to be strongest. This bond consists of alternate courses of headers and stretchers. In this bond joints of header course come over each other, similarly joints of stretchers. A queen closer is used after first header in each header course to break vertical joints in successive courses.
Flemish Bond	In this type of joint each course is made up of alternate header and stretchers. Queen closers are placed next to header in alternate course to form face lap.

Relevant Standards and References

1. IS: 2212 – 1991, Brick Works-Code of Practice, Bureau of Indian Standards, New Delhi.
2. IS: 1905 – 1987, Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi.
3. IS : 3102 – 1971, Classification of burnt clay solid bricks, Bureau of Indian Standards, New Delhi.
4. IS : 1077 – j1992 Common burnt clay building bricks – specification, , Bureau of Indian Standards, New Delhi.
5. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi.
6. IS : 3466 – 1988, Specification for masonry cement, Bureau of Indian Standards, New Delhi.

Rat Trap Bond
(Alternate Scheme for Walls)

Suitable Regions



Predominantly in Alluvial soil region and Deccan plateau with relatively low strength bricks.

About the Technology

Rat-Trap bond is a masonry system in which high strength standard 230 x 115 x 75mm bricks are used to make walls with a 75mm hollow space in middle and two 75mm thick widths on the faces. This achieved by laying bricks on edges in masonry work. It consumes about 25% less material.

The air gaps that are created by the bond, helps in maintaining a good thermal comfort inside the building. In Rat-Trap bond the bricks are laid in alternate Shiner and Rowlock pattern so that a cavity is maintained in the Rat-trap bond. The internal cavity is bridged by the rowlock. Thus materials like brick, top soil, cement etc. can be saved. This is therefore considered a Green building technology and is more sustainable against conventional solid brick wall masonry.

The Rat trap bond construction is a modular type of masonry construction. Due care must be taken while designing the wall lengths and heights for a structure. The openings and the wall dimensions are to be in multiples of the 300 mm (12") module. When sill, lintel, roof and gable RCC bands are to be laid, or at window sills a header course of bricks is laid to cover the hollow cavity. The masonry on the side jambs of door/ window should also to be solid so that door/window frames could be firmly fixed to the walls.

Material Requirements *(per cubic meter)*

230 mm thick Brick wall	Mortar- 0.15 cum Bricks- 370 nos.

Tools and Equipments

a) Masonry Hammer b) Trowel, Masonry Square
c) Mason's Level d) Straight Edges e) Plumb bob
d) Mixing Tools e) Mason's Line f) Measuring tape and other mason's tool.

Salient Features

1. Rat trap bond wall is a kind of cavity wall with added advantage of thermal comfort. The interiors remain cooler in summer and warmer in winters.
2. It is a green building system
3. Compared to a 230 mm thick solid brick wall, brick consumption is reduced by 25% in rat-trap bond.
4. Due to increased course height and hollow cavity the consumption of cement mortar is also reduced.
5. Stability of wall is not affected as the excess material is eliminated from the center maintaining the full thickness of the wall.

Economic Aspects

1. The overall cost saving on this wall compared to the conventional 230 mm wall is about 25%

Sustainability Aspects

1. Economical solution where burnt clay bricks are commonly used. Reduces pressure on fertile top soil by about 25% and with consequent reduction in coal consumption.

Limitations

1. Suitable where min.7.5N/mm^2 bricks are available.
2. Poor sound insulation as compared to solid brick walls.
3. All concealed conduits and pipes must be laid through the cavity. Avoid chasing of walls.
4. Labor intensive technology.

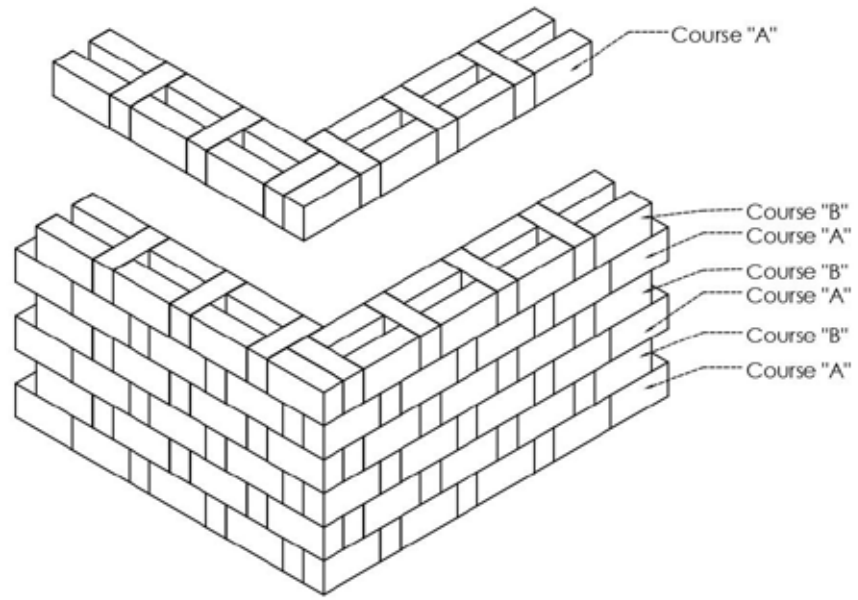
Market Linkages

1. Conventional materials like bricks, sand cement etc. are used. Masons can be trained to adopt this method of brick laying by a short duration training.

Cost

1. About 20% savings as compared to solid masonry.

Walling system



Rat trap bond for wall construction

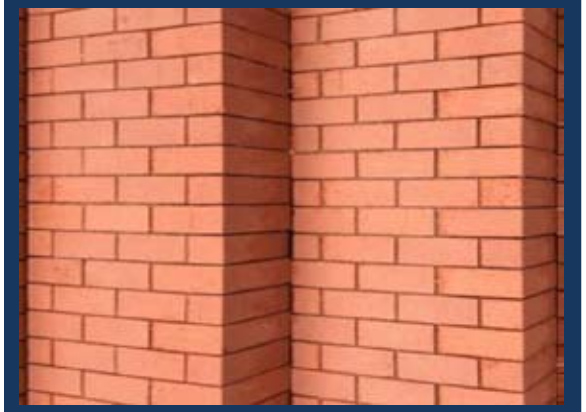
Specifications

Masonry Details	In first course all voids are filled with bricks. The wall height should not surpass more than 8 layers in a day to allow mortar to get ample duration to harden. This ensure no cracks development due to above lying course.
Construction Details for Earthquake Resistant design	Rat-trap masonry walls can be covered with steel bars at all junctions, around openings (door and windows), T-junctions and filled with a M20 grade of concrete. Reinforcement diameter depends on number of story, story height, seismic zone, importance of building and soil type.
Compressive strength	1.30 MPa with 1:4 Mortar
Type	Load Bearing Wall
Maximum wall height	3600 mm

Relevant Standards and References

1. IS: 2212 - 1991, Brick Works-Code of Practice, Bureau of Indian Standards, New Delhi
2. IS: 1905-1987, Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi
3. IS : 3102 – 1971, Classification of burnt clay solid bricks, Bureau of Indian Standards, New Delhi
4. IS : 1077 - 1992 Common burnt clay building bricks – specification, , Bureau of Indian Standards, New Delhi
5. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi
6. IS: 1893 – 2016, Criteria for earthquake resistant design of structures, Part-1 General provisions and buildings, Bureau of Indian Standards, New Delhi
7. Is: 4326 – 2013, Earthquake Resistant Design and Construction of Buildings--Code of Practice, Bureau of Indian Standards, New Delhi

Staggered Masonry
(Alternate Scheme for Wall)



Suitable Regions

Along Alluvial soil region where high strength bricks are available.

About the Technology

Staggered masonry is a special type of masonry technique suitable for half brick/single wall 115 mm wall construction. Bricks require for this masonry technique should be of high quality and strength with can withstand the above-lying roof and other structural loads.

Staggered masonry constitutes the half/single brick masonry construction for about the span of 1200 to 1800 mm, after which a 230 mm x 230 mm brick column is constructed at regular intervals to support the lateral loads. After construction of the brick column the next panels of the wall is shifted to the other half 115 mm of the stone column.

This results into the zig-zag shape of the wall along its face, in which one span of the wall is lying on the front section of the 230 mm wide brick while the other span is lies on the rear 115 mm section of the wall. The thinner course masonry involved in this system is generally stretcher bond masonry as it can withstand greater load and provide ample support to the structure. Sometimes alternate stretcher are removed during the time of masonry to form a brick jali which provide good aesthetic appearance to the wall. Jaali masonry generally provided in partition walls of non load bearing structures like boundary wall or parapet walls.

Material Requirements *(per cubic meter)*

115 mm thick Brick wall	Mortar (1:4)- 0.20 cum Bricks- 470 nos.

Tools and Equipments

a) Masonry Hammer b) Trowel c) Masonry Square
d) Mason's Level e) Straight Edges f) Plumb bob
g) Mixing Tools h) Mason's Line i) Measuring tape and other mason's tools.

Salient Features

1. Labor intensive technique.
2. Requires almost half of brick consumption.
3. Suitable for one to two storey load bearing structures.

Economic Aspects

1. Due to material reduction in this type of masonry work i.e. for 115 mm wall, the cost of construction reduces.

Sustainability Aspects

1. Saves the fertile topsoil.

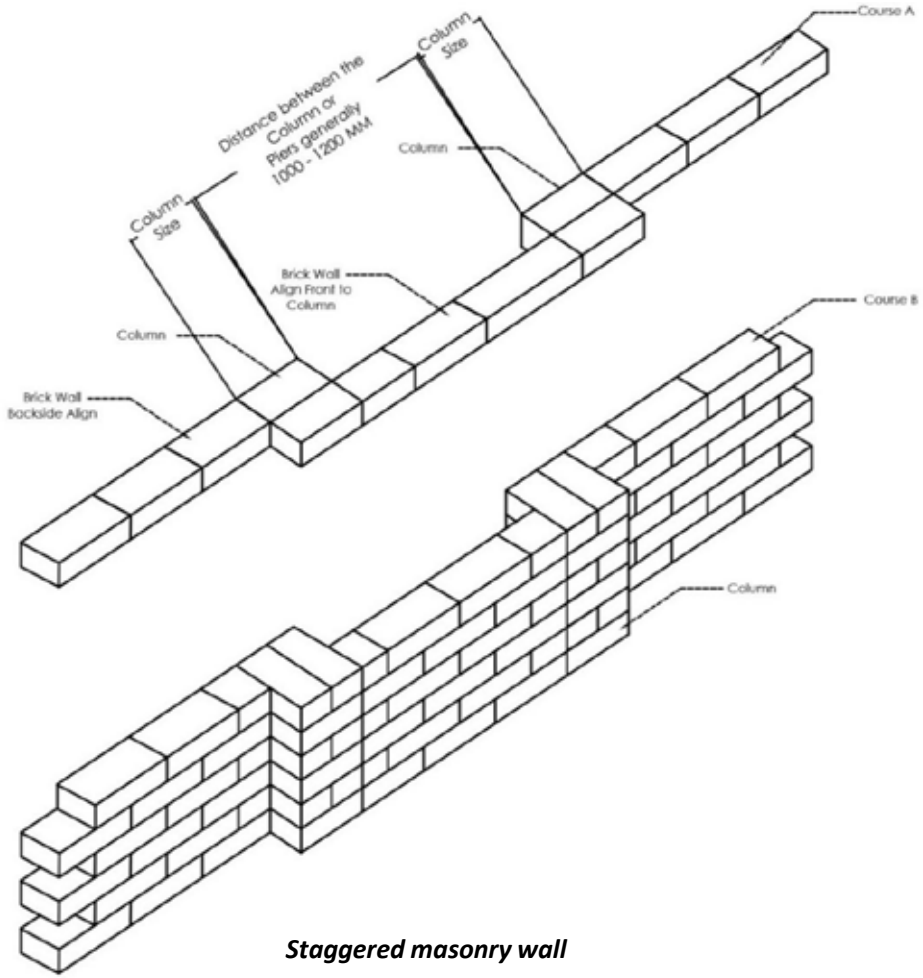
Limitations

1. Only high quality bricks of standard dimension and characteristic is used in this masonry techniques.
2. Suitable for small housing units.
3. Only recommended for the regions where high strength bricks are available.

Market Linkages

1. Bricks masonry can be executed by local masons/contractors.

Walling system



Staggered masonry wall

Specifications

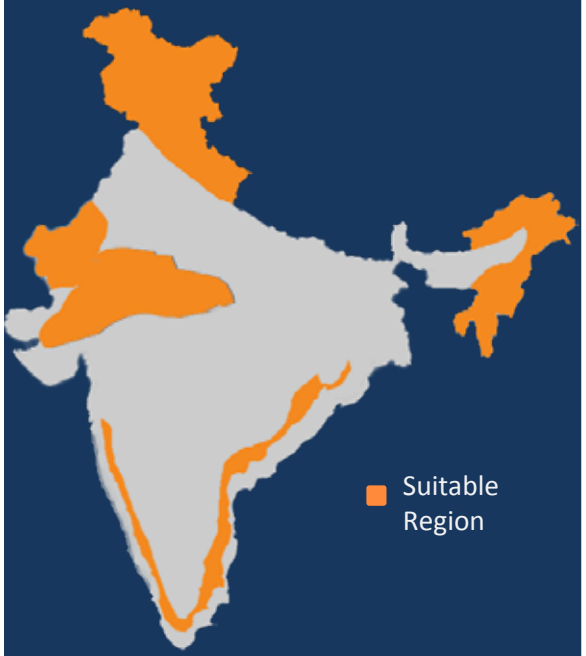
Masonry Bond	All the bricks are laid as stretchers on the faces of the walls with 230 mm x 230 mm brick masonry columns at about 1200 mm to 1800 mm centre to centre distance. The 115 mm thick wall panels are flushed with internal and external faces of the column alternatively. These can also be used as load bearing walls for single storey houses.
Overlap	Bricks should be of uniform size i.e. length of the brick should be twice its width plus one joint, to obtain uniform lap.
Mortar	1:4 Cement Sand mortar
Note: Amount of lap should be minimum ½ brick (115 mm) along the length of the wall. Continuous plinth, sill and lintel bands are provided.	

Relevant Standards and References

1. IS: 2212 - 1991, Brick Works-Code of Practice, Bureau of Indian Standards, New Delhi
2. IS: 1905-1987, Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi
3. IS : 3102 – 1971, Classification of burnt clay solid bricks, Bureau of Indian Standards, New Delhi
4. IS : 1077 - 1992 Common burnt clay building bricks – specification, , Bureau of Indian Standards, New Delhi
5. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi

Solid Concrete Block
(Alternate of Brick Wall)

Suitable Regions



Hilly areas, Western & Eastern Ghats, Regions of Rajasthan, Gujarat Northeast and Deccan Plateau.

About the Technology

Concrete masonry blocks are cast using cement concrete, e.g. Portland cement, sand and gravel or stone aggregate in various proportions to achieve required strength. Blocks may also use industrial and demolition wastes as aggregate, as per availability locally. Concrete masonry units are used for both load-bearing and non-load bearing walls, partitions and panel walls. Concrete masonry building units used in the construction of load-bearing and partition walls could be hollow and/or Solid that conform to the IS: 2185-1 (2005). Conventionally 1 cement: 3 sand: 6 stone aggregate – 12mm down are used to cast solid concrete blocks that yields 30-35 blocks (300x200x150 mm) per bag of cement. Besides standard size masonry blocks, part size and slotted blocks are also made for breaking bond in masonry and to provide vertical reinforcement at corners etc. The variation in the length of the units shall not be more than ±5 mm and variation in height and width of units, not more than ± 3 mm. Concrete blocks are durable have necessary strength, structural stability, fire resistance, thermal and noise insulation, and are economical for masonry construction.

CSIR-CBRI recommends mixes as 1 cement: 4 sand: 6-10 mm dia. stone aggregate/ gravel : 8 stone ballast or gravel (40mm) with low water – cement ratio (0.35) and good vibro-compaction technique. This yields about 55 to 60 blocks per bag of cement of 5 to 7 MPa strength.

Material Requirements *(per cubic meter)*

200 mm thick Solid Concrete block wall	Cement concrete- 0.95 cum Blocks- 100 nos. 1:6 Cement sand mortar- 0.15 cum

Tools and Equipments

a) Molds b) Vibrator c) Brick making machine and other normal T&P.

Salient Features

1. Labor intensive technique, with good strength and durability, when cast using vibro-compaction technique.
2. Can be manufactured locally.
3. Suitable for load bearing wall structures.
4. Fire and flood resistance
5. Good acoustic performance due to mass and damping qualities.

Economic Aspects

1. Concrete block masonry is an economical option for places where bricks cannot be produced locally such as in non alluvial soil hilly regions and Deccan plateau. Block production also generates local employment.

Sustainability Aspects

1. Reduce up to 80% of green house gases emission against clay brick production and transport.

Limitations

1. Suitable where sand and coarse aggregate are locally available.
2. Slightly more density as compared to brick masonry.
3. Difficulties in installing plumbing, electrical fittings.

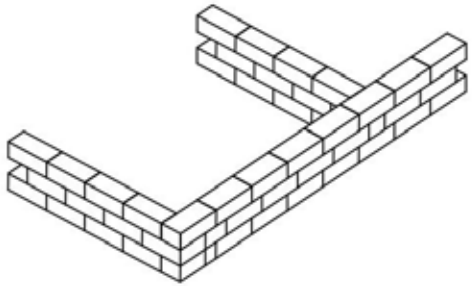
Market Linkages

1. Concrete blocks can be produced by small entrepreneurs and supplied to consumers at State/Block/village level.

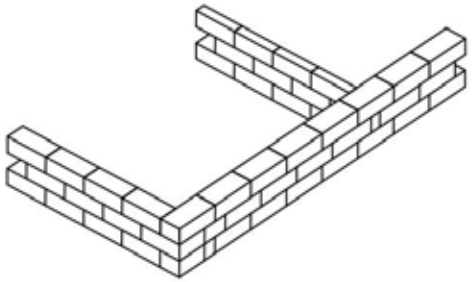
Cost

1. In remote hilly areas, desert areas and deccan plateau these blocks are up to 4 times cheaper than bricks that are transported from long distances.

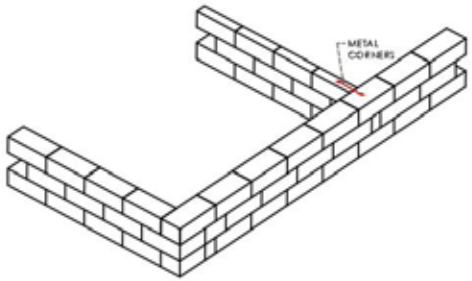
Walling system



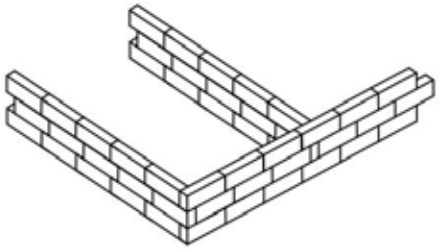
CORNER & T-JUNCTION OF 150 X150 MM WALL



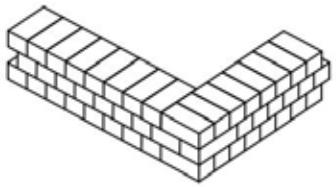
CORNER & T-JUNCTION OF 200 X 100 MM WALL



CORNER & T-JUNCTION OF 150 X100 MM WALL



CORNER & T-JUNCTION OF 100 X100 MM WALL



CORNER OF 300 X300 MM WALL

Solid Concrete block wall construction

Specifications

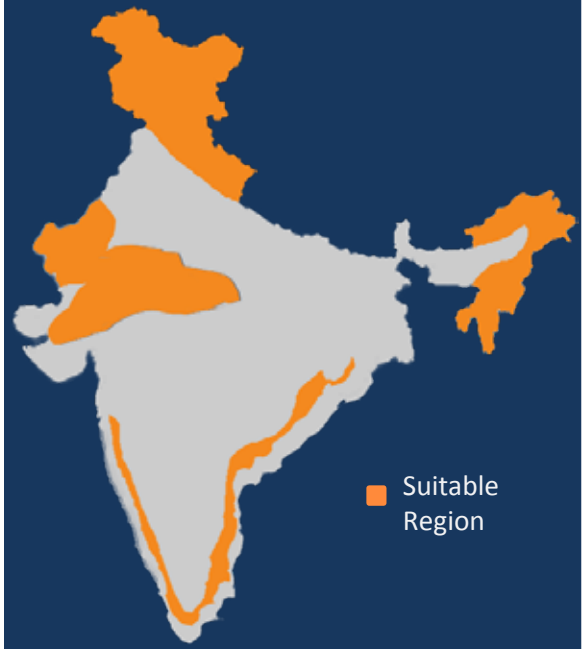
Masonry Bonds	Typical 'T' & 'L' junctions.
Dimensions	Length: 300 mm Height: 150 mm Width: 100, 150, 200 mm
Compressive strength	3.2 – 7 MPa for individual units 4 – 6 MPa Minimum Average
Density	2050 kg/m^3
Drying shrinkage	0.06 %
Mortar	1:6 Cement sand mortar 1:2:9 Composite lime mortar (recommended)
Mixed Proportion	1:4:6:8 :: Cement : Sand : Stone Aggregate (10 mm) : Stone ballast (40 mm), Water Cement Ratio 0.35. Vibro – Compaction Technique is preferred.

Relevant Standards and References

1. IS: 2185 (Part 1) - 2005, Concrete Masonry Units — Specification: Part 1 Hollow and Solid Concrete Blocks, Bureau Of Indian Standards, New Delhi.
2. IS: 2572 - 2005, Construction of Hollow And Solid Concrete Block Masonry-Code of Practice, Bureau Of Indian Standards, New Delhi.

Precast Stone Block Masonry
(Alternate of Brick Wall)

Suitable Regions



Hilly areas, Western & Eastern Ghats, Regions of Rajasthan, Gujarat Northeast and Deccan Plateau.

About the Technology

In Some parts of country, stone is available in abundance and forms the chief walling material. There walls are made in the form of random rubble masonry with thickness generally 380 to 450 mm . CBRI has carried out studies to reduce thickness and labor normally required in rubble masonry. Precast technique to produce stone masonry blocks with stone spalls and cement concrete such that natural stone texture is obtained on the face of the block has been developed. It is easy to produce with semi-skilled workers and requires very little machinery. These blocks are successful for load bearing and non load bearing wall up to 3 storey. Steel moulds of size 290 mm x 190 mm x 140 mm, are used for casting these blocks. First large locally available stone pieces (100 to 160mm size) are placed in the moulds and then Concrete mix 1:5:8 (can vary depending upon strength required) is poured into the moulds to fill all the gaps. Plate vibrator is used to compact the concrete. Demoulding is done after a few minutes. The average compressive strength of such blocks is about 6N/sq.mm, depending upon the size of stones, mix and method of compaction.

For breaking of vertical joints in alternate courses 1/3 and 2/3 size smaller length blocks are also cast. Special slotted blocks are used for providing vertical steel bars at the corners and T-junctions.

Material Requirements (per cubic meter)

200 mm thick wall	1:5:8 Concrete- 0.65 cum Stone spalls- 0.40 cum 1:6 Cement sand mortar- 0.15 cum

Tools and Equipments

a) Casting Blocks b) Plate Vibrators c) Pallets
d) Steel moulds e) Mason's tools f) concrete mixer
g) casting platform h) space for stacking.

Salient Features

1. Labor intensive technique, with greater strength and durability.
2. Stone spalls save cement consumption
3. Does not require heavy capital investment
4. High performance in load bearing wall structures.
5. Fire, Sound and water resistance
6. Good thermal insulation.

Economic Aspects

1. This construction system provides about 30 to 300% economy in comparison to other conventional walling systems in remote hilly areas where stone is locally available.

Sustainability Aspects

1. Reduce up to 70% of green house gases emission compared to kiln burnt clay bricks. Can be cast locally so transportation cost is reduced in remote hilly areas.

Limitations

1. Used where only good stone and stone aggregate is available.

Market Linkages

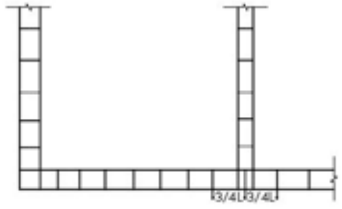
1. Precast stone blocks can be produced by small entrepreneurs and supplied to consumers at State/Block/village level.

Cost

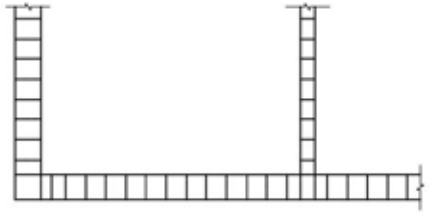
1. In stone abundant areas of hills & plateaus where clay bricks are transported from long distances, cost economy ranges from 200 to 500% over burnt clay brick masonry. Employment is generated through local level casting and laying of these blocks.

Walling system

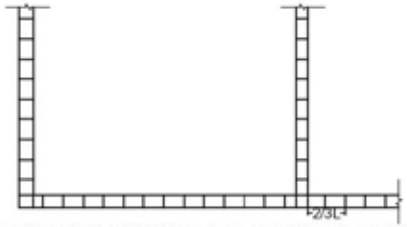
CORNER T-JUNCTION OF 200 X200 MM WALL



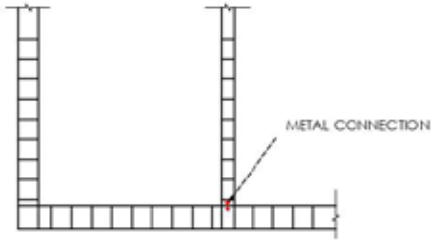
CORNER T-JUNCTION OF 150 X150 MM WALL



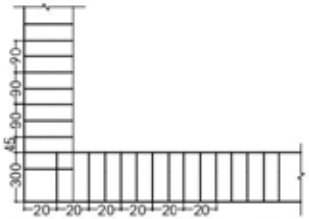
CORNER T-JUNCTION OF 200 X100 MM WALL



CORNER T-JUNCTION OF 100 X100 MM WALL



CORNER T-JUNCTION OF 200 X200 MM WALL



CORNER T-JUNCTION OF 200 X200 MM WALL

Precast Stone block masonry

Specifications

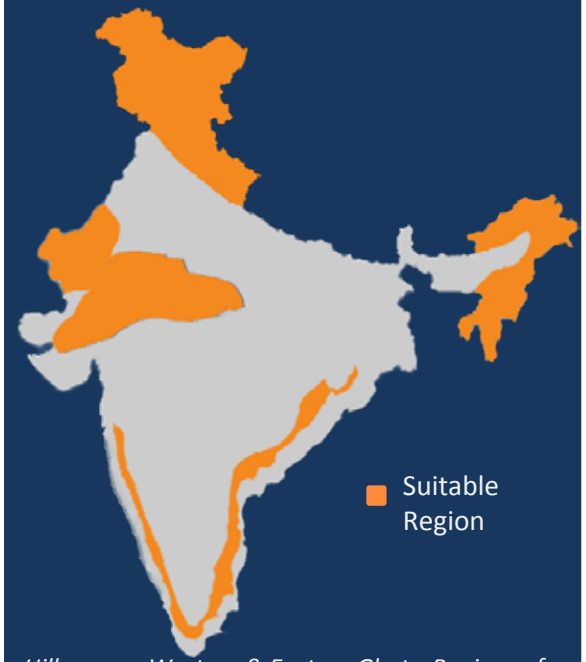
Dimensions	Length: 300 mm Height: 200 mm Width: 150 mm
Compressive strength	Concrete mix 1:3:6 9.8 MPa (with manual compaction) 12.2 MPa (with vibrator) Concrete mix 1:4:7 8.3 MPa (with manual compaction) 10.7 MPa (with vibrator) Concrete mix 1:5:8 + stone spalls 6.8 MPa (with manual compaction) 8.82 MPa (with vibrator)
Water absorption	4 – 6 %
Drying shrinkage	0.033 – 0.38 %
Mortar	1:6 Cement sand mortar (recommended) 1:2:9 Composite Cement lime mortar
Thermal Performance	100 mm wall 3.75 Kcal/hr/C/m^2 200 mm wall 2.668 Kcal/hr/C/m^2

Relevant Standards and References

1. IS 2185 (Part 1) :2005, Concrete Masonry Units — Specification: Part 1 Hollow and Solid Concrete Blocks, Bureau Of Indian Standards, New Delhi.
2. IS 2572:2005, Construction of Hollow And Solid Concrete Block Masonry-Code of Practice, Bureau Of Indian Standards, New Delhi.

Hollow Concrete Block
(Alternate of Brick Wall)

Suitable Regions



Hilly areas, Western & Eastern Ghats, Regions of Rajasthan, Gujarat Northeast and Deccan Plateau.

About the Technology

Hollow concrete blocks are gaining popularity in most parts of India particularly in multi-storey buildings due to lesser dead weight of walls, easy availability of materials, economy and faster construction. These blocks could be through cavity type or the cavity may be closed on one end. Hollow masonry blocks also improve physical properties of walls, such as noise and thermal insulation. If required the hollow cavities can be reinforced with steel bars and filled with concrete for safety against earthquakes and cyclones.

For better resistance to tensile loading and for enhancing the ductile behavior of the hollow concrete block masonry walls, horizontal reinforcement is provided for improved shear wall behavior and reducing the vulnerability against dynamic forces. Various locally available materials like fly ash, cinder, river shingle, hydraulic lime etc. can also be used in the production of these blocks. Details on load bearing and non load bearing blocks and block masonry can be obtained from IS 2185 (Part 1): 2005 and IS 2572:2005. if required, cavities in blocks and wall corner joints can be reinforced by filling concrete in the hollow part of the block, also, reinforced in-wall columns or ring beams can be installed.

Material Requirements (per cubic meter)

200 mm thick Hollow Concrete block wall	Cement concrete- 0.60 cum Blocks- 60 nos.

Tools and Equipments

a) Vibrating table with mould for manual production or Hollow block making machine (egg-laying type) or semi-automatic vibro-compaction machine for fast production.
b) Concrete mixer
c) trolleys and arrangements for curing and stacking.

Salient Features

1. Density of hollow concrete block is 1100 - 1500 kg/cubic meter against 2200 to 2400 for solid walls.
2. Reduced dead load of the building structure leads to economic foundation and structural members.
3. Reduces construction time due to larger sizes of the blocks as compared to bricks.
4. It provides better thermal insulation, particularly when there are several layers of thin cavities
5. The masonry work is similar to traditional masonry work in stretcher bond.

Economic Aspects

1. It is a faster and economical construction system. Can be produced near the construction site to minimize loading-unloading and transport.

Sustainability Aspects

1. Reduces carbon footprint as it does not require burning as in the case of bricks. Use of locally available materials and skills.

Limitations

1. Suitable for non-load bearing or single storey load bearing walls.
2. Water seepage through these blocks is often more than burnt clay bricks.

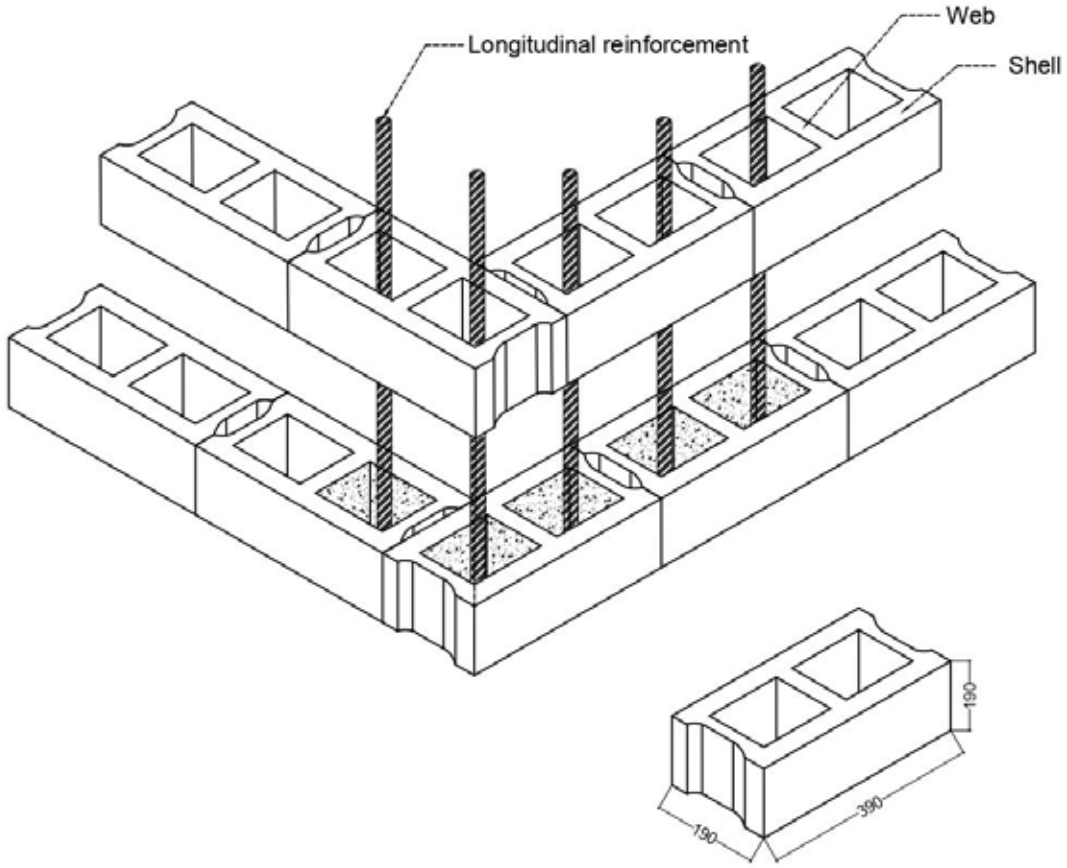
Market Linkages

1. These blocks can be produced by small entrepreneurs meeting the requirements of IS : 2572-2005 and supplied to consumers at State/ Block/village level.





Walling system



Hollow Concrete block wall construction

Specifications

Dimension *(Refer IS 2185 Part-1)*	390 x 190 x 190 mm with face shell thickness not less than 30 mm and web thickness not less than 25 mm.
Block Density *(Refer IS 2185 Part-1)*	1100 – 1500 kg/m^3
Compressive Strength *(Refer IS 2185 Part-1)*	5-28 MPa depending upon block size and concrete mix
Water Absorption *(Refer IS 2185 Part-1)*	Less than 10%
Drying Shrinkage *(Refer IS 2185 Part-1)*	Less than 0.06 %

Relevant Standards and References

1. IS 2185 (Part 1) :2005, Concrete Masonry Units — Specification: Part 1 Hollow and Solid Concrete Blocks, Bureau Of Indian Standards, New Delhi.
2. IS 2572:2005, Construction of Hollow And Solid Concrete Block Masonry-Code of Practice, Bureau Of Indian Standards, New Delhi.

Autoclaved Aerated Concrete (AAC) Blocks

(Alternate of Brick Wall)

Suitable Regions

All parts of India

About the Technology

Aerated concrete blocks are masonry units used in the construction of partition/ non load bearing walls in RC framed buildings using cement mortars. Autoclaved Aerated Concrete (AAC) Blocks are manufactured in specialized manufacturing facilities in various sizes. These Blocks have low density and low thermal conductivity compared to clay bricks or concrete blocks. There are many advantages of Aerated Concrete blocks such as, reduction of dead load, faster building rate and lower transport cost. Autoclaved Aerated concrete (AAC) have a porous structure created by small air bubbles by foaming agents or aluminum powder in cement, fly ash and sand slurry and cured in high-pressure steam (autoclaved).

AAC blocks are 2-3 times lighter than traditional bricks. Incorporation of pozzolanic materials like fly ash into cement or concrete provide advantages such as reduction in the heat, low permeability and resistance to sulphate attack. Fly ash is also used to replace part of Portland cement and part of fine aggregates for the production of AAC blocks.

Material Requirements (per cubic meter)

200 mm thick Aerated Concrete block wall	Mortar- 1:6 cement sand or 1 cement: 2 lime: 9 sand Blocks- depending upon size

Tools and Equipments

a) Steel-moulds b) Foam generators c) ribbon mixers c) batching plants d) autoclaves e) wire cutters

Salient Features

1. Reduce construction time up to 50%.
2. Good thermal insulation.
3. It offers sound attenuation of about 42 dB.
4. Due to low density (600-1100 Kg/m^3) economic structure design is achieved.
5. Suitable as masonry in-fill in frame structure.

Economic Aspects

1. AAC reduces the operating cost by 30% to 40%. It also reduces overall construction cost by 2.5% as it requires less jointing mortar and reduces the quantity of cement and steel in RCC frame, leading to economy in structure cost.

Sustainability Aspects

1. AAC consume (about 60% of its mass) fly ash. AAC helps to reduce at least 30% of environmental waste as compared to traditional concrete. There is a decrease of 50% of greenhouse gas emissions.

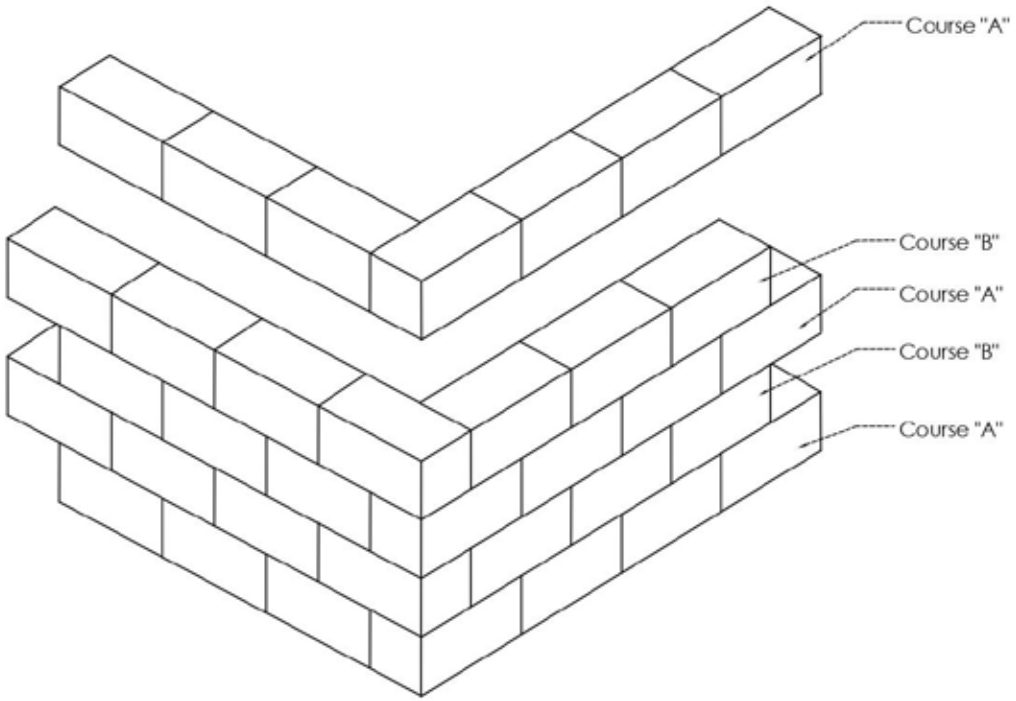
Limitations

1. Precautions needed to prevent drying shrinkage cracks and stress concentration cracks.
2. Not perfectly suitable for load bearing walls.
3. Not recommended in wet regions without good plaster due to water absorption (50%) problem through porous surface of AAC blocks.

Market Linkages

1. Can be produced by small entrepreneurs and supplied to consumers at State/ Block/village level. Suitable where sand and fly ash are available.

Walling system



Aerated Concrete block wall construction

Specifications

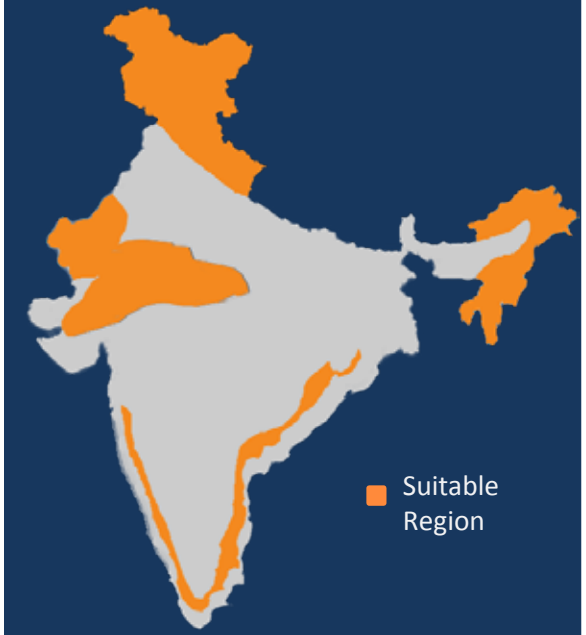
Dimension	Length : 400, 500 or 600mm Height : 200, 250 or 360 mm Width : 100,150,200 or 250 mm
Density	451-950 kg/m^3
Compressive strength	An average compressive strength of 2.86 MPa has been achieved on 0.650 gm/cm^3 density AAC cubes following 28 days of the standard water-curing.
Thermal Insulation	AAC has very good thermal insulation qualities relative to other masonry. A 200 mm thick AAC wall gives an R-value rating of 1.43 with 5% moisture content by weight. With a 2–3 mm texture coating and 10 mm plasterboard internal lining it achieves an R rating of 1.75.
Sound insulation	AAC offers sound attenuation of about 42 dB.

Relevant Standards and References

1. IS: 2185 (PART 3) 1984, Specification for concrete masonry units, Autoclaved cellular(aerated) Concrete blocks, Bureau of Indian Standards New Delhi
2. IS: 269 - 1989, Ordinary Portland Cement, 33 Grade Specification, Bureau of Indian Standards, New Delhi
3. IS: 383 - 1970, Specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi
4. IS: 456 - 2000, Plain and Reinforced concrete - code of practice , Bureau of Indian Standards, New Delhi

Ashlar Masonry
(Scheme for Wall)

Suitable Regions



Hilly areas, Western & Eastern Ghats, Regions of Rajasthan, Gujarat Northeast and Deccan Plateau.

About the Technology

Ashlar masonry is a type of stone masonry which is formed using dressed stones of same size, shape, and texture laid together in cement or lime mortar of equal size joints at right angles to each other and in level courses.

For ashlar masonry work, it is specified that the length should not exceed three times its height. The breadth should not be greater than three-fourths of the thickness of the wall or less than 150 mm. The height can be up to 300 mm. The stones should not be larger than what can be handled and placed by one person. It is considered best suitable for load bearing walls. Ashlar masonry can be classified as, ashlar fine , ashlar rough, ashlar rock or quarry faced , ashlar facing, ashlar chamfered, ashlar block in course. The main criterion of this classification in based upon the degree and process of dressing.

Types of stone commonly used in building construction are granite, trap, basalt, quartzite, limestone, and sandstone. Hard stones without flaws should be used as bed blocks below the beams. The courses shall be built perpendicular to the pressure which the masonry will bear. In case of battered walls, the beds of stone and the plane of courses shall be at right angle to the batter.

Material Requirements (per cubic meter)

200 mm thick Ashlar masonry wall	Mortar- 0.15 cum Dressed Stone- 100 nos.

Tools and Equipments

a) Spall Hammer b) Waller hammer c) Club hammers d) Mallet e) Cross-cut saw f) Square g) Chisel h) Masonry line i) Plumb bob j) Mason's Level k) Mixing Tools l) Tape Measure

Salient Features

1. Durability of structure constructed by stone masonry is more in comparison to other conventional systems.
2. Ashlar Stone masonry is weather resistant .
3. Walls constructed using ashlar masonry are aesthetically pleasing.
4. No plaster is required to finish the surface.
5. Labour intensive technology.

Economic Aspects

1. This stone masonry technique is ten times expensive than the normal rubble masonry. Skilled work force and special equipments and machines are required for this construction methodology, which increases the overall cost of the project.

Sustainability Aspects

1. Quarrying of stone causes degradation of resources and environmental hazard in the surrounding. And large amount of material is wasted in the process of dressing.

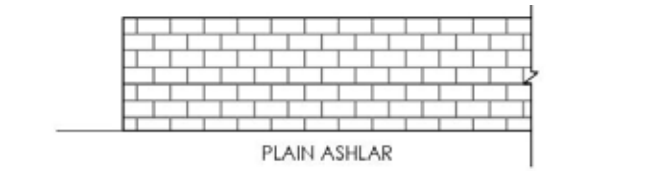
Limitations

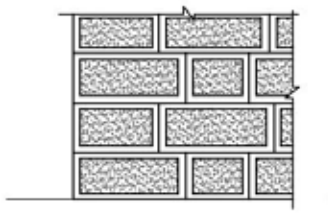
1. Very Expensive masonry as stone involved needs costly dressing.
2. High density of structure leads to difficulty in handling/transportation and high load on footing and structure.

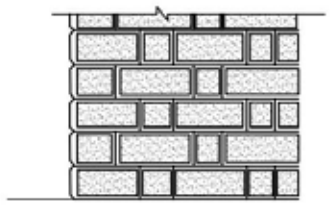
Market Linkages

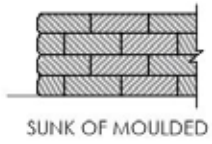
1. Stone, can be dressed by small entrepreneurs and supplied to consumers at State/ Block/village level.

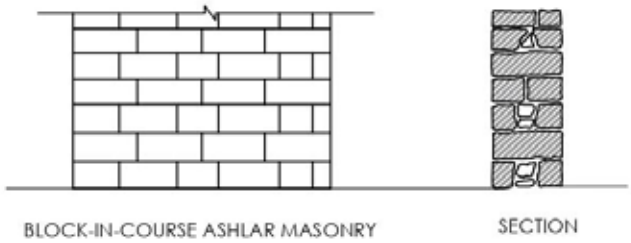
Walling system











Ashlar masonry for wall construction

Specifications

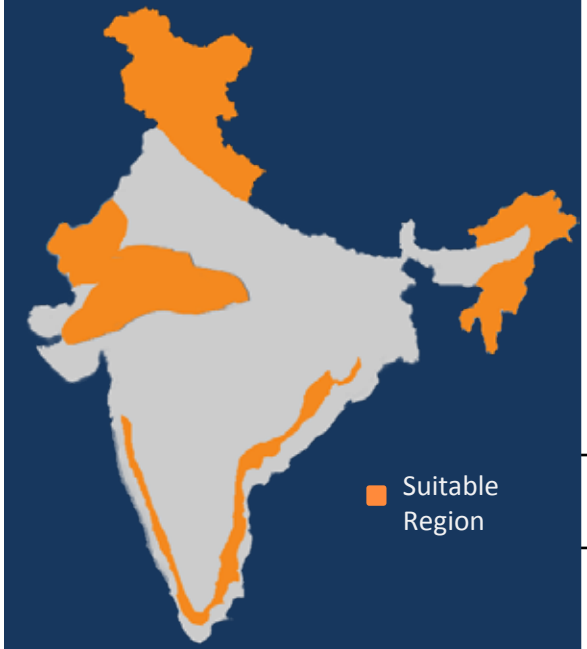
Size of Stone	Length : 300 mm – 900 mm Breadth: 150 mm – 300 mm Height : 150 mm - 300 mm
Dressing of stones	No point should be deeper than 1 mm – Exposed Face 3 mm - Bed Face 6 mm - Side Face 10 mm - Rear Surface
Laying	Laying is done as headers and stretchers alternately. Headers should not lie over stretchers placed below.
Bond Stone	Through bond stones shall be provided in walls up to 600 mm thick.
Joints	Up to 5 mm only
Mortar	Cement-sand mortar - 1 : 5, 1 : 4 or 1 : 3 Composite cement-lime-sand mortar – 1 : 1 : 6, 1 : ½ : 4 ½ , depending on load.

Relevant Standards and References

1. IS :1597 (Part 2) - 1992 Construction of stone masonry code of practice part 2 - Ashlar masonry, Bureau of Indian Standards, New Delhi
2. IS :1127 - 1970, Recommendations for dimensions and workmanship of natural building stones for masonry work, Bureau of Indian Standards, New Delhi
3. IS :1123 - 1975 Method of identification of natural building stones, Bureau of Indian Standards, New Delhi .

Random Rubble Masonry
(Conventional Scheme for Wall)

Suitable Regions



Hilly areas, Western & Eastern Ghats, Regions of Rajasthan, Gujarat Northeast and Deccan Plateau.

About the Technology

In Random rubble masonry irregular undressed stones are fixed together with mortar, in best stable arrangement to form a wall. The stones are used as available locally or as obtained from the quarry. These walls can usually sustain static compressive loads only. Required steel reinforcement is provided with cement concrete in the form of RCC beams, bands, columns etc. at proper locations develop resistance against in-plane wind and earthquake bending. Types of stone commonly used in building construction are granite, trap, basalt, quartzite, limestone, and sandstone etc. some times locally available softer varieties of stone like Laterite is also used in low rise houses. Stones used in random rubble masonry should not be less than 150 mm with height up to 300 mm.

IS:1597(1)–1992 recommends that for every half meter square wall surface a bond/through stone should be provided. In case of a walls up to 600 mm thick, length of bond stones should be equal to the thickness of wall. Bond stones should have a minimum section of 40000 mm2. Where bond stones of suitable length are not available precast cement concrete 1 : 3 : 6 (I cement : 3 sand : 6 stone aggregate of 20 mm nominal gauge). With a steel bar can be used or in-situ M15 cement concrete with a 10mm dia. steel bar equal to the width of the wall can be placed at appropriate intervals at the time of masonry work. Ensure that the headers extend at least 12 in (300 mm) into the core or backing. The headers shall occupy at least 20 percent of the face of the wall.

Material Requirements (per cubic meter)

400 mm thick wall	Mortar (1:8 or 1:5:8)- 0.35 cum Stone- 1.1 cum

Tools and Equipments

a) Masonry Hammer b) Stone breaking hammer c) Trowel d) Masonry Square e) Mason's Level f) Straight Edges g) Plumb bob h) mortar mixer i) Mason's Line j) Measuring tape

Salient Features

1. Random rubble masonry is the cheapest stone masonry as it utilizes undressed stones.
2. It is most economical solution for the hilly regions where bricks cannot be produced locally.
3. Properly constructed masonry is durable when necessary precautions are taken
4. Stone masonry is weather resistant.

Economic Aspects

1. Rubble masonry involves undressed, irregular stone which reduce the overall construction of the structure.
2. Requires more mortar, Provides local employment
3. Requires special provisions against earthquake damages when used above plinth level.

Sustainability Aspects

1. No green house gases evolve as in brick burning process. Reduced transportation
2. Rock blasting and quarrying from hills and rivers sometimes affects local ecology.

Limitations

1. Wall thickness is considerably large that decreases the carpet area of the building.
2. Stone masonry walls without required RCC reinforcement may fail in cyclic loading during earthquakes/ cyclones.
3. Mortar consumption is more, which increases cost.
4. Large size key stone at corner joint to be placed properly.

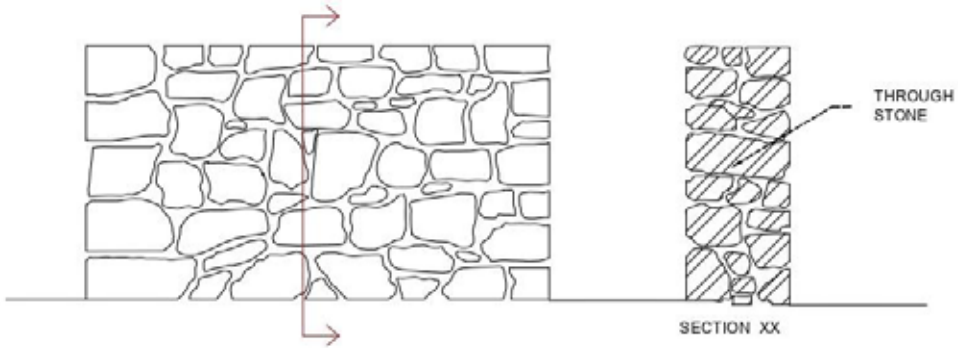
Market Linkages

1. Stone for masonry construction can be obtained from local quarries. Local masons and contractors can do the masonry jobs.

Cost

1. Random rubble masonry is cheaper in stone abundant areas where bricks are transported from long distances.

Walling system



Random Rubble masonry for wall construction

Specifications

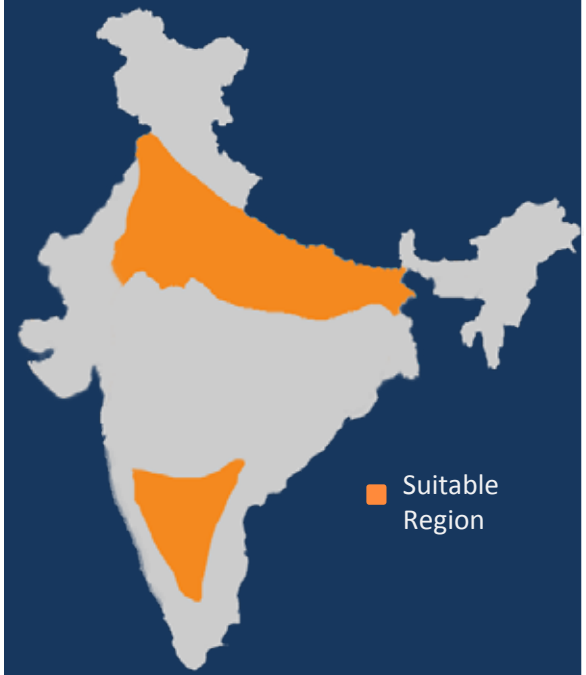
Size	>150 mm with height up to 300 mm Breadth of a stone at base should not be greater than three-fourth of the thickness of wall nor less than its height.
Bond stones	Minimum area 40000 mm^2, In every 500000 mm^2 area of wall in case of un-coursed rubble masonry and in the case of coursed rubble masonry it should be provided at every 1800 mm span.
Quoin stones	1. Length of these stones should be 450 mm or more and at least 25 percent of the stone should be 500 mm or more in length. 2. The quoins should have a uniform chisel draft of at least 25 mm width at four edges of each exposed face, all the edges of a face being in one plane. 3. No quoin should be smaller than 25000 mm^2 in volume.
Jambs	Stones used in jambs should be similar to those in quoin, excepting the length of the stem which should be 450 mm or thickness of wall whichever is less.

Relevant Standards and References

1. IS:1597 (1) – 1992, Construction of stone masonry code of practice part 1 rubble stone masonry, Bureau of Indian Standards, New Delhi
2. IS :1127 - 1970, Recommendations for dimensions and workmanship of natural building stones for masonry work, Bureau of Indian Standards, New Delhi
3. IS :1123 - 1975 Method of identification of natural building stones, Bureau of Indian Standards, New Delhi
4. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi

Rammed Earth Walls
(Scheme for Wall)

Suitable Regions



Predominantly in Deccan plateau region and along alluvial soil with rain protection.

About the Technology

This technique involves construction of walls using natural raw materials such as earth, chalk, lime, and/or gravel. Making rammed earth walls involves compacting sub soil at optimum moisture content (OMC) that has suitable proportions of sand, gravel, clay, and stabilizer, if any into a formwork (an externally supported frame or mould). Soil mix is poured into the formwork to a depth of 10 to 250 mm (4 to 10 in) and then compacted to approximately 50% of its original volume. The soil is compacted iteratively, in batches or courses, so as to gradually erect the wall up to the top of the formwork.

Tamping was historically manual with a long ramming pole, and was very laborious, but modern construction can be made less so by employing pneumatically powered tampers. After a wall is complete, it is sufficiently strong to immediately remove the formwork. To finish the surface wire brushing, carving, or removing mould impression is done. The compressive strength of rammed earth is dictated by factors like, soil type, particle size distribution, amount of compaction, moisture content of the mix and type/amount of stabilizer used. Well produced cement stabilized Rammed Earth walls can be anywhere between 5 to 20 MPa. Higher compressive strength might require more cement. But addition of more cement can affect the permeability of the walls.

Material Requirements (per cubic meter)

300 mm thick wall	Soil- 1.40 cum Cement- 3 bags

Tools and Equipments

a) Trowel, Mason's level b) plumb bob c) mixing tools
d) Measuring Tape other mason’s tool e) formwork
f) rammer g) Scaffolding

Salient Features

1. The external walls of our rammed earth buildings are a minimum of 300mm (1ft) thick, providing excellent thermal comfort.
2. Durable and weather resistant when protected from moisture.
3. Rammed earth is non-toxic, non-polluting

Economic Aspects

1. Produced locally, with natural local resources, semi-skilled labor and, reduced transport needs. Promotes employment generation at low capital investment.

Sustainability Aspects

1. Low carbon footprint, no disposal of waste problems, environment friendly.

Limitations

1. Not recommended in high rainfall, flood prone, seismic zone IV and V and black cotton soil region.
2. More maintenance
3. Protection against Water and moisture needed.
4. Walls should be constructed upon raised platforms.
5. Plinth protection, non-erodable mud plaster, ferrocement plaster, large roof projections, good drainage, termite and mouse control etc. should be ensured.

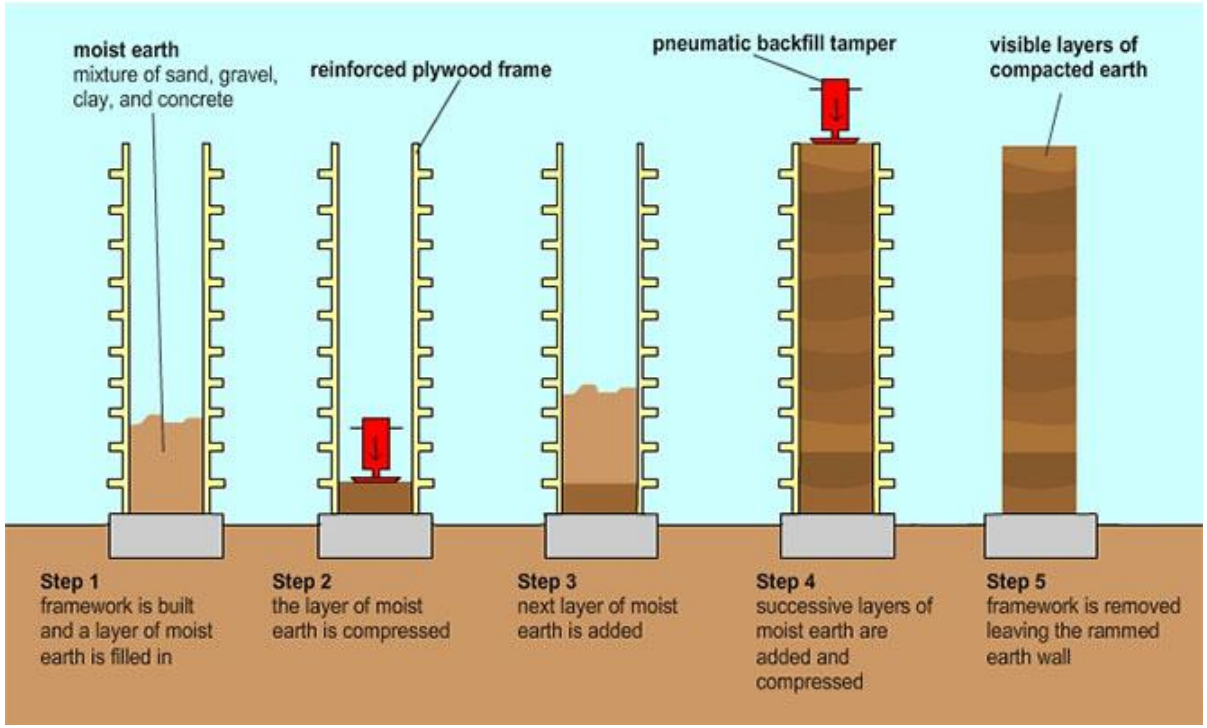
Market Linkages

1. Rammed earth wall is cast at the construction site by a group of experienced workmen.

Cost

1. 20 to 40% cheaper than brick masonry.

Walling system



Rammed Earth wall construction

Specifications

Thickness	These rammed earth walls can be anywhere from 300 mm to 1000 mm thick going up in 100mm increments.
Density	2 gm/cm³
Insulated Rammed Earth wall	Insulated rammed earth walls start at 400 mm thick with a 50 mm Styrofoam insert and can go up to your desired thickness in 100mm increments.
Compressive strength	5-20 MPa
Axial Strength	Holds 2000 kg pull.
Note:	Soil stabilization and mechanized ramming have shown marked improvement on traditional practices. Light composite formwork made of plywood, wood and steel or sometimes aluminium. Pneumatic rammers, dumpy loaders, mixers, conveyors, etc. are used to build faster and get a better quality finish. Walls can thus be built to their full height at once. This way of building changed totally the design pattern of structure.

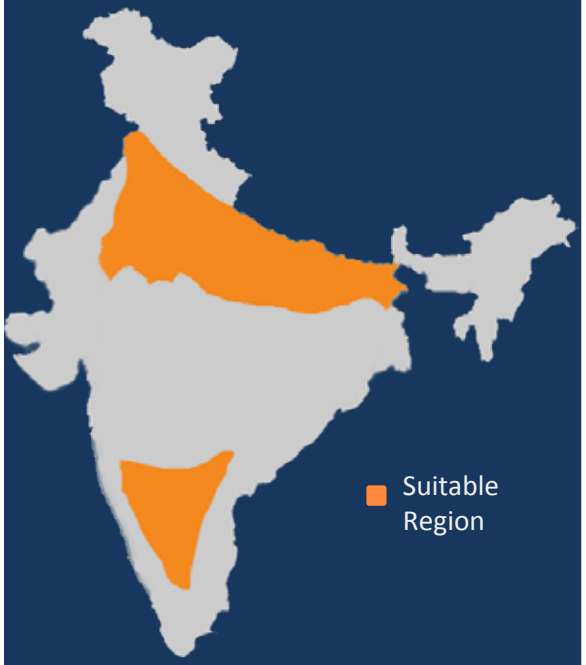
Relevant Standards and References

1. Advanced work has been done in Australia, USA, Canada, countries of Europe, UK, Auroville, IISc India.
2. http://www.rammedearthworks.com/
3. http://www.earthstructures.co.uk/
4. http://www.lehmtonerde.at/.

Compressed Earth Block Masonry

(Alternate of Brick Wall)

Suitable Regions



Predominantly in Deccan plateau region and along alluvial soil with rain protection.

About the Technology

A compressed earth block (CEB), is a building material made primarily from damp soil compressed at high pressure to from blocks. Compressed earth blocks use a mechanical press to form blocks out of an appropriate mix of fairly dry inorganic subsoil and aggregate. if the blocks are stabilized with a chemical binder such as Portland cement they are called compressed stabilized earth block (CSEB) or stabilized earth block (SEB).The production of compressed earth blocks can be regarded as similar to that of fired earth blocks produced by compaction, except that there is no firing stage. Compressive strength of earth blocks is about 3.12 MPa).

Production, drying and stocking areas depend on the methods of production and the production conditions dictated by the climatic, social, technical and economic environment.

Earth blocks construction requires careful design, quality production and use in construction to meet requirements of building codes. The masonry is done using mud/ lime + fly ash or cement sand mortars. Compressive strength is between the 1.13 to 1.83 MPa.

Material Requirements (per cubic meter)

300 mm thick wall	Mortar- 0.25 cum Mud Blocks- 220 nos.

Tools and Equipments

a) Moulds b) compaction machine c) Pulverizers d)Mixer e) Trowel f) Screen

Salient Features

1. Non Toxic construction material.
2. Economical in comparison to burnt bricks and blocks
3. Can be produced locally in the Indo-Gangetic Plains.
4. Provide good thermal insulation.
5. A single mechanical press can produce from 800 to over 5,000 blocks per day.

Economic Aspects

1. Cost effective for the construction of single or double storey houses duly strengthened by RBC/ RCC corners, junctions and bands.
2. The walls must be provided with cement plaster over a layer of wire mesh fixed to the wall surface using long nails.
3. Can be produced locally, with local resources by semi-skilled labor, hence economical and generates local employment .
4. Production rates depend largely on the method, scale and quality of production.

Sustainability Aspects

1. Energy efficient, use of local materials, no disposal problem and thermally comfortable. Low green house gases are evolved during the manufacturing or transport process of these blocks.

Limitations

1. Cannot be applied in seismic or flood prone areas.
2. Less durable for aggressive weather conditions.
3. Good quality soil is required for making these blocks to achieve the desired strength of 3.5 MPa.
4. Protect the walls from moisture by plinth protection and ferro-cement plaster.

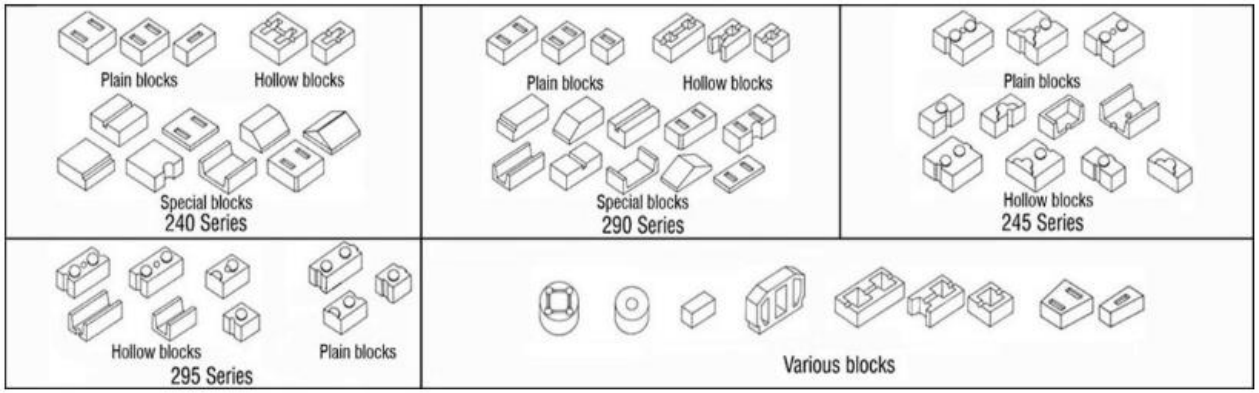
Market Linkages

1. Can be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.

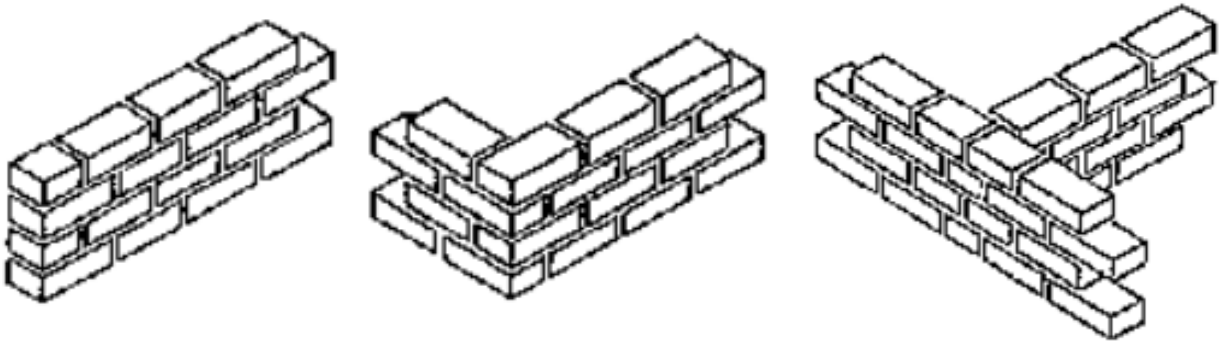
Cost

1. 50 to 60% cheaper than kiln fired bricks. Can be produced locally in villages.

Walling system



Types of Compressed Earth blocks *(source: Auroville Earth Institute)*



Half block used at the end of alternate courses and continuous wall

Corner of wall using full block

"T"-shaped bonding pattern using three-quarter blocks

Compressed Earth block wall construction

Specifications

Production	Excavation, drying, pulverizing, screening, measuring out, dry mixing, wet mixing, molding, compression, ejection, wet curing, drying , stocking etc
Particle Size Analysis	The constituents of soil could be around: Sand 40%, Silt 35%, Clay 25%
Block size	300 mm x 140 mm x 150 mm
Specific Gravity	1.80-1.85
Compressive strength	5 MPa (Unit Block of Size 305 X 143 X 105 mm) 1.5-2.24 MPa (Wall)
Sustainability	A bio-degradable material. Energy efficient and eco friendly. Earth buildings provide better noise control and thermal comfort.
Specifications	Cement, lime, gypsum stabilized soil bricks or blocks of specified size , clean cuboid shape with wet compressive strength of minimum 3.5N/mm^2

Relevant Standards and References

1. IS: 725:1982, Soil based blocks used in general building construction, Bureau of Indian Standards, New Delhi
2. Auroville Earth Institute, http://www.earthauroville.com/auram_earth_equipment_introduction_en.php

RC Precast Wall
(Alternate Scheme for Wall)

Suitable Regions

All parts of India

About the Technology

Precast technology involves casting of concrete building components in a reusable mold or "form" which are then cured in a controlled environment, transported to the construction site and installed into place.

Precast wall units can be used for both exterior and interior walls. By producing precast concrete components in a controlled environment (typically referred to as a precast plant), the precast concrete gets time for proper curing under the supervision of plant employees, leading to better quality.

The precast components are joined at site to bear the forces of the system. Resistance to horizontal loading is provided by having appropriate moment and shear resisting joints. The individual components are designed, taking into consideration the appropriate end conditions and loads at various stages of construction. The components of the structure shall be designed for loads in accordance with IS 875 (Parts 1-5):1987 and IS 1893 (Part 1):2002. In addition members shall be designed for handling, erection and impact loads that might be expected during handling and erection.

Material Requirements (per unit)

150 mm thick wall Size 3000 mm x 3000 mm	M20 concrete- 1.40 cum Steel- 40 kg

Tools and Equipments

a) Steel moulds b) shutter vibrators c) Reinforcing steel d) Trowel e) Concrete mixer f) casting and handling equipment g) cranes and general construction tools.

Salient Features

1. Industrialized production technique, with greater strength and durability.
2. Can be manufactured and processed in almost every region of the country.
3. High performance in load bearing wall structures.
4. Fire and flood resistance
5. Good acoustic performance due to mass and damping qualities.
6. Economic for mass scale production.

Economic Aspects

1. RC Pre-cast wall is an economical option for places where fast construction is required.

Sustainability Aspects

1. Saves material due to thinner wall sections Lower carbon foot print compared to brick walls.

Limitations

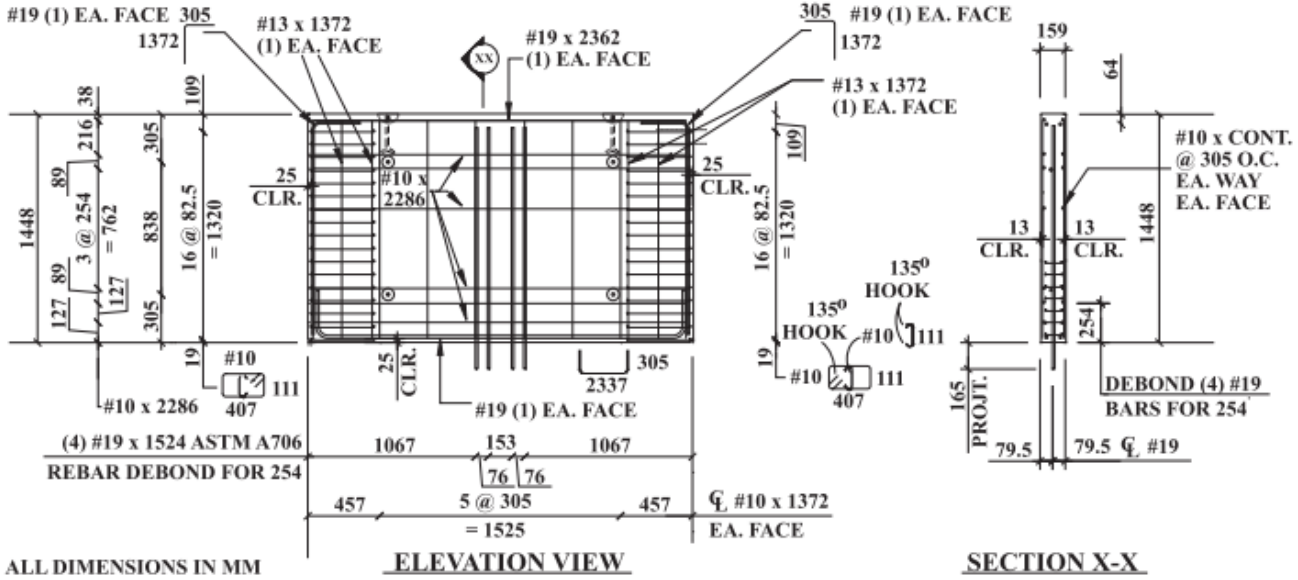
1. Initial capital investment is higher in comparison to other conventional systems.
2. Heavy construction machinery is required.
3. Difficulties in installing services such as plumbing, electrical fittings etc.
4. Thermally uncomfortable, requires insulation.

Market Linkages

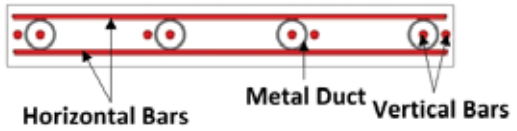
1. The precast components can be cast at construction site. Suitable for industrialized production and large number of identical houses at one site.



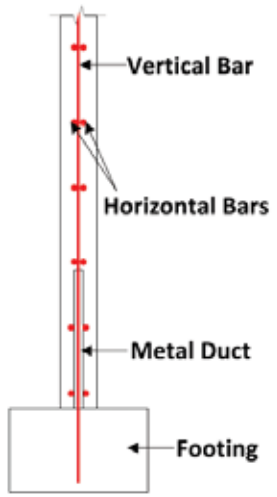

Walling system



RC Precast wall construction



Cross-sectional view



Side view

Specifications

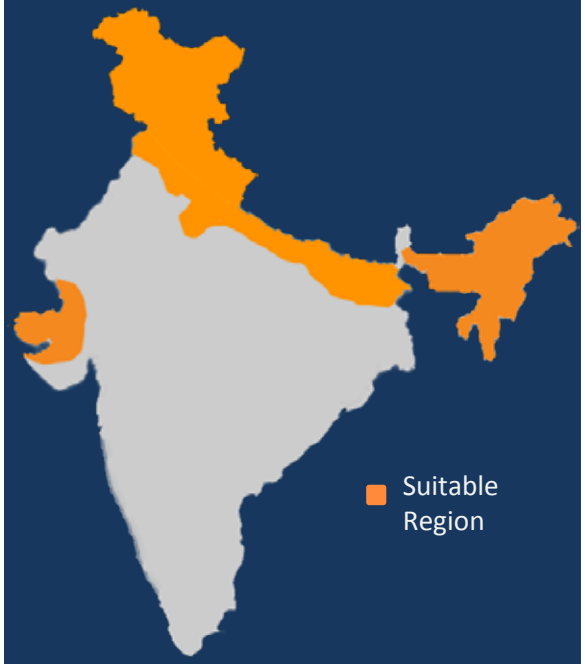
Design	The architectural and structural design shall be modular to minimize number of types of precast panels. All panels, Beams, columns and joints shall be designed to take all static and dynamic loads and ease of execution at site.
Materials	To be specially designed using durable, weather resistant materials like cement concrete, Foam concrete, steel etc to withstand all dead, live and other loads like seismic loads, cyclone/ wind/snow/floods /rains etc as prevalent at site and joints that can withstand all forces without any signs of failure.
Construction	All loading, unloading, handling and erection to be done using skilled manpower and appropriate construction machinery at site. All joints shall make monolithic connections between precast wall/roof panels and the foundations for structural integrity , leakages etc.

Relevant Standards and References

1. IS : 15916 - 2010, Building design and erection using prefabricated concrete — Code of practice, Bureau of Indian Standards, New Delhi
2. IS: 11447-2003, Code of practice for construction with large panel prefabricates, Bureau of Indian Standards, New Delhi
3. IS: 456 - 2000, Indian Standard Plain and Reinforced Concrete - Code of practice, Bureau of Indian Standards, New Delhi

Containment Masonry Walls
(Alternate Scheme for Wall)

Suitable Regions



Major Seismic activity prone regions .

About the Technology

Unreinforced Masonry construction is the most common type of construction in rural as well as urban areas due to its lower cost, ease of construction and thermal + acoustic insulation. When such a masonry structure is subjected to lateral inertial earthquake loads, the walls develop shear and flexural stresses within. Therefore it become prominent to provide reinforcement in the zone of flexural failure pattern zone. And since flexural tension can occur on both faces of the wall due to reversal of stresses during an earthquake, there is a need to provide ductile reinforcement on both faces. This can be accomplished by placing vertical reinforcement either on the surface or close to the surface and surrounding the wall, which is termed as containment reinforcement.

Containment reinforcement is provided as vertical reinforcement on both faces in a parallel manner. It may be either on the surface or hidden in 30 mm grooves beneath the surface. It is generally provided every 1000 mm in the horizontal direction and also next to door and window jambs

Material Requirements (per cubic meter)

230 mm thick wall	M20 concrete- 0.10 cum Bricks- 460 nos. Cement Mortar- 0.25 cum Steel- 4 kg/cum

Tools and Equipments

a) Masonry Hammer b) Trowel c) Masonry Square d) Mason's Level e) Straight Edges f) Plumb bob g) Mixing Tools h) Mason's Line i) Measuring tape j) Jointers k) Mashing hammer l) Blocking Chisel m) Scaffolding n) Shuttering

Salient Features

1. Prevent brittle failure of the masonry walls by allowing larger deformation in the zone of flexural tension.
2. Overall strength and integrity of the structure is ensured with less susceptibility to earthquake motions.
3. Economic solution for earthquake resistant building design.
4. Labor Intensive technology.

Economic Aspects

1. Much less investment to make the masonry wall earthquake resistant compared to RC frame construction.

Sustainability Aspects

1. Reduced consumption of cement and steel as compared to RCC frame construction.
2. Can be used in mud/stabilized mud wall construction also.

Limitations

1. Initial cost of installation is slightly (1-2%) higher in comparison to other conventional systems.
2. Good workmanship and protection of rebars from corrosion is essential.
3. Since thin wires are used, corrosion may become a problem in coastal and chemical industrial areas.

Market Linkages

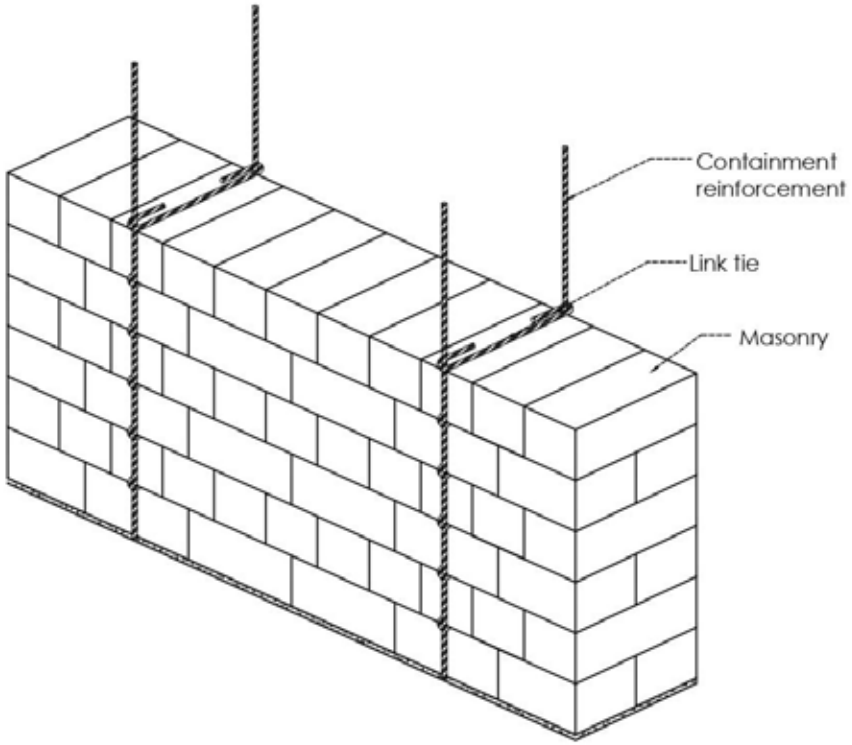
1. Can be constructed by Building contractors and general masons after short training.

Cost

1. Reinforcement included in masonry increases the cost of the structure by 1 – 2% to unreinforced masonry cost.

Walling system

Specifications



Masonry with containment reinforcement and links/ties connecting them through bed joints

Mild Steel rods	6mm corrosion prevented ductile rods covered with plaster can be used. Alternatively 20-25mm wide, 3mm thick MS flats could also be used, holes could be made at regular intervals to insert links/bolts to tie the flats provided on both faces of the wall.
Stainless Steel	Perfectly suitable for containment reinforcement, 3mm to 4mm wires could be used at 1.0m spacing.
Ferrocement strips	Thin ferrocement strips (about 150mm wide) with sufficient amount of reinforcing material such as chicken mesh, expanded metal, weld mesh etc.; can be used at about 1.2m spacing; the strips have to be bonded to the masonry wall by using grouted hooks.

Relevant Standards and References

1. IS: 4326 – 1993, Earthquake resistant design and construction of buildings — Code of practice, Bureau of Indian Standards, New Delhi
2. IS: 2212 - 1991, Brick Works-Code of Practice, Bureau of Indian Standards, New Delhi
3. IS:1905-1987, Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi
4. IS: 3102 – 1971, Classification of burnt clay solid bricks, Bureau of Indian Standards, New Delhi
5. IS: 1077 - 1992 Common burnt clay building bricks – specification, , Bureau of Indian Standards, New Delhi

Bamboo Strip Walling
(Scheme for Walls)

Suitable Regions

North-east India and some other parts of country where structural grade bamboo is available.

About the Technology

The most extensive use of bamboo in construction is for walls and partitions. Bamboo can also be used in the main load bearing columns, beams, trusses and so where they are required to carry the self-weight and imposed loads by the occupants, weather and earthquakes. An infill between framing members is required to complete the wall. The purpose of the infill is to protect against weather, intruders, animals, to offer privacy and to provide in-plane bracing for the overall stability of the structure when subjected to horizontal forces. The bamboo walls have a high architectural and aesthetic value. This infill can be made using whole or halved vertical or horizontal bamboo strips (with or without bamboo mats), Split or flattened bamboo (with mats and/or plaster), Bajareque, Wattle (wattle & daub, lath and plaster), Woven bamboo, or bamboo grids, with or without plaster, split Bamboo panels.

The wall infill is non-load bearing and comprises a grid or woven mesh of split bamboos (19 mm × 9 mm) tied together with MS binding wire to form a tight panel. The panels are fixed to the columns and beams. Chicken wire mesh is fixed on the outside face of the panel. A 1:5 mix cement sand mortar is applied on both side of the panel to a finished thickness of about 30 mm. The technique can be extended to the construction of gables. Alternatively gables may be formed with bamboo mat board. The natural durability of bamboo can be enhanced by impregnating with preservative compounds that help insect and fungal attack.

Material Requirements (per square meter)

75-90 mm thick wall	Bamboo strips- 50 m Bamboo (50mm dia.)- 4m Wire mesh- 2.2 sq.m 20 mm Cement plaster- 2.2 sq.m

Tools and Equipments

a) Carpentry tools b) hacksaw and files c) other masonry tools

Salient Features

1. Labor intensive technique, with greater strength and durability.
2. Economical for the area where bamboo is available locally.

Economic Aspects

1. Considerably cheaper than other conventional masonry systems. As it is a labor intensive technology, therefore it provides local employment and improves the economy of the area.

Sustainability Aspects

1. Low carbon emission as efficient use of local materials and manpower .

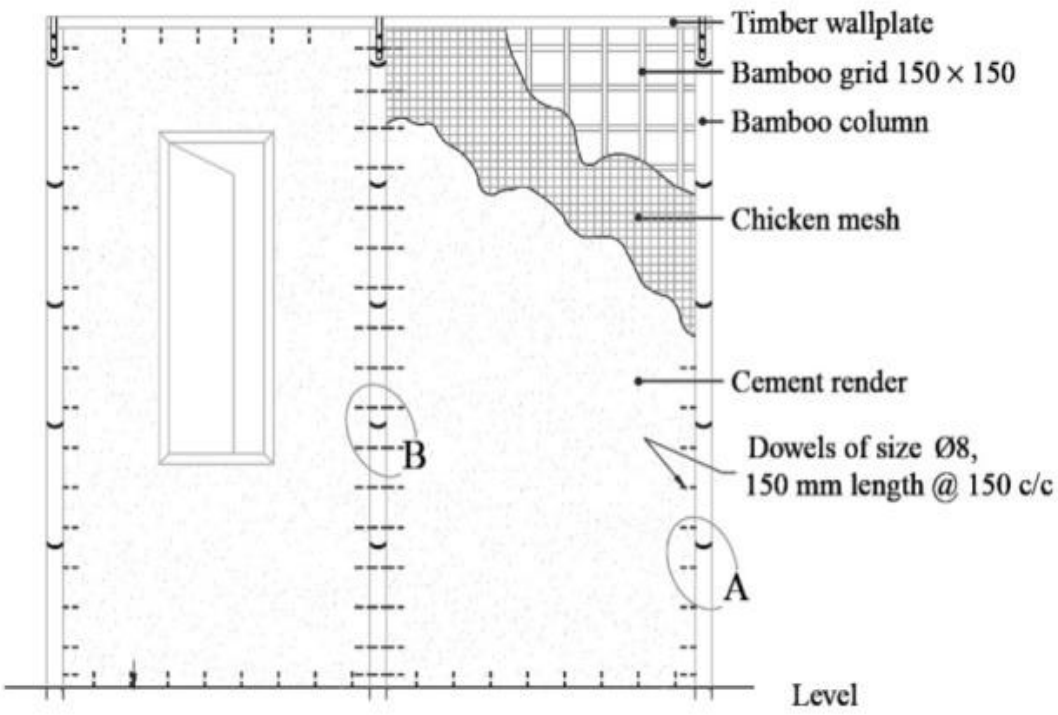
Limitations

1. Bamboo wall is suitable in the region where bamboo is available easily and in large quantity
2. Skilled laborers are required.
3. Durability is reduced if not protected from moisture, termites, insects, fungus and fire.
4. Concealed service lines for water supply, sanitation and electric supply are difficult.

Market Linkages

1. Can be constructed at site were properly treated and seasoned bamboo is readily available.
2. Trained and skilled workers / contractors can take up the construction work.

Walling system



Bamboo Ekra/strip wall

Specifications

Wall Infill	Panels of splits bamboo (19 mm × 9 mm) tied with MS binding wire.
Mortar	1:5 mix cement mortar, 30 mm thick with 12.5 x 12.5 sq.m wire mesh.
Wall thickness	600 mm
Strength	Maximum 2m x 2m size bamboo strip panels with Ferro-cement plaster can be used within load bearing framework of bamboo columns and beams.
Preservation agents	Tar oil, creosote oil, boric acid, borax and copper sulphate.

Relevant Standards and References

1. IS :15912 – 2012, Structural design using bamboo - code of practice, Bureau of Indian Standards, New Delhi
2. IS :13958 – 1994, Bamboo mat board for general purposes –Specification, Bureau of Indian Standards, New Delhi
3. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi
4. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi

Kath Kuni
(Scheme for Walls)

Suitable Regions

Majorly in Himachal Pradesh, Uttarakhand, Jammu Kashmir and Ladakh.

About the Technology

Kath-Kuni is an indigenous construction technique prevalent in the isolated hills of northern India, especially in the region of Himachal Pradesh. Kath-Kuni building employs locally available wood and stone as prime materials for construction.

The word kath means wood, and Kuni means an angle or a corner. There are several variations observed from region to region. The construction typically involves laying courses whose outer layer comprises random rubble masonry and wood, laid out alternately. The walls are almost 600 mm thick in dimension. After one course of wood, which is interlocked by dovetail random intermediate joints, to hold the wooden members in place. The courses alternate until a ceiling height is attained. The cavity inside the layers of wood and stone is filled with smaller stones within. They also act as insulation fillers between the outer layers.

Kath Kuni walls are characterized by layers of wood and stone that are interlocked at the corners. Here the walls are properly bound together by strong wooden members that help the structure to resist earthquake forces. Restrictions on cutting trees has made timber too costly for Kath Kuni type houses. Houses with out or with too less timber bands performed very badly during the recent earthquakes. The quantity of stones depends on the thickness of the walls and the sizes of timber sleepers used .

Material Requirements (per cubic meter)

600 mm thick wall	Timber- 1200 cum Stone- 4.5 cum Mortar (1:8)- 1.5 cum

Tools and Equipments

a) Masonry Hammer b) Stone breaking hammer c) Trowel
d) Masonry Square e) Mason's Level f) Straight Edges
g) Plumb bob h) mortar mixer i) Mason's Line
j) Measuring tape

Salient Features

1. Cost effective technology for the hilly regions where stone is freely available and local timber is cheap.
2. Performed well in the recent earthquakes
3. With restrictions on the use of timber, this system is gradually being overcome by RCC framed construction..
4. Thick walls and air entrapped in the spaces between stones and wood provide thermal insulation.
5. Low maintenance with good seismic performance.

Economic Aspects

1. Economical where timber is available cheap. The timber bands need to be replaced by RCC bands for economy. Generates local employment through stone quarrying and building construction activity.

Sustainability Aspects

1. Low Carbon foot print due to the use of locally available materials.
2. The timber bands may be replaced by RCC bands to conserve timber.

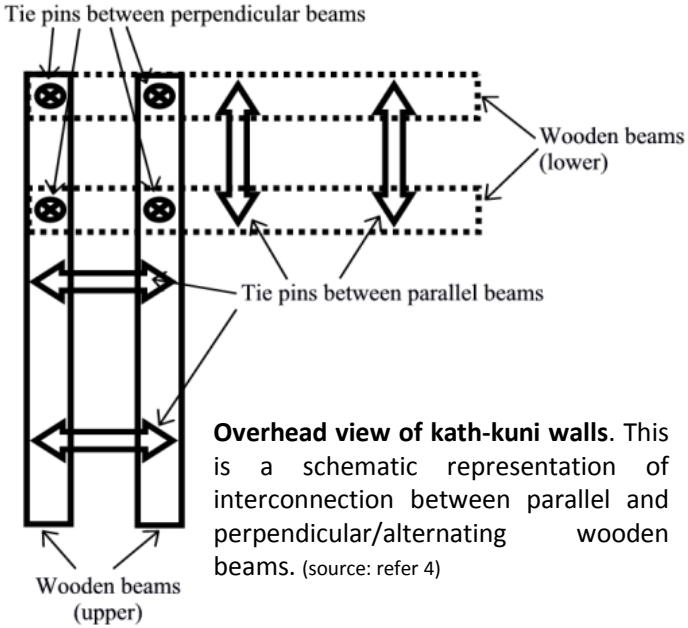
Limitations

1. Deterioration rate is higher. Structural integrity and seismic performance of the structure is not as good as of RCC construction.
2. Laborious, Time consuming and not environment friendly.
3. Absence of adequate design methods.

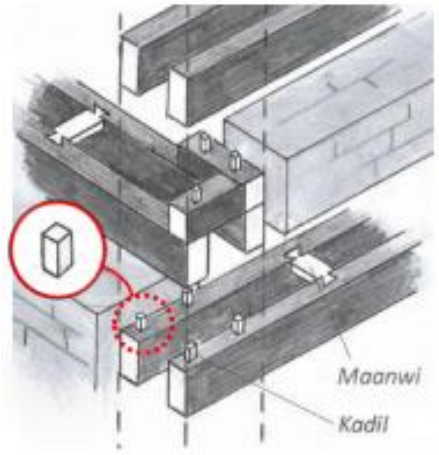
Market Linkages

1. Can be constructed using traditional artisans/ contractors and locally available materials.

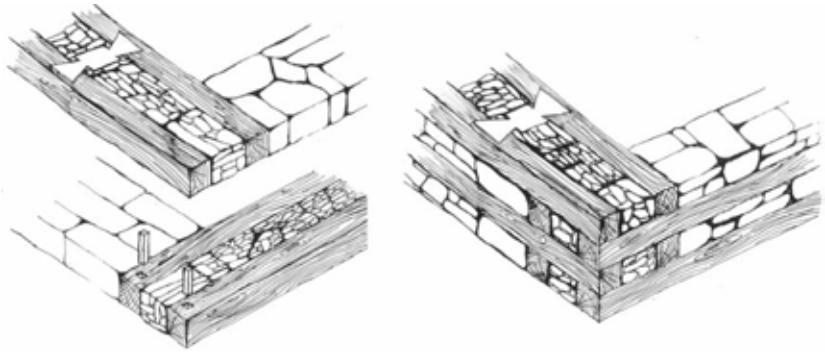
Walling system



Overhead view of kath-kuni walls. This is a schematic representation of interconnection between parallel and perpendicular/alternating wooden beams. (source: refer 4)



Corner connection (source: refer 6)



Kath-kuni wall construction (source: refer 5)

Specifications

Wall Thickness	The thickness of the wall is about 450 to 600 mm.
Materials	Deodar & similar wood (12% moisture) Slate stone (roof) or CGI Sheet roof Natural stone Concrete or cement mortar Cement or Lime plaster – 1730
Foundation	Generally strip foundation in rubble masonry is constructed.
Note: The absence of cementing material in dry masonry makes the structure non-rigid which dissipates stresses developed in the structure during earthquakes thus preventing large-scale destruction and loss of life.	

Relevant Standards and References

1. IS:1597 (1) – 1992, Construction of stone masonry code of practice (part 1) rubble stone masonry, Bureau of Indian Standards, New Delhi
2. IS :1127 - 1970, Recommendations for dimensions and workmanship of natural building stones for masonry work, Bureau of Indian Standards, New Delhi
3. IS :1123 - 1975 Method of identification of natural building stones, Bureau of Indian Standards, New Delhi
4. Traditional A-seismic Architecture of the Western Central Himalayas by Rishiraj Das, https://pdfs.semanticscholar.org/529e/8b66da384adeeb61960c163747f02d95cf17.pdf
5. The Himalayan Vernacular: Kath-Khuni Architecture, https://www.sahapedia.org/the-himalayan-vernacular-kath-khuni-architecture
6. Thesis Report - M.L. van der Zanden, repository.tudelft.nl

Dhajji Diwari
(Scheme for Walls)

Suitable Regions

Majorly in Himachal Pradesh, Uttarakhand, Jammu Kashmir and Ladakh.

About the Technology

The term dhajji dewari is derived from a Persian word meaning "patchwork quilt wall" and is a traditional building type found in the western Himalayas. It can be easily constructed by using local materials; timber and masonry infill. Dhajji dewari consists of an extensively braced timber frame. The relatively small space left between the framing is filled with a wall of stone or brick masonry laid traditionally in mud mortar.

They are typically founded on shallow foundations made from stone masonry. Completed walls are plastered with mud mortar. This form of construction is also referred to in the Indian Standard Codes as brick nogged timber frame construction.

Dhajji buildings are typically 1-4 storey high and the roof may be a flat timber and mud roof, or a pitched roof with timber/metal sheeting. This building system is often used side-by-side or above timber laced masonry bearing-wall construction known as taq, bhater, unreinforced masonry and is also used extensively in combination with timber frame and board/plank construction or load bearing timber board construction.

These structures are environmental friendly and traditionally would not have incorporated any toxic products in their construction, apart from the natural fungal and insect resistant chemicals in the timber itself.

Material Requirements (per cubic meter)

100 mm thick wall	Stone- Timber- Mud Mortar- 0.54 cum Cement- Steel-

Tools and Equipments

a) Carpentry tools b) Stone breaking hammer c) Trowel
d) Masonry Square e) Mason's Level f) Straight Edges
g) Plumb bob h) mortar mixer i) Mason's Line
j) Measuring tape.

Salient Features

1. Cost effective and economical maintenance.
2. Use of locally available materials.

Economic Aspects

1. Cost of construction in hilly region is very less in comparison to other masonry technologies due to the use of locally available material.
2. Generate local employment through stone quarrying and building construction.

Sustainability Aspects

1. Involves excessive use of local timber and stone from forest and quarry which could degrade the environment health.

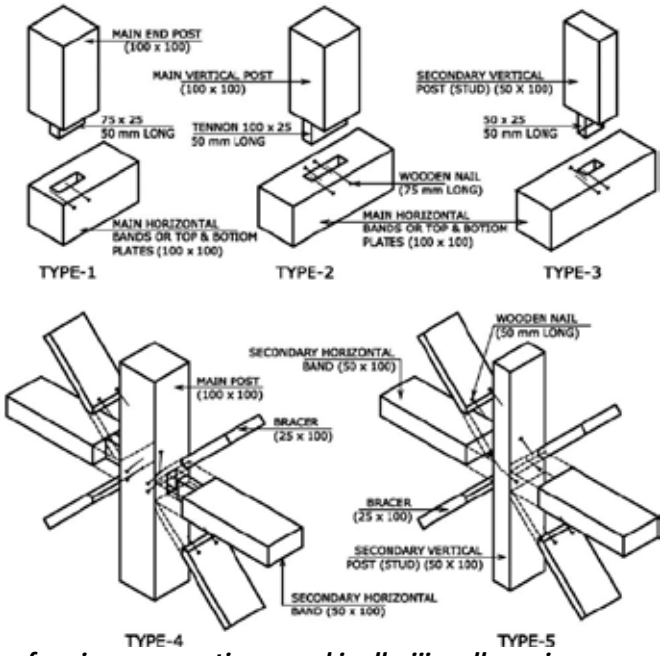
Limitations

1. Structural integrity and seismic performance of the structure is lowered with age due to degradation of wooden planks and mud mortar.
2. Prone to termite attack.
3. Less durable, laborious and time consuming.

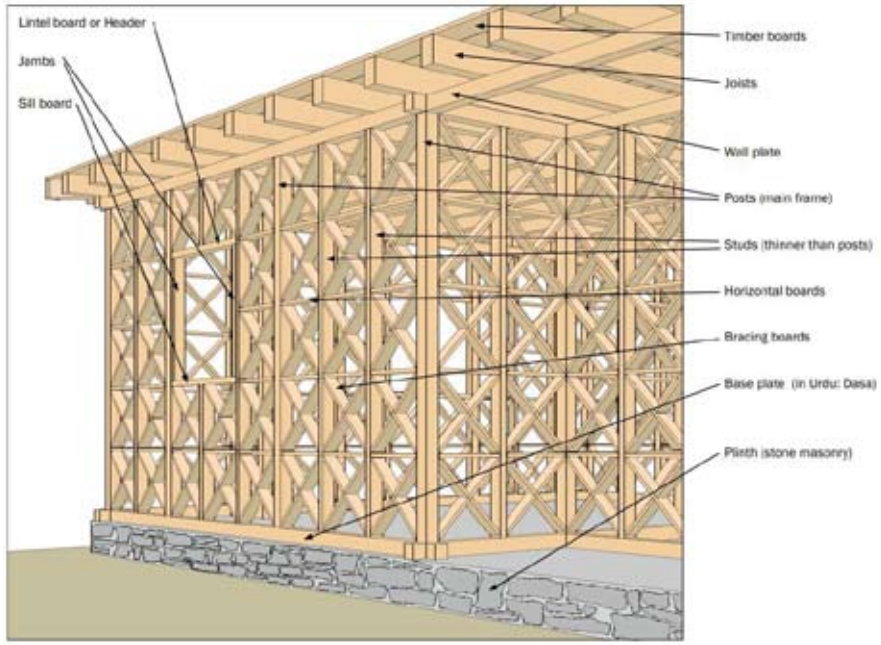
Market Linkages

1. These walls can be constructed by local contractors or masons being their traditional practice.

Walling system



Details of various connections used in dhajji wall specimens (source: refer 7)



Specifications

Exterior Walls	Stone masonry in mud/cement mortar inside the empty spaces of timber frame ,that is heavily braced by timber planks, fixed perpendicular to the face of the wall. A coat of Ferro-cement plaster can be provided for protection against rain and moisture.
Interior Walls	Stone masonry in mud/cement mortar inside the empty spaces of timber frame ,that is heavily braced by timber planks, fixed perpendicular to the face of the wall. A coat of Ferro-cement plaster can be omitted.
Roof	CGI roofing on timber/steel structure with attic floor securely anchored to lintel band.
Gable walls	Should be made of timber planks attached to timber frame.
Floor	IPS/Cement stabilized mud floor in all rooms and cement floor in bathroom.

Relevant Standards and References

1. IS 883: Design of Structural Timber In Building -Code of Practice, Bureau of Indian Standards, New Delhi
2. National Centre for Peoples'-Action in Disaster Preparedness (NCPDP), Ahmadabad, Gujarat, India. Web: www.ncpdpindia.org
3. IS:1597 (1) – 1992, Construction of stone masonry code of practice (part 1) rubble stone masonry, Bureau of Indian Standards, New Delhi
4. IS :1127 - 1970, Recommendations for dimensions and workmanship of natural building stones for masonry work, Bureau of Indian Standards, New Delhi
5. IS :1123 - 1975 Method of identification of natural building stones, Bureau of Indian Standards, New Delhi
6. IS: 13828 – 1993, Indian Standards code of practice for improving earthquake resistance of low strength masonry buildings
7. https://www.researchgate.net/publication/224771434_In-Plane_Behavior_of_the_Dhajji-Dewari_Structural_System_Wooden_Braced_Frame_with_Masonry_Infill

Prefabricated Sandwich Panels

(Alternate Scheme for Walls)

Suitable Regions

About the Technology

The panels are the lightweight EPS concrete sandwich panels, which are used as ready to use wall panels for all types of segments like residential, commercial and Industrial. Panels are made using 5mm thick non asbestos fibre cement boards as facing sheets with cementations core made with expanded polystyrene beads, cement, sand.

Tools and Equipments

a) Drilling Machines b) Board cutting machines
c) Grinding Machine d) Anchoring drilling machine.

Salient Features

1. Eco-friendly solution with ready to use thin panels.
2. Fire, water and termite resistant wall panels.
3. 25% Lighter than Aerated Concrete Panels.
4. 2 hours fire rating for 75mm thick and 1 Hour for 50mm thick panels.
5. Good acoustic properties (35 dB).
6. Low thermal conductivity.
7. Strong walls to withstand all impacts.

Economic Aspects

1. Economical as walling system than conventional walls.
2. Best suitable for internal walls as a semi-permanent wall for economic results.

Sustainability Aspects

1. Manufactured using recyclable materials, available nearest to the site of execution and also it can be re-used number of times makes it a sustainable material.

Limitations

1. Not suggested as external walls above 4 floors, also, not as load bearing walls.

Market Linkages

1. Easily available pan India through our dealers and distributors network.
2. Number of Installers are trained pan India to execute works
3. Manufacturer: Rising Japan Infra Pvt. Ltd., Bhargava Infrastructure, Visaka Industries Ltd., etc.

Cost

1. Approx. 10% costlier than the conventional walls. But, in high rise buildings, hilly areas, in-accessible areas, it is very much economical than other type of walls.

Walling system

V-panel installation

Industrial Building with external walls

Weekend resort

V-panels

Interior walls with Lamination finish

Specifications

Size and thickness	600x2400/2700/3000/3300mm; 50mm, 75mm;
Weight- Kgs	34 Kg/ sq mtr- 50mm
Thermal Resistance	0.30 M2. *K/W- 50mm
Acoustic properties	33dB,50mm : 75 mm
Fire rating	1 Hr for 50mm; 2 Hrs for 75mm
Surface Spread of flame	Class-1
Ignitability	Class-P
Resistance to weather	No effect on panels

Relevant Standards and References

1. IS : 1641 – 1988, Indian Standard, Code of practice for fire safety of building (general): general principles of fire grading and classification, Bureau of Indian Standards, New Delhi.
2. IS: 1642 – 1989, Code of practice for fire safety of buildings (general): Details of construction, Bureau of Indian Standards, New Delhi.
3. IS : 3346 – 1980, Method for the determination of thermal conductivity of thermal insulation materials (two slab, guarded hot-plate method), Bureau of Indian Standards, New Delhi.
4. IS 9489 – 1980, Method Of Test For Thermal Conductivity Of Thermal Insulation Materials By Means Of Heat Flow Meter, Bureau of Indian Standards, New Delhi.
5. IS: 9736 – 1981, Glossary of terms applicable to acoustics in buildings. Bureau of Indian Standards, New Delhi.
6. IS: 2526 – 1963, Code of practice for acoustical design of auditoriums and conference halls. , Bureau of Indian Standards, New Delhi.
7. National Building Code of India 2016 (NBC 2016), , Bureau of Indian Standards, New Delhi.

LGSF with Light Weight EPS Concrete In-Situ Filling between Boards

(alternate of traditional Plastered walls)

Suitable Regions

About the Technology

LGSF (Light Gauge Steel Framing) is a framed structure using high yield strength (550 MPa) roll formed GI sections (89mm to 150mm) for studs and tracks which will take all types of loads including earthquake. The frames are clad with V-next boards and gap between the boards is filled with EPS light weight concrete of 700 Kg/m3 density to make solid wall and to avoid the hollow sound when tapped.

Tools and Equipments

a) Screw Driving Machines b) Board cutting machines
c) Grinding Machine d) Anchoring drilling machine.

Salient Features

1. Aesthetic design, wide range of choice and flexibility.
2. Exceptionally durable due to high GSM coating.
3. Lightweight and very good strength to weight ratio.
4. Earthquake resistance due to framed construction.
5. Rapid, economical, and error free production.
6. Design flexibility for complex buildings.
7. High level of water, heat, acoustic, corrosion resistance and Non-combustible.
8. Environmentally friendly with due to recyclable materials used in construction.

Economic Aspects

1. Being a pre-engineered construction, material wastages are minimised and the construction is very fast which makes this economical than conventional cost.

Sustainability Aspects

1. G.I. framed structure and other recycled materials are used for walls, the sustainability factor is met.

Limitations

1. External walls above 5 floors to be checked for structural stability. Accordingly, the studs and the frame is to be designed.

Market Linkages

1. Local can be trained in LGSF framing assembly and installation procedures.
2. Manufacturer: Visaka Industries Ltd.

Cost

1. Approx. 10% costlier than the conventional walls. But, in high rise buildings, lightweight LGSF with EPS concrete infill will be economical due to easier transport and lifting. Can be cast at construction site.

Walling system

LGS Framing in progress

LGS Frames cladding with FCB-V-next

LGS Frames cladding with FCB-V-next and Planks

Specifications

Wall Framing	LGSF-0.75mm thick
Cladding Materials	V-next Fibre Cement Boards
Infill Material	600-700 Kg/cum density EPS Concrete
Wall thickness	109mm – 175mm
Weight of the wall- per sq.m	93 kg- 120 Kg
Fire rating	Min. 2 Hrs
Acoustic properties	Min. 45 dB
Termite	100% termite Proof

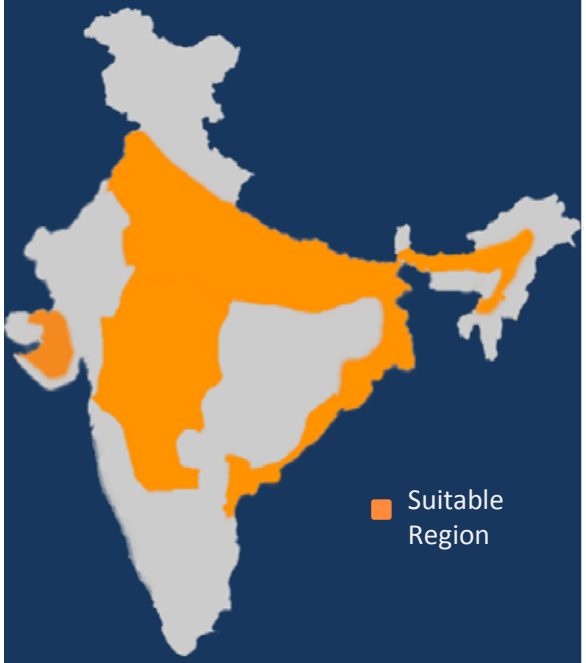
Relevant Standards and References

1. IS: 875-1987 Code of Practice for Design Loads, Bureau of Indian Standards, New Delhi.
2. IS: 800-1984 Code Of Practice For General Construction In Steel, Bureau of Indian Standards, New Delhi.
3. IS: 801-1975 Code of Practice for Use of Cold Formed Light Gauge Steel Structural Members In General Building Construction, Bureau of Indian Standards, New Delhi.

Foundation Construction Technologies

Brick/Block Masonry Strip Foundation

Suitable Regions



Predominantly in Black cotton soil and Flood prone areas with caution.

About the Technology

Strip Foundations consist of a continuous strip, made up of brick/block under load bearing walls. The continuous strip serves as a level base on which the wall is built and is of such a width as is necessary to spread the load on the foundations to an area of subsoil capable of supporting the load without undue settlement. Such type of foundation provides continuous and longitudinal bearing for loads carried by vertical elements, such as continuous wall foundation pillars and so.

Strip foundations (or strip footings) are a type of shallow foundation that are used to provide a continuous, level (or sometimes stepped) strip of support to a linear structure such as a wall or closely-spaced rows of columns built centrally above them. Strip foundations can be used for most subsoil's, but are most suitable for soil which is of relatively good soil bearing capacity (minimum 15 tons/sq.m). They are particularly suited to light structural loadings such as those found in many low-to-medium rise (up to 3-4 storey) domestic buildings.

Very broadly, the size and position of strip foundations is typically related to the wall's overall width.

The width and depth of the strip foundation should be properly designed according to the super-imposed load and bearing capacity of the soil. As a thumb rule the minimum width of the foundation must not be less than equal to two times width of wall + 300 mm.

Material Requirements

Size as per design	Concrete Waterproofing agent Bricks/blocks Brick/stone ash

Tools and Equipments

a) General masons b) Masonry tools

Salient Features

1. Ability to distribute loads over a safe area.
2. Easy to build, no special training requirements for personnel.
3. Very long service life.
4. The price is much lower than RCC foundation.

Economic Aspects

1. This type of foundation can be used all over India where stable soil is available for low to medium rise domestic building , hence it is most popular and common type of foundation.
2. Use of local material makes it economical than RCC
3. Local masons can easily construct it.

Sustainability Aspects

1. Does not cause any appreciable damage to environment.

Limitations

1. Not suitable for expansive filled up and low bearing capacity soils.
2. There are chances of moisture movement through the masonry from the ground to the superstructure, therefore a good Dam-proof course or RCC plinth band must be provided.

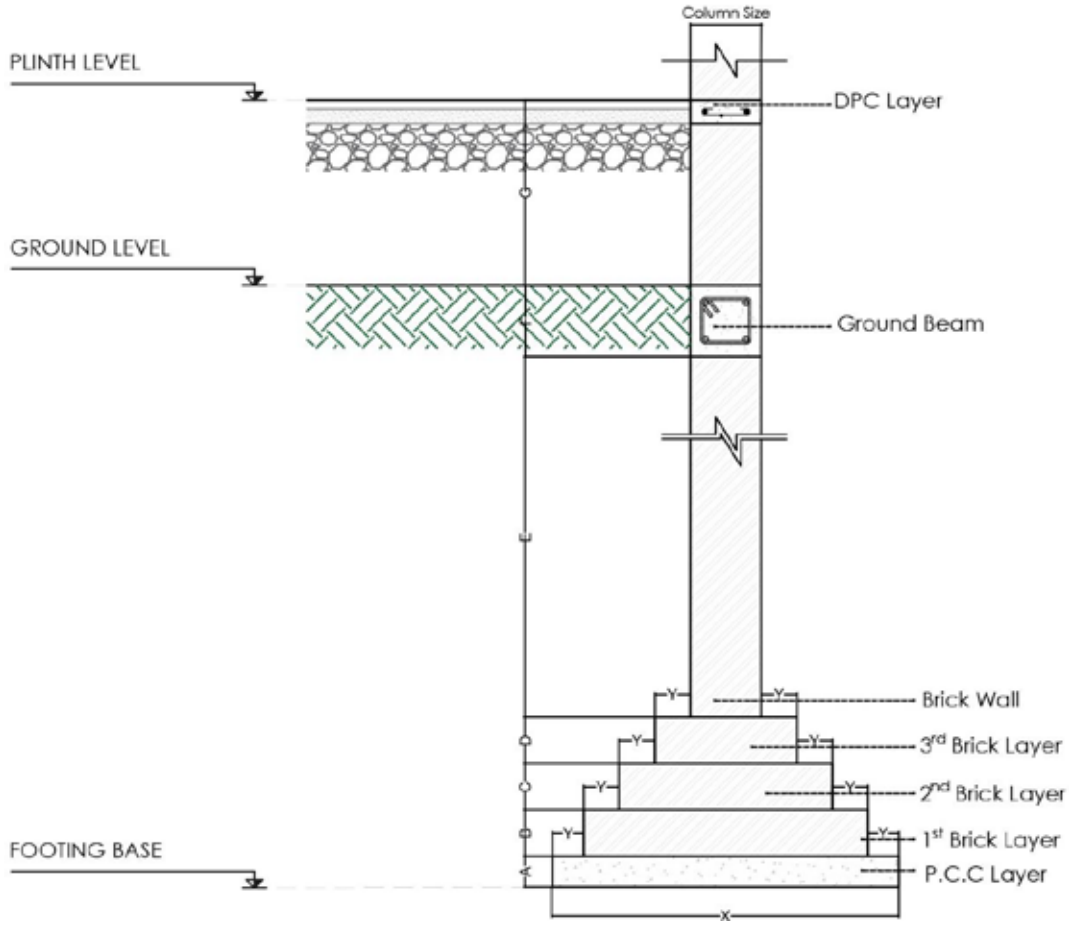
Market Linkages

1. Can be constructed at site using local masons and labor as per design.

Cost

1. Cost of the foundation depends totally on the type of soil and expected load.

Foundation



Brick masonry Strip foundation

Specifications

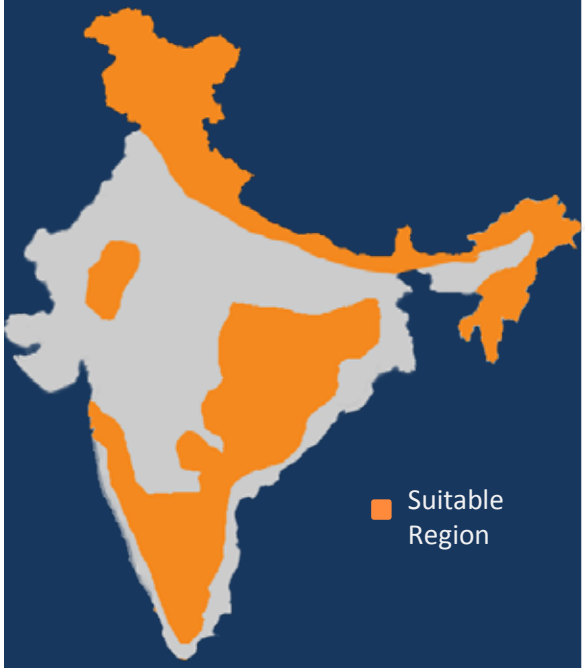
Excavation *(Refer IS 3764:1966)*	The plan dimensions of excavation for foundations should be wide enough to ensure safe and efficient working.
Design *(Refer IS 456:1987 and IS 1905:1987)*	The cement concrete foundation (plain or reinforced) should be designed in accordance with IS : 456-1978 and masonry foundation in accordance with IS : 1905-1987.
Size *(Refer IS 2212:1962)*	The width of the footings shall be such that maximum stress in the concrete or masonry remains within the permissible limits. The width of wall foundation shall not be less than that Given by: B = W + 300 mm, where B = width at base in cm & W = width of supported wall in cm.
Construction *(Refer IS 1080:1985)*	Brick masonry construction should conform to IS : 2212-1962. Masonry should be constructed over the base concrete After curing the base of concrete for at least 3 days. Before laying concrete, the bed of the foundation pit/trench should be thoroughly compacted by manual ramming.

Relevant Standards and References

1. IS 1080-1985: Code of practice for design and construction of Shallow foundations in soils, Bureau of Indian Standards, New Delhi.
2. IS 2212-1962: Brick Works-Code Of Practice, Bureau of Indian Standards, New Delhi.
3. IS 3764-1966 : Code of safety for excavation work, Bureau of Indian Standards, New Delhi.
4. IS 1905-1987: Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi.
5. IS 456:2000, Code of practice for plain and reinforced cement concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Stone Masonry Foundation

Suitable Regions



Hilly areas, Deccan plateau region and places where stone is locally available.

About the Technology

A foundation is a structure that creates a strong, level base on which to build. It's critically important that the foundation is properly built and leveled or there will be serious problems in the house later. Improperly done foundations cause settlement issues, wall cracking, bowing, water penetration and a host of other issues.

Natural stone has been used for thousands of years in making foundations. Its main attributes are high compressive strength, incredible durability and local availability.

Prior to the construction of stone masonry footing, a trench with suitable depth and width should be excavated. The width of footing is specified based on the imposed loads and properties of soil on which the footing is constructed. The soil at the bottom of the trench needs to be compacted properly. Now, the excavation is ready for the construction of stone masonry footing. Stones need to be cleaned and adequately wetted before they are laid in the foundation. This is necessary to prevent water absorption which detrimentally affect the mortar.

This technology is very common in areas where stones are locally available, which also makes this technology economical.

Material Requirements

Size as per design	Cement Fine Sand Stone Waterproofing agent

Tools and Equipments

a) Trowels b) Shovel c) Plumb bob d) Pick axes
e) Thread f) Baskets g) Pans h) Hammer (Big & small)

Salient Features

1. To provide a level surface for construction of the superstructure.
2. To provide safe transfer and distribution of building loads to the underlying soil.
3. It is the most widely used and economical foundation type.

Economic Aspects

1. Can be very economical in region where stone is locally available.

Sustainability Aspects

1. It adds to sustainability aspect as it utilizes local stones and generates local level employment. Also, it is economical and easy to construct.

Limitations

1. May not be suitable for Large building.
2. Can be best suited for places where stone is s locally available material.
3. Generally used for constructions up to plinth level only.

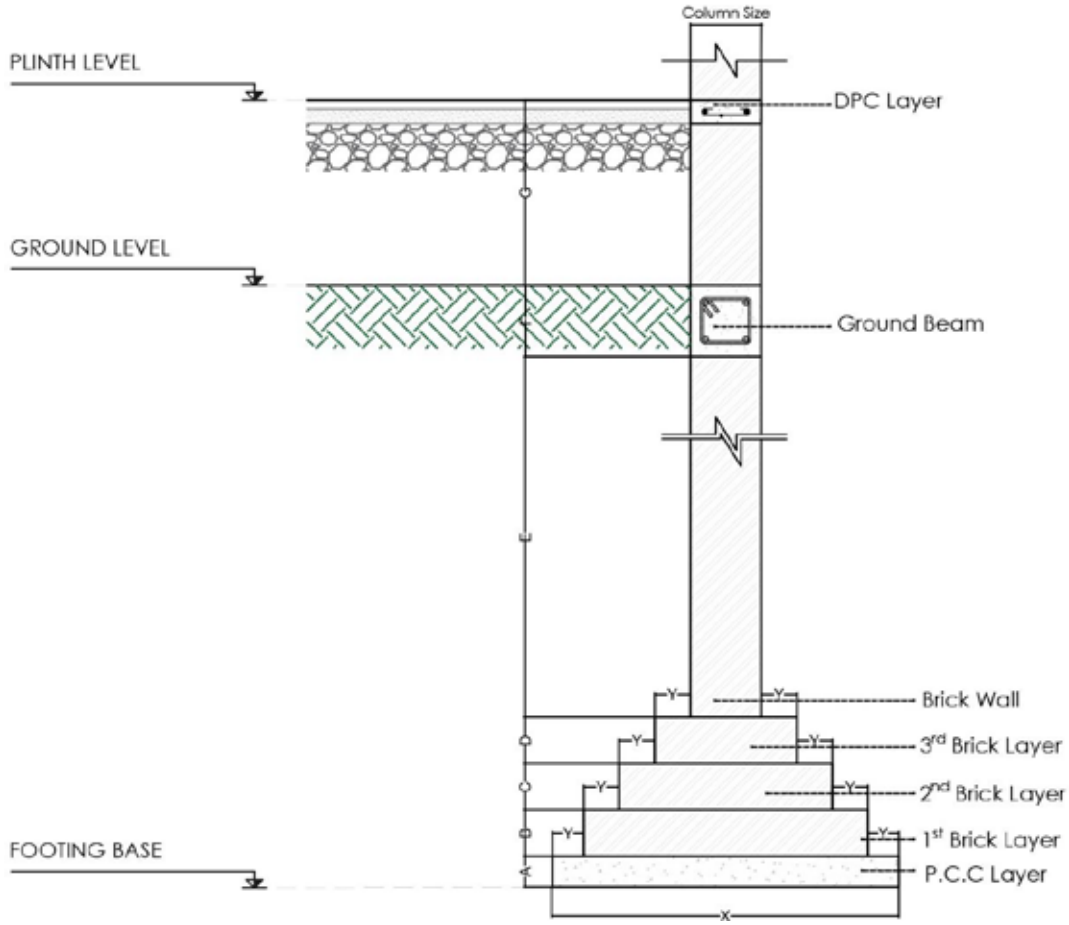
Market Linkages

1. Can be constructed at site using local masons and labors as per design.

Cost

1. In location where Stone is a local material the cost of Stone masonry foundation is very less compared to RCC, brick/block masonry used for foundation .

Foundation



Brick masonry Strip foundation

Specifications

Excavation *(Refer IS 3764:1966)*	The plan dimensions of excavation for foundations should be wide enough to ensure safe and efficient working.
Design *(Refer IS 456:1987 and IS 1905:1987)*	The cement concrete foundation (plain or reinforced) should be designed in accordance with IS : 456-1978 and masonry foundation in accordance with IS : 1905-1987.
Size *(Refer IS 2212:1962)*	The width of the footings shall be such that maximum stress in the concrete or masonry remains within the permissible limits. The width of wall foundation shall not be less than that Given by: B = W + 300 mm, where B = width at base in cm & W = width of supported wall in cm.
Construction *(Refer IS 1080:1985)*	Brick masonry construction should conform to IS : 2212-1962. Masonry should be constructed over the base concrete After curing the base of concrete for at least 3 days. Before laying concrete, the bed of the foundation pit/trench should be thoroughly compacted by manual ramming.

Relevant Standards and References

1. IS 1080-1985: Code of practice for design and construction of Shallow foundations in soils, Bureau of Indian Standards, New Delhi.
2. IS 2212-1962: Brick Works-Code Of Practice, Bureau of Indian Standards, New Delhi.
3. IS 3764-1966 : Code of safety for excavation work, Bureau of Indian Standards, New Delhi.
4. IS 1905-1987: Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi.
5. IS 456:2000, Code of practice for plain and reinforced cement concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

R.C. Column Foundation

Suitable Regions

All parts of India

About the Technology

Foundation is the part of structure below plinth level up to the soil. It is in direct contact of soil and transmits load of super structure to soil. Generally it is below the ground level. If some part of foundation is above ground level, it is also covered with earth filling. This portion of structure is not in contact of air, light etc., or to say that it is the hidden part of the structure.

Material Requirements

Size as per design	Cement Sand Aggregate Water Steel reinforcement

Tools and Equipments

a) Screeds b) Portable Mixer c) Shovels
d) Needle vibrator e) Shuttering & shoring

Salient Features

1. Distribute the weight of the structure over a large area of soil.
2. Prevent the lateral movement of the structure.
3. Increase structural stability.
4. Stability against sliding & overturning.
5. Provide level surface.
6. Very good resistance to insects.

Economic Aspects

1. RC Foundation is a very economic option for the places where heavy concentrated loads are to be distributed over a deep strata.

Sustainability Aspects

1. Lesser carbon footprint.

Limitations

1. Cost of installation is higher than normal brick masonry foundation.
2. Proper design and thorough geotechnical investigation is required which can increase the cost of construction.

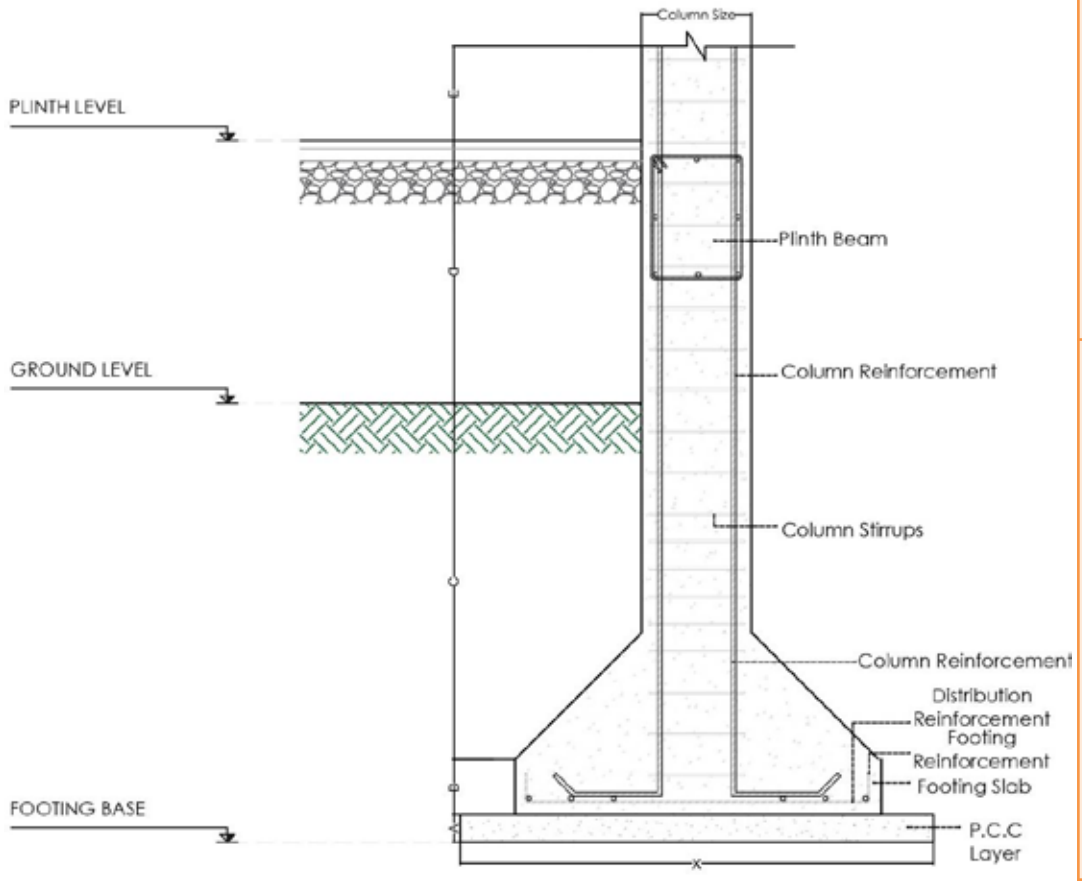
Market Linkages

1. Should be constructed at site using local labor/contractors as per design.

Cost

1. Cost of the Foundation depends totally on the type of soil and load design.

Foundation



RC column foundation

Specifications

Excavation *(Refer IS 456:2000)*	1. Precautions during Excavation of Foundation Work The depth of the foundation should not be less than 1000 mm in case the design is not available. 2. The excavated material/ earth should be dumped at a distance of 1000 mm from the edges. 3. Practical minimum depth of foundation should not be less than 500 mm. to allow removal of top soil and variations in ground level.
Construction *(Refer IS 456:2000)*	1. All reinforced concrete in the works shall be "Design Mix Concrete" as defined in I.S. 456-2000. Mix Design. 2. The proportions of the mix shall be determined by weight. 3. Adjustment of aggregate proportions due to moisture present in the aggregate shall be made. 4. Aggregates having a specific gravity below 2.6 (saturated surface dry basis) shall not be used without special permission of the Engineer-in-Charge.

Relevant Standards and References

1. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
2. IS 6403: 1981, Indian standard code of practice for determination of bearing capacity of shallow foundations, Bureau of Indian Standards, New Delhi.

Raft Foundation

Suitable Regions

All over the country particularly in high water table areas soft soils and where heavy loads are coming on the foundation.

About the Technology

Raft Foundation consists of a reinforced concrete slab or T-beam slab placed over the entire area of the structure. In this type of foundation, the entire basement floor slab acts as the foundation. The total load of the structure is spread evenly over the entire area of the structure. This is called Raft because in this case, the building seems like a vessel which floats on a sea of soil. Sometimes referred to as raft footings or mat foundations, are formed by reinforced concrete slabs of uniform thickness (typically 150 mm to 300 mm) that cover a wide area, often the entire footprint of a building. They spread the load imposed by a number of columns or walls over the area of foundation, and can be considered to 'float' on the ground as a raft floats on water.

Raft foundation transmits the total load from the building to the entire ground floor area. Stress distribution mechanism of raft foundation is very simple. Total weight of the structure and self-weight of the mat is calculated and is divided by the total area of the foundation it is covering to calculate the stress on the soil.

They can be fast and inexpensive to construct, as they tend not to require deep excavations compared to strip or pad foundations and they may use less material as they combine the foundation with the ground slab. However, they tend to be less effective where structural loads are focussed on in a few concentrated areas, and they can be prone to erosion at their edges.

Raft foundation is used where other shallow foundation or pile foundation is not suitable. It is also recommended in situation where the bearing capacity of the soil is poor, the load of the structure is to be distributed over a large area or structure is constantly subjected to shocks or jerks.

Material Requirements

Size as per design	Cement + Sand + Aggregate Water Steel reinforcement

Tools and Equipments

a) Shuttering & shoring b) Plate vibrator c) Light hoisting equipment d) needle vibrator e) miner

Salient Features

1. It may be able to overcome differential settlement problems for the raft acts as a unit.
2. Load incurred by raft foundation will be transferred to the underlying soil by reinforced concrete continuous slab by covering the entire site structure.
3. Reduce differential settlements as the concrete slab resists differential movements between the loading positions.
4. To withstand uplift forces in foundations as in expensive soils and floating foundations.
5. Applicable for watertight construction under basements below groundwater table
6. Used for highly compressible soil and extends to a great depth.

Economic Aspects

1. Very useful as it can transfer heavy load of the superstructure to the ground.

Sustainability Aspects

1. Reduce up to 80% of green house gases emission against clay brick masonry foundations.

Limitations

1. Large amount of reinforcement is required for raft foundation which increases the cost of project.

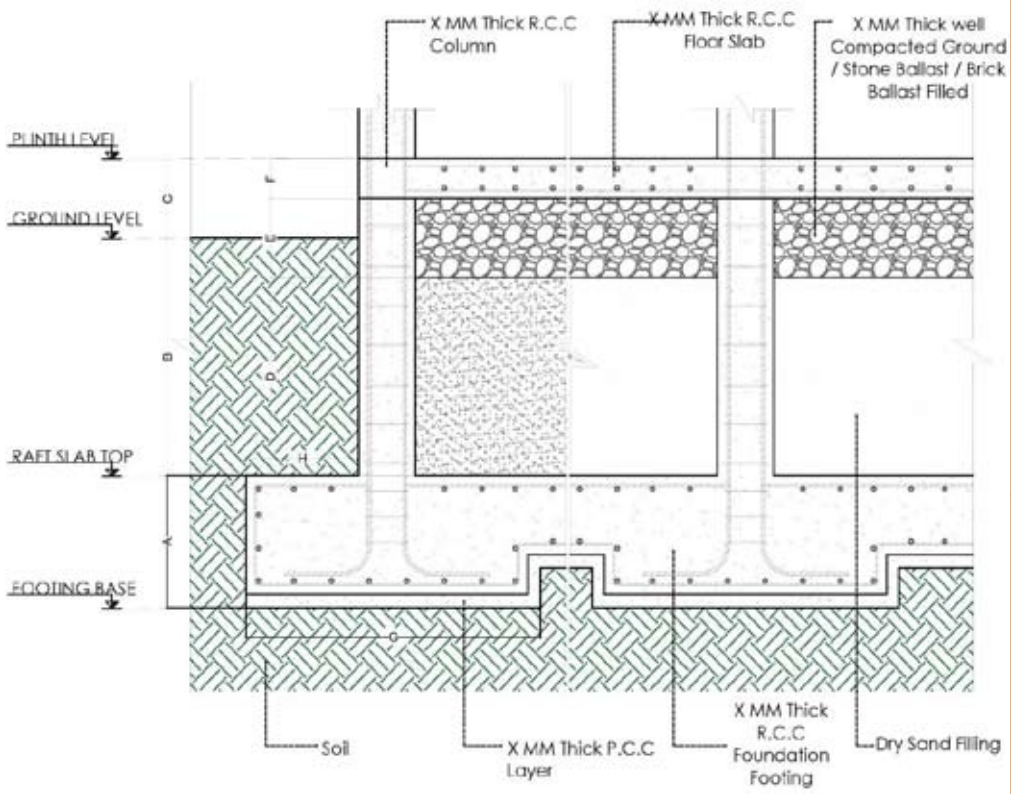
Market Linkages

1. Should be constructed at site using local labour as per design.

Cost

1. Cost of the Foundation depends totally on the type and load design.

Foundation



Raft foundation

Specifications

Dimensions *(Refer IS 1080:1985 and IS 456:2000)*	1. As per IS 1080-1985, a minimum depth of 500 mm shall be used for Raft foundation. This is required to ensure that the soil has a safe bearing capacity which is assumed in the design. 2. A uniform thickness can be used for raft foundation if columns are equally spaced and the loads are not very heavy. 3. According to IS 456-2000; a minimum cover of 50 mm is required for RC raft foundation. 4. When mat foundation is constructed on sand, the minimum depth of foundation is around 2500 mm below the surrounding ground surface. if a smaller depth is considered, the edges of the raft settle appreciably more than the interior due to lack of confinement of the sand. 5. Indian standards specify a minimum depth of 600 mm below the surrounding ground surface.
Column spacing and load (Refer IS 2950:1981)	1. The column spacing is less than 1.75/λ. (is code IS-2950 part 1 1981.) 2. Variation in adjacent column load does not exceed 20% of the higher value (IS-2950 part 1 1981.) 3. The continuing cell pressure may be so selected as to be representative of the depth of average stress influence zone (about 0.5 B to B). (IS: 2720 (Part XII)-1981.) 4. The maximum differential settlement in foundation on clayey soils and sandy soils should not exceed 40mm and 25mm respectively, as per is 2950:1965. 5. The structure behaves as rigid (due to the combined action of the superstructure and the foundation) with a relative stiffness factor K > 0.5 as per is code IS-2950 part 1 1981.

Relevant Standards and References

1. IS 1080-1985: Code of practice for design and construction of Shallow foundations in soils, Bureau of Indian Standards, New Delhi.
2. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
3. IS 2720 (PART 12)-1981 Indian standard methods of test for soils determination of shear strength parameters of soil, Bureau of Indian Standards, New Delhi.
4. IS 6403: 1981, Indian standard code of practice for determination of bearing capacity of shallow foundations, Bureau of Indian Standards, New Delhi.
5. IS:2950(Part I)-1981 Indian Standard code of practice for design and construction of Raft foundations, Bureau of Indian Standards, New Delhi.

R.C. Pile Foundation

Suitable Regions

All parts of India. Only caution that needs to be taken for coastal region is that the clear cover is more.

About the Technology

RC Pile foundations are formed by long, slender, columnar elements typically made from reinforced concrete. A foundation is described as 'piled' when its depth is more than three times its breadth. RC Pile foundations are principally used to transfer the loads from superstructures, through weak, compressible strata or water onto stronger, more compact, less compressible and stiffer soil or rock at depth, increasing the effective size of a foundation and resisting horizontal loads.

Pile foundations shall be designed in such a way that the load from the structure can be transmitted to the sub-surface with adequate factor of safety against shear failure of sub-surface and without causing such settlement (differential or total), which may result in structural damage and/or functional distress under permanent/transient loading. The pile shaft should have adequate structural capacity to withstand all loads (vertical, axial or otherwise) and moments which are to be transmitted to the subsoil and shall be designed according to IS 456-2000 & IS- 2911-1979.

Material Requirements

Size as per design	Cement + Sand + Aggregate Water Steel reinforcement

Tools and Equipments

a) Crane b) Concrete mixer c) Pile Rig
d) Hydraulic Hammer e) Pile-Driving Equipment

Salient Features

1. Transfer load to stratum of adequate capacity.
2. Resists lateral loads.
3. Transfer loads through a scour zone to bearing stratum.
4. Anchor structures subjected to hydrostatic uplift or overturning.
5. Used when mat footing cannot be used due to low bearing capacity of soil.
6. Pile foundation have high load capacities (300kN-3000kN).
7. Corrosion resistance.
8. Can be easily combined with concrete super structure.

Economic Aspects

1. It is economical for high load bearing buildings where shallow foundation is not possible.

Sustainability Aspects

1. Lesser carbon emission as compared to RC column foundation.

Limitations

1. Difficult to achieve proper cutoff.
2. Difficult to transport.
3. Vertical drilling breakage due to hammering

Market Linkages

1. Should be constructed at site using local labour as per design.

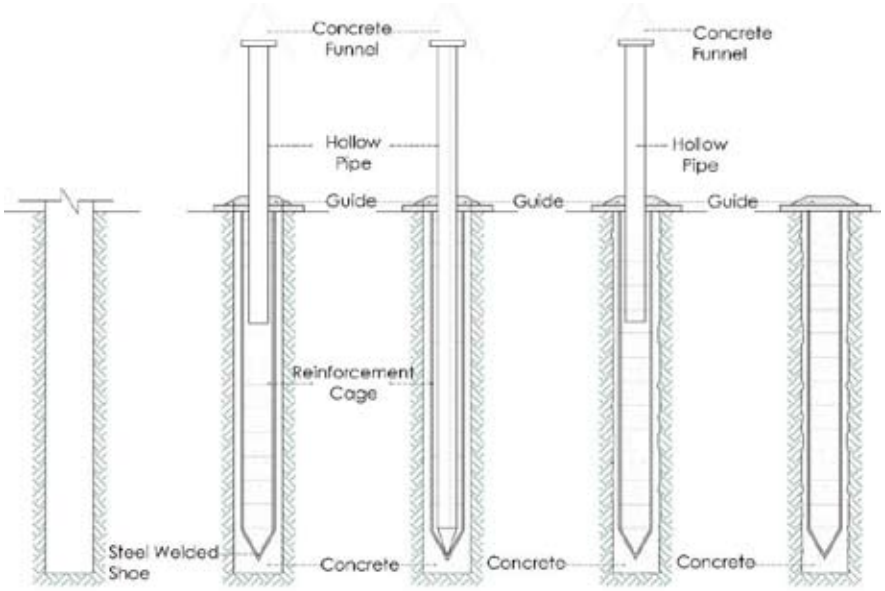
Cost

1. Cost of the Foundation depends totally on the type and design load.

Foundation

Specifications

Construction *(Refer IS 2911:1980 and IS 2911:1979 PART 1)*	1. The minimum area of longitudinal reinforcement of any type or grade within the pile shaft shall be 0.4% of the cross-sectional area of the pile shaft. 2. Clear cover to all main reinforcement in pile shaft shall be not less than 50 mm. 3. The minimum diameter of the links or spirals shall be 8 mm and the spacing of the links or spirals shall be not less than 150 mm. Stiffener rings preferably of 16 mm diameter at every 1500 mm centre-to-centre should be provided along the length of the cage for providing rigidity to reinforcement cage. 4. Minimum 6 numbers of vertical bars shall be used for a circular pile and minimum diameter of vertical bar shall be 12 mm. The clear horizontal spacing between the adjacent vertical bars shall be four times the maximum aggregate size in concrete. 5. The minimum factor of safety on static formula shall be 2.5. The final selection of a factor of safety shall take into consideration the load settlement characteristics of the structure as a whole at a given site. 6. Provide leads that are parallel and not bent beyond a 15mm deviation from the straight line over any 5000 mm length (0.3%). 7. Do not drive piles within a radius of 8000 mm of concrete which has been in place for a time shorter than 3 days unless authorized by engineer. 8. Stop jetting at a minimum of 1000 mm above expected final toe elevation and at a minimum of 1m above the toe elevation of piles previously driven within 2000 mm of jetted pile, expect where piles are carried to bedrock. 9. Drive each Pile to a final penetration resistance during initial driving of at least 120 blows for 3 consecutive penetration of 300mm, or to a penetration resistance of at least 200 blows for a penetration smaller than 300mm, or to a penetration smaller than 25mm for 2 consecutive series of 50 blows, whichever occurs first.



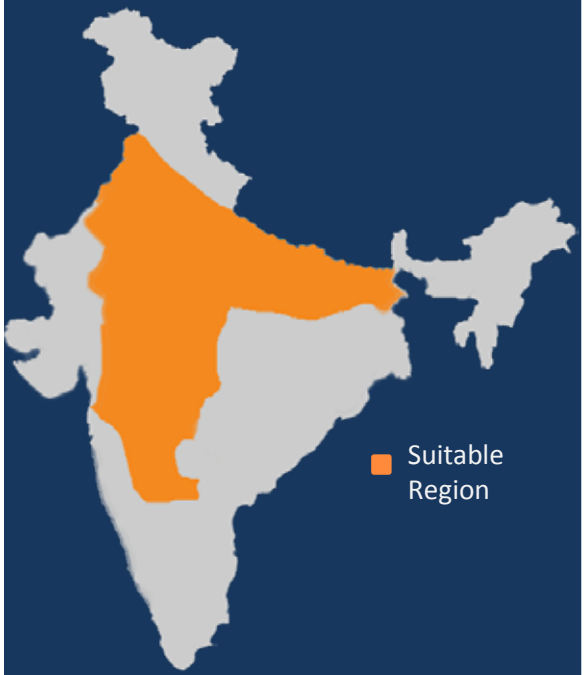
RC pile foundation

Relevant Standards and References

1. IS 2911 : Part 1 : Sec 1 : 1979, RC Pile, Bureau of Indian Standards, New Delhi.
2. IS 456-2000, Code of practice for plain and reinforced concrete, Bureau of Indian Standards, New Delhi.
3. IS 2911 :1980, Code Of Practice For Design And Construction Of Pile Foundations, Bureau of Indian Standards, New Delhi.

Precast RC driven Pile Foundation

Suitable Regions



Predominantly along Alluvial soil region and Black cotton soil.

About the Technology

Driven precast concrete piles are constructed by hammering the piles into the soil to a depth greater than 40 meter by an adjustable hydraulic or diesel hammer. Driven precast concrete piles are widely used because of their versatility and suitability for most ground conditions. They are particularly suited where the founding stratum is overlain by soft deposits and aggressive or contaminated soils. Piles are manufactured in factories under high-quality control, and consist of segmental lengths of reinforced concrete sections of lengths between 3000mm and 1500 mm with required or standard cross-section.

These piles generate no spoil or raising's from the installation and removes the need for additional traffic movements in and out of the site. Piles can be provided in various sizes, formed in high strength concrete, with varying reinforcement.

It can be used in almost all types of construction, especially in aggressive soil condition. In case of deep excavations adjacent to piles, proper shoring or other suitable arrangement shall be done to guard against the lateral movement of soil stratum or releasing the confining soil stress.

Material Requirements

Size as per design	Concrete Pre-stressing Steel reinforcement

Tools and Equipments

a) Pile-Driving Equipment: The equipment and accessories will have to be selected depending upon the hardness of driving, the capacity suitable for the size and weight of the pile to be handled and the location of work.
b) Hammer
c) Driving Cap
d) Formwork

Salient Features

1. Suitable for construction sites where thick soft soil and / or high water table are present and create problems for conventional pile construction.
2. Capable of accommodating simple compressive loads or complex combined loadings.
3. Piling is unaffected by groundwater table.
4. It is a cost-effective form of deep foundation.
5. Suitable for small to large complex projects.

Economic Aspects

1. It is upto 50% cheaper as compared to column foundation in soft/loose deep layer of soil.

Sustainability Aspects

1. Generates no spoil or raising's from the installation and removes the need for additional traffic movements in and out of the site.

Limitations

1. Damage may occur in the pile at a position not visible from the surface during the driving process.
2. Pile may get laterally displaced if it encounters any obstructions like rocks in the ground.
3. The length of the pile is estimated before driving commences, but the accuracy of this assumption is only known on site, where short piles can be difficult to extend and long piles may prove to be expensive and wasteful.

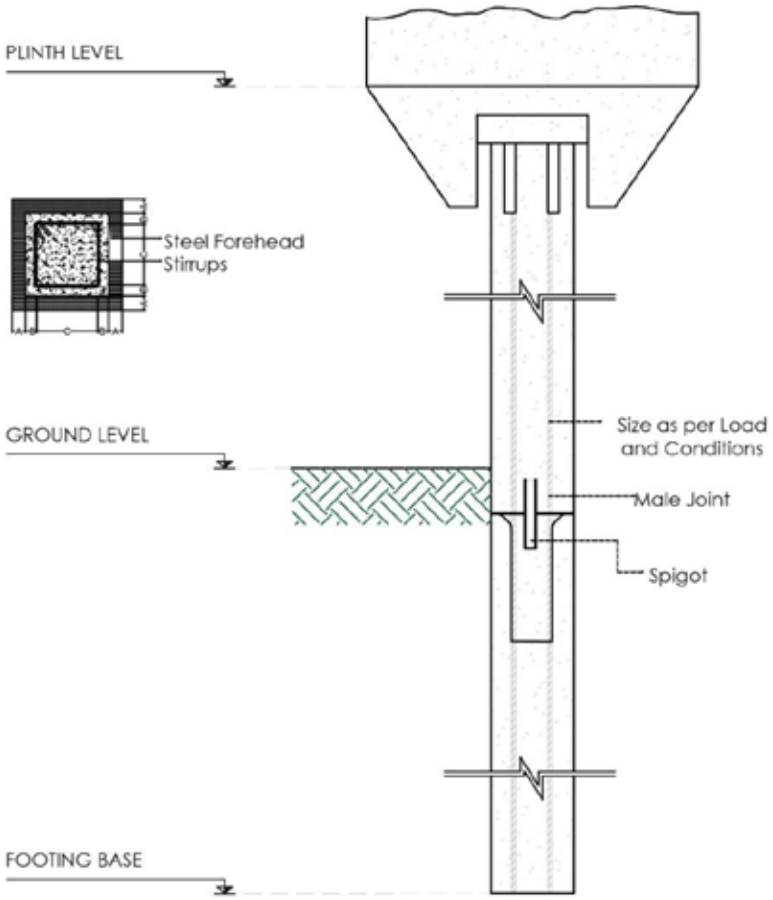
Market Linkages

1. The piles are produced by reputed manufacturer and are driven by equipment on the site.

Cost

1. Cost of the Foundation depends totally on the type and load design.

Specifications



Precast RC driven pile foundation

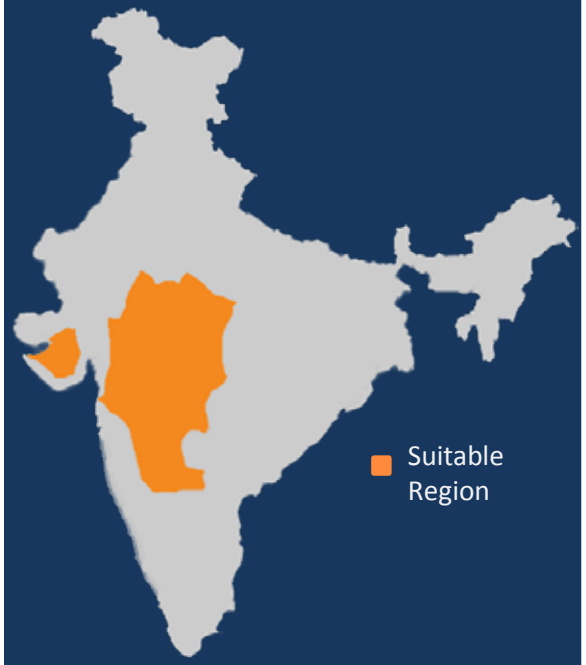
Construction *(Refer IS 2911:2010 PART 1)*	1. Piles shall not be driven until the concrete has achieved the specified 28 day strength. 2. When gravity hammers are used for driving concrete piles, the drop of the hammer shall not exceed 1000 mm and the hammer shall have a weight of not less than 80% of the weight of the pile and the driving head. 3. The fall shall be regulated so as to prevent injury to the pile. 4. The final set of each pile shall be recorded either as the penetration in millimetres per 10 blows or as the number of blows required to produce a penetration of 250 mm. 5. Piles shall be driven in an approved sequence to minimise the detrimental effects of heave and lateral displacement of the ground. 6. Pre-stressed concrete piles shall be cut off at such elevation that they shall extend into the cap or footing as indicated on the Drawing. 7. The maximum permitted deviation of the finished pile from the vertical shall be 1 in 50. 8. The piling rig shall be set and maintained to attain the required rake. The maximum permitted deviation of the finished pile from the specified rake shall be 1 in 25. 9. Spacing of Piles - The centre to centre spacing of pile is considered from two aspects, namely: • practical aspects of installing the piles; and • the nature of the load transfer to the soil and possible reduction in the bearing capacity of a group of piles thereby. The choice of the spacing is normally made on semi-empirical approach.

Relevant Standards and References

1. IS 2911 : Part 1 : Sec 3 : 2010 Driven precast concrete piles, Bureau of Indian Standards, New Delhi.
2. IS 6427 : 1972 Glossary of Terms Relating to Pile Driving Equipment, Bureau of Indian Standards, New Delhi.
3. IS 9716 : 1981 Guide for lateral dynamic load test on piles, Bureau of Indian Standards, New Delhi.
4. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Under Reamed Pile Foundation

Suitable Regions



Predominantly in Black cotton soil area.

About the Technology

Under reamed piles are bored cast-in-situ concrete piles having one or more number of bulbs formed by enlarging the pile stem. These piles are best suited in soils where considerable ground movements occur due to seasonal variations, filled up grounds or in soft soil strata. Provision of under reamed bulbs has the advantage of increasing the bearing and uplift capacities. It also provides better anchorage at greater depths. These piles are efficiently used in machine foundations, over bridges, electrical transmission tower foundation and water tanks. Indian Standard IS 2911 (Part III) -1980 covers the design and construction of under reamed piles having one or more bulbs. According to the code the diameter of under reamed bulbs may vary from 2 to 3 times the stem diameter depending upon the feasibility of construction and design requirements. The code suggests a spacing of 1.25 to 1.5 times the bulb diameter for the bulbs. An angle of 45^0 with horizontal is recommended for all under reamed bulbs. This code also gives Mathematical expressions for calculating the bearing and uplift capacities.
Under-Reamed Piles have been studied and experimented upon by Central Building Research Institute (CBRI), Roorkee, for use in black cotton soils and appears to provide an excellent solution to foundation problems in expansive soils.

Material Requirements

Size as per design	Concrete Steel reinforcement

Tools and Equipments required

a) An auger b) An under-reamer c) A boring guide
d) Accessories like spare extensions, cutting tool, concreting funnel, etc.
The selection of equipment and accessories will depend upon the type of under-reamed piles, site conditions and nature of strata.

Salient Features

1. By providing under reamed bulbs the ultimate load capacities of piles increases significantly.
2. Used in black cotton soils and appears to provide an excellent solution to foundation problems in expansive soils to avoid the undesirable effect of seasonal moisture changes in expansive soils such as black cotton soils.
3. To reach deep hard strata.
4. To obtain adequate capacity for downward, upward, lateral loads and moments.
5. To take the foundations below the scour level.
6. They have also been found useful for factory buildings and machine foundations.
7. Under-Reamed Piles are also used under situations, where the vibration and noise caused during construction of piles, are to be avoided.
8. The load carrying capacity of Under-Reamed Piles can be increased by making more bulbs at base.

Economic Aspects

1. It is 20-50% economical over RC column foundation

Sustainability Aspects

1. It saves cement, steel, and construction time.

Limitations

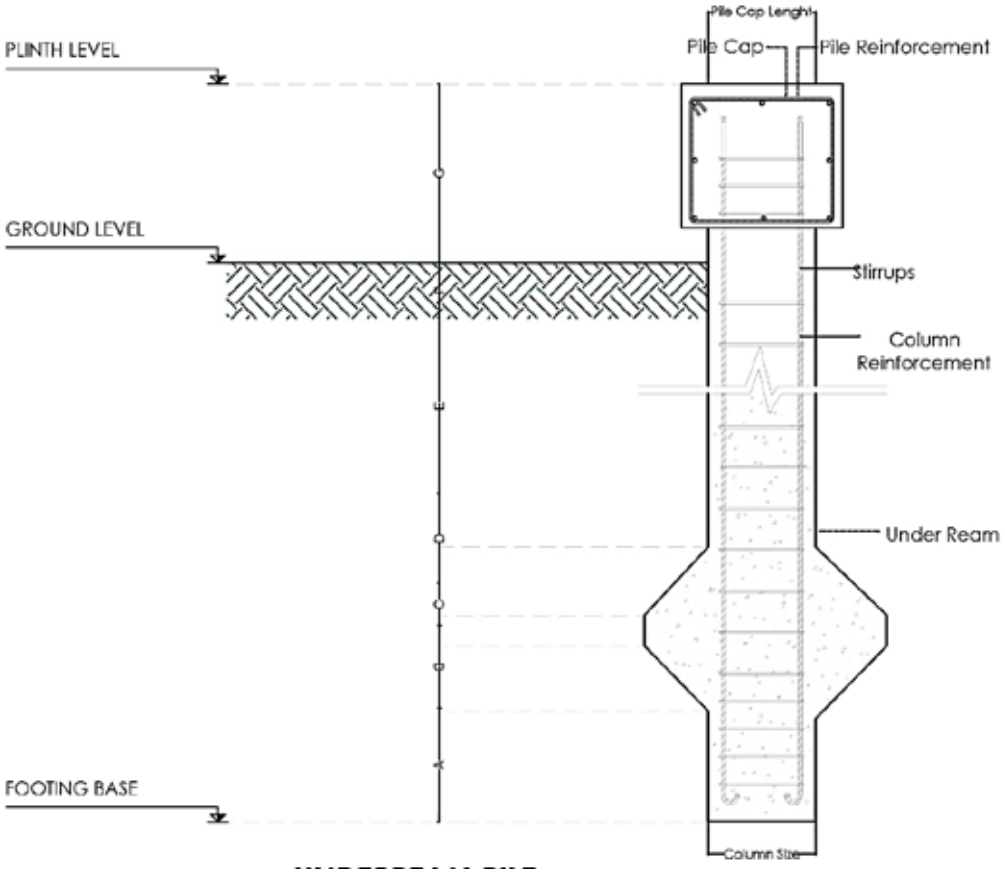
1. The choice of an under-reamed pile in unstable or water-bearing ground is generally to be avoided.
2. There is a danger of collapse of the under-ream, either when personnel are down the hole, or during concreting.

Market Linkages

1. The pile will be produced by reputed manufacturer and will be cast by suitable equipment on the site.

Cost

1. Cost of the Foundation to be estimated as per design.



Under reamed pile foundation

Specifications

Construction *(Refer IS 2911:1980 and IS 456:2000)*	1. In deep deposits of expansive soils, the minimum length of piles, irrespective of any other consideration shall be 3500 mm below the ground level. 2. If the expansive soil deposits are of shallow depth and overlying non-expansive soil strata or hard strata, Piles of smaller length can also be provided. 3. The diameter of Under-Reamed Piles varies from 200 mm to 500 mm. 4. Minimum length of Under-Reamed Pile is 3500 mm. 5. The diameter of under reamed bulbs may vary from 2 to 3 times the diameter of the pile depending upon the feasibility of construction and design requirements. 6. The centre to centre spacing for Under-Reamed Piles should not be less than the 2 times diameter of the pile. 7. The vertical spacing between two bulbs varies from 1.25 to 1.50 times the diameter of the bulb. 8. The ultimate load bearing capacities of the under reamed piles with angle of under reamed bulbs of 45^0 and zero are almost same. 9. Three or more under reamed bulbs are advantageous only when the spacing ratio (S / D_u) is two or less, and when (S / D_u) is greater than two, multi-under reamed piles do not have specific advantages. 10. The ultimate load bearing capacities of piles are maximum when the spacing between two under reamed bulb is 2.5 times the diameter of the under reamed bulb. 11. The expression suggested in IS 2911-1980 can be used for predicting the ultimate load carrying capacity of under reamed piles with spacing ratio (S / D_u) less than 2.5.

Relevant Standards and References

1. IS 2911 -1980 Under-Reamed Piles, Bureau of Indian Standards, New Delhi.
2. IS 2911 :1980 Code Of Practice For Design And Construction Of Pile Foundations, Bureau of Indian Standards, New Delhi.
3. IS 14893 : 2001 Non-Destructive Integrity Testing of Piles (NDT) –Guidelines, Bureau of Indian Standards, New Delhi.
4. IS 6427 : 1972 Glossary of Terms Relating to Pile Driving Equipment, Bureau of Indian Standards, New Delhi.
5. IS 9716 : 1981 Guide for lateral dynamic load test on piles, Bureau of Indian Standards, New Delhi.
6. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Bored Compaction Pile Foundation

Suitable Regions

It can be used anywhere in India except hilly regions and Deccan plateau.

About the Technology

Cast in-situ bored piles of a special type developed at the Central Building Research Institute, Roorkee, India, have proved particularly useful for loose soils with a high water table as well as in other situations. Used for foundation of structures of various types such as residential and industrial buildings, overhead tanks, towers, substations, gantry foundations, underground tanks, over bridges etc.

Bored compaction pile foundation are the modification of under-reamed pile.

These piles are bored cast in situ pile foundation which combine the advantages of both bored and driven pile. The method of boring the piles and concreting the pile is the same as that for the under-reamed pile, except that the reinforcement cage is not placed in the bore hole before concreting. After the concreting is over, the reinforcement cage is driven through the freshly laid concrete. In the bored compaction pile load carrying capacity depends upon the stem diameter of piles

Bored Compaction Pile Considerations :

1. Bore pile base maybe difficult to Clean.
2. Bulging / Necking may occur , so special care must be taken.
3. Collapsing of Sidewalls may occur.
4. There are uncertainties on the Level of Weathered Rock.

Material Requirements

Size as per design	Concrete Steel reinforcement

Tools and Equipments

a) Equipment for boring .
b) Augers.
c) Under reamer.
d) Steel pipes for concreting and driving low weight driving Equipment.

Salient Features

1. Combines the advantages of both bored and driven piles by compacting freshly laid concrete and soil around obtaining increased load carrying capacity over normal piles.
2. In the bored compaction pile load carrying capacity depends upon the stem diameter of piles
3. Suitable for loose to medium silt/sandy soils specially with high water table.
4. The pile is suitable for all types of soil especially high water content soil.
5. No adverse effect on the environment

Economic Aspects

1. Compared to RCC column foundation these piles are 30-200% economical.

Sustainability Aspects

1. No adverse effect on the environment as there is no waste production.

Limitations

1. It is used in loose to medium silt/sandy soils specially with high water table.

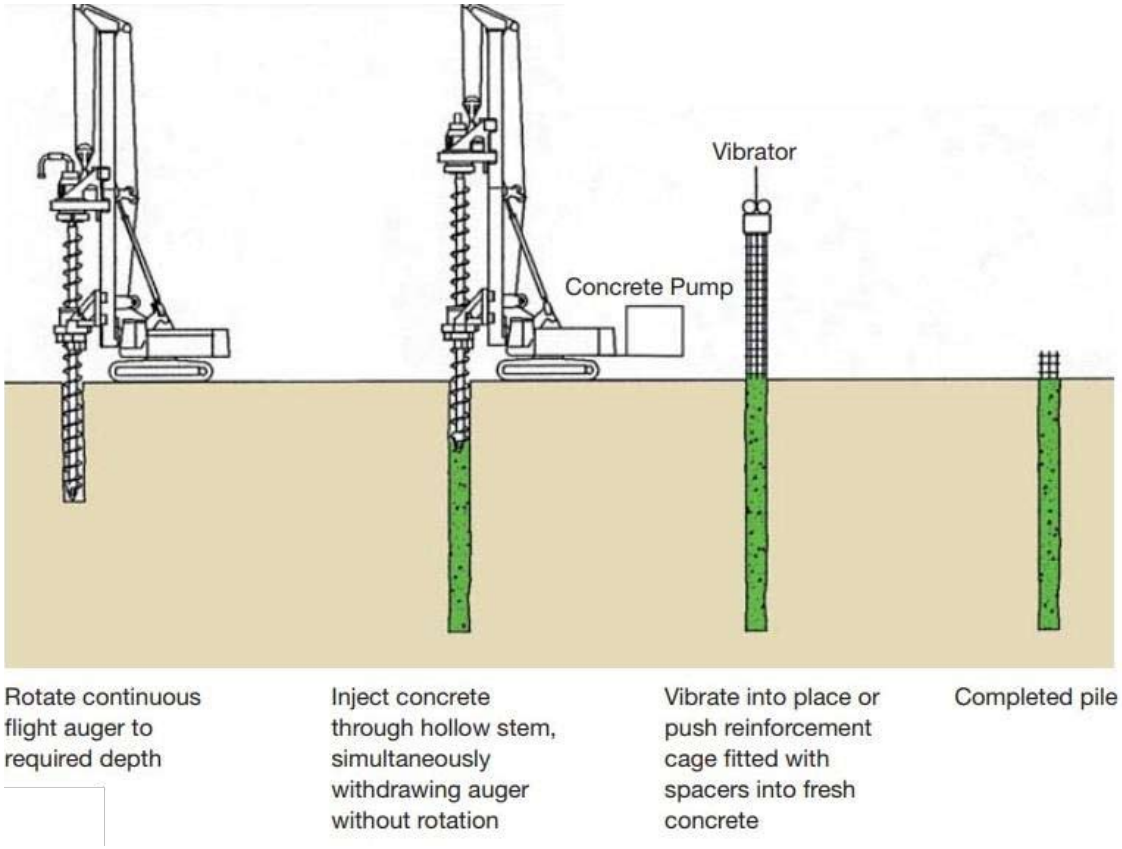
Market Linkages

1. Cast-in-situ construction and the work is done by specified piling companies.
2. Piles upto 300mm diameter and 3500mm deep can be cast at site by normal construction companies also.

Cost

1. Cost of the Foundation depends totally on the site and load design.

Foundation



Bored compaction pile foundation

Specifications

Size *(Refer IS 2911:1979 PART 1 and IS 2911:1980)*	Depth: 300mm to 2000 mm (Up to 3000 mm for special case) Lengths : Varies
Structural Capacity *(Refer IS 9716:1981)*	80Ton to 2,300Tons
Concrete Grade *(Refer IS 2911:1979 PART 1 and IS 2911:1980)*	20MPa to 35MPa
Installation Method *(Refer IS 6427:1972)*	Drill then Cast-In-Situ
Aggregate Size *(Refer IS 2911:1979 PART 1 and IS 2911:1980)*	20mm-40mm

Relevant Standards and References

1. IS 2911 : Part 1 : Sec 2 : 1979 Bored cast-in-situ piles, Bureau of Indian Standards, New Delhi.
2. IS 2911 :1980 Code Of Practice For Design And Construction Of Pile Foundations, Bureau of Indian Standards, New Delhi.
3. IS 14893 : 2001 Non-Destructive Integrity Testing of Piles (NDT) –Guidelines, Bureau of Indian Standards, New Delhi.
4. IS 6427 : 1972 Glossary of Terms Relating to Pile Driving Equipment, Bureau of Indian Standards, New Delhi.
5. IS 9716 : 1981 Guide for lateral dynamic load test on piles, Bureau of Indian Standards, New Delhi.

Pedestal Pile Foundation

Suitable Regions

Predominantly in Black cotton soil area.

About the Technology

The pedestal pile is used where good bearing stratum is reached within reasonable depth. The pedestal of the pile gives the effect of spread footing on this soil.

This technology is an economical substitute to under-reamed pile foundation for small buildings where load on pile is less in comparison to the capacity of under reamed piles. This system consists of a reinforced precast concrete pile which is lowered in a boreholes . The lower part of the pile has projected reinforcement for embedding the pile in-situ concretes and lay in the bottom of borehole to form pedestal

When structural members are connected to the foundation, pedestals are normally designed to carry loads through the ground surface to the footings which are located below the ground surface.

The soils around the pedestals should be properly compacted to provide sufficient lateral resistance to prevent buckling of pedestals.

Material Requirements

Size as per design	Concrete Steel reinforcement

Tools and Equipments

a) Concrete mixer b) Auger with accessories for making bore holes c) Mould for pre-casting pile stems d) Vibrator e) Mason’s tools

Salient Features

1. This type of piles are used where the bearing stratum is reached within reasonable depth. The pedestal of the pile gives the effect of spread footing on the soil.
2. This technology is an economical substitute to under-reamed pile foundation for small buildings where load on pile is less in comparison to the capacity of under-reamed piles.

Economic Aspects

1. Cost effective, fast and simple foundation system for small buildings.

Sustainability Aspects

1. Construction of low cost houses in black cotton soil and other filled-up or weak soil areas

Limitations

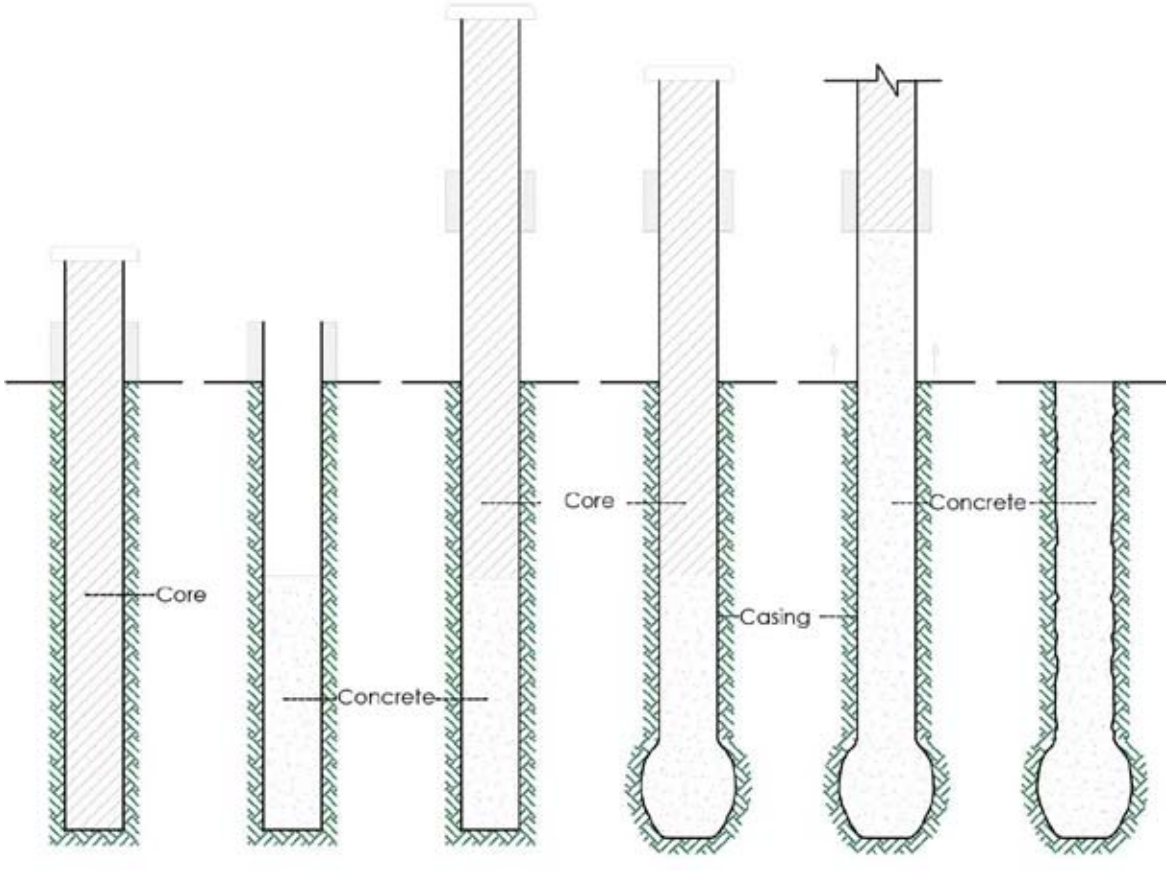
1. Heavy machinery and equipment's are required.
2. Not suitable where water table is high

Market Linkages

1. Details can be obtained from Central Building Research Institute, Roorkee.
2. Can be cast at site by contractors.

Cost

1. Cost of the Foundation to be estimated as per design.



Pedestal pile foundation

Specifications

Construction *(Refer IS 2911:2010)*	1. This system consists of a reinforced precast concrete pile stem (100mm x 100mm) which is lowered in a borehole of 300 mm diameter which has M20 concrete at the bottom to a height of about 400mm. 2. The lower part of the pile has projected reinforcement for embedding the pile in-situ concretes and lay in the bottom of borehole to form pedestal. 3. The method of analysis and allowable stresses should be in accordance with IS 456-2000. 4. The minimum factor of safety on static formula shall be 2.5.

Relevant Standards and References

1. IS 2911:2010, Design and construction of pile foundations — code of practice, Bureau of Indian Standards, New Delhi.
2. IS 9716 : 1981, Guide for lateral dynamic load test on piles, Bureau of Indian Standards, New Delhi.
3. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Stilt Foundation

Suitable Regions

Predominantly in flood prone river valley and coastal region.

About the Technology

Stilts are poles, posts or pillars used to allow a structure or building to stand at a distance above the ground. In flood plains, and on beaches or unstable ground, buildings are often constructed on stilts to protect them from damage by water, waves or shifting soil or sand.

Stilt foundation houses are houses raised on piles over the surface of the soil or a body of water. Stilt houses are built primarily as a protection against flooding. They also keep out vermin. The shady space under the house can be used for work or storage. There are ecological as well as environmental advantages to stilt foundation.

This type of house must be built on land or water that is free from rocks or metallic debris. When possible, deep holes are dug and are filled with a concrete mixture to offer additional weight and reinforcement before sturdy posts are added. If digging holes is impossible because of water, then the posts are sharpened on one side and erected, often by a team of men, during low or medium tide. When the necessary posts are in place, a base is built by laying deck boards on top of the posts to create more support. This combination of posts and base forms the "stilts," and the rest of the house can be completed on top of the stilts as desired. This kind of house is suitable in steep terrain and muddy soil.

The length of stilts may vary widely; stilts of traditional houses can be measured half meter to five or six meters. Created from bamboo or other water-resistant timber and reinforced with deck boards and sometimes concrete, stilt houses can be found throughout the world.

Material Requirements

Size as per design	Piling: a) Timber b) Concrete c) Steel d) Composite (depending upon the type of foundation)

Tools and Equipments

a) Pneumatic Caissons b) Cutter Suction Dredgers
c) Immersed-tube Tunnels d) Sheet piling e) Bracing frame
f) Concrete seal

Salient Features

1. More airflow in hot climates. Both increased airflow from underneath the floorboards, and increased wind from the raised elevation.
2. Dry space underneath house in rainy seasons. People can use this space for storage, chores, keeping and tending animals, hanging things, and other useful activities.
3. Stilt foundations may be provided where water stagnates for more than 3 days to a depth of more than 1500 mm.
4. Can be built on hilly/non-flat terrain. You don't need to modify the terrain to place your house.
5. Slight visual advantage.
6. This kind of house is suitable with the steep terrain and muddy soil.

Economic Aspects

1. When local material is used as pile for Stilt foundation, it may be very economical.

Sustainability Aspects

1. Can be constructed with locally available material and local labour.

Limitations

1. Constructed predominantly in flood prone river valley and coastal region.

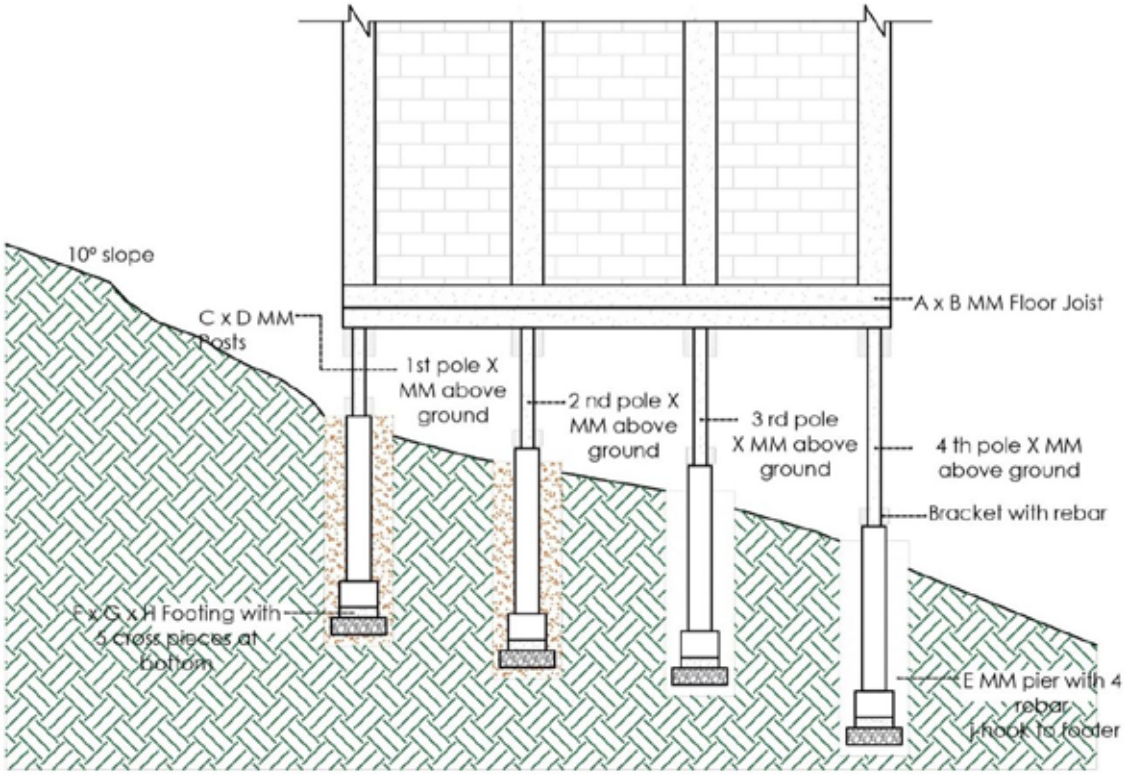
Market Linkages

1. Should be constructed at site using local labor/contractors as per design.

Cost

1. Cost of the Foundation depends totally on the type and design load.

Foundation



Stilt foundation

Specifications

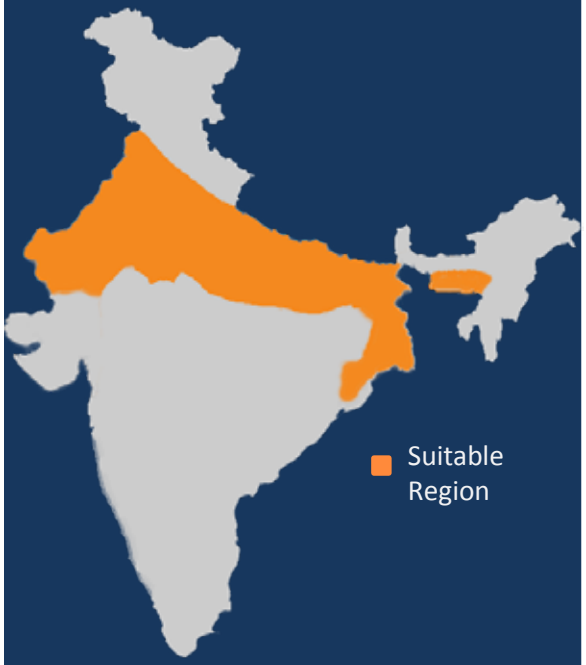
Construction	1. Stilt foundations may be provided where water stagnates for more than 3 days to a depth of more than 1500mm. 2. The expected maximum flood levels may be determined from appropriate authorities or by enquiry at the village level.

Relevant Standards and References

1. National Disaster Management Authority guidelines.

Inverted Arch Foundation

Suitable Regions



Predominantly in desert soft soil and alluvial region.

About the Technology

The inverted arch footing is used in places where the bearing capacity of the soil is very poor and the load of the structure is concentrated over the walls and deep excavations are not possible. This is not a common type of foundation. Arch is constructed between the two walls of the base. To withstand this outward horizontal thrust the Walls must be sufficiently thick and strong.

When the SBC of the soil is very poor and the load of the structure is transferred through walls. In such cases inverted arches are constructed between the walls. End walls should be sufficiently thick and strong to withstand the outward horizontal thrust due to arch action. Semi-circular arches may be used to avoid side thrust. The outer walls may be provided with buttress walls to strengthen them.

It used to be provided for multi-storeyed buildings in olden times. However, with the advent of reinforced cement concrete construction practice, inverted arch footing is rarely done these days. One of the drawbacks in this type of construction is that the ends have to be specially strengthened by buttresses to avoid the arch thrust tending to rapture the pier junction.

Nowadays Inverted arches are used where sideways forces must be restrained, and where space is most easily available beneath a construction. They have often been applied to railway cuttings, but are perhaps most distinctively used as the base of docks, particularly dry docks and locks that must be supported even when they are empty of water that could otherwise resist the side thrust of their walls.

Material Requirements

Size as per design	Good masonry bricks/stones

Tools and Equipments

a) Steel/timber moulds b) Plate vibrator c) Light hoisting equipment d) Trowels e) Chisel-Jointer f) Squares-Mason's Level g) Straightedge.

Salient Features

1. Provided for multi storeyed buildings in old times.
2. For this foundation an inverted arch is constructed below the foot of Piers etc.
3. Primarily used where the soil bearing capacity is very less and deep excavation is not possible.
4. Load of the structure is concentrated over the pillars.
5. The advantage of inverted arch construction is that in soft soils the depth of foundation is greatly reduced.
6. However, with the advent of reinforced cement concrete construction practice, inverted arch footing is rarely done these days.

Economic Aspects

1. Inverted arch masonry footing consist of an inverted arch constructed from brick or stone masonry on which masonry wall or pier is placed, hence if the material is a locally available material it is a cost efficient technology.

Sustainability Aspects

1. It has been used in ancient buildings which has surpassed many earthquakes and are still standing tall. Hence if inverted arch foundation is build appropriately, the building is resistant to earthquakes.

Limitations

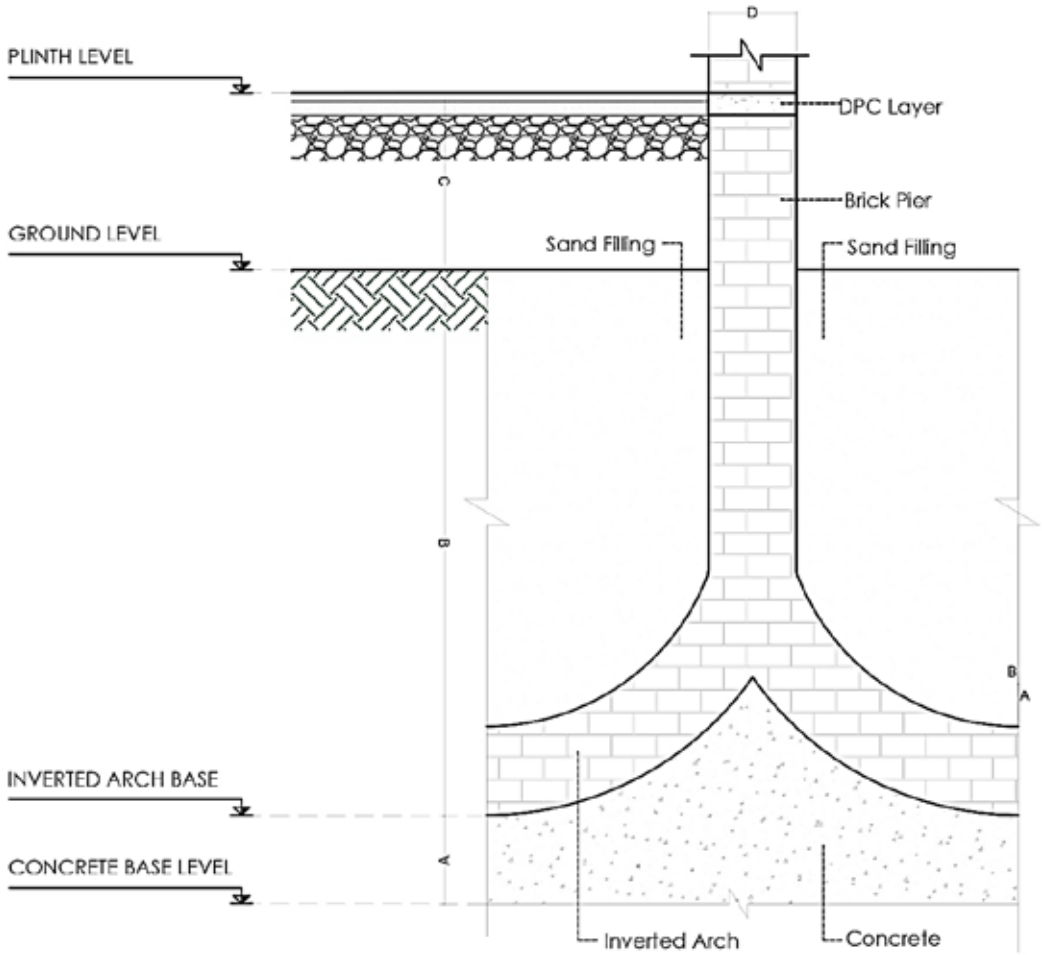
1. Can be used where space is most easily available beneath a construction.
2. In inverted arch skilled labour is needed.
3. This is a costly footing.

Market Linkages

1. Should be constructed at site using local labour as per design.

Cost

1. Cost of the Foundation depends totally on the type and design load.



Inverted arch foundation

Specifications

Construction	1. Segmental arches with a rise of l/5th to l/10th of the span are used. 2. The span of arches will of course depend upon the arrangement of the pillars. 3. The thickness of the arch ring, should not be less than 300mm. 4. End walls should be sufficiently thick and strong to withstand the outward horizontal thrust due to arch action. 5. The outer walls may be provided with buttress walls to strengthen them.

Relevant Standards and References

1. IS: 2212 – 1991, Brick Works-Code of Practice, Bureau of Indian Standards, New Delhi.
2. IS: 1905 – 1987, Code of practice for structural use of unreinforced masonry, Bureau of Indian Standards, New Delhi.
3. IS : 2250 – 1981, Code of practice for preparation and use of masonry mortars, Bureau of Indian Standards, New Delhi.
4. IS:1597 (1) – 1992, Construction of stone masonry code of practice part 1 rubble stone masonry, Bureau of Indian Standards, New Delhi

Granular Anchor Pile

Region specific application

All parts of India except some hilly regions.

About the Technology

One of the current advancement devised for improving the ground condition of soft/expansive soil is through Granular Anchor Pile System. Granular pile is among one of the conventional method for mitigating the problems of expansive clayey beds, such as settlement and low load bearing capacity. Granular pile furthermore accelerates consolidation process, thus enhancing the engineering properties of soil. However the foundations of high raised structures are not only subjected to compressive loads but also they should be capable of carrying tensile loads or uplift loads. But granular pile alone lack the ability to resist the tensile load of any structure.

Thus a variation was introduced in the granular pile system to alter the effect of uplift force on foundation. In a Granular Anchor Pile System (GAPS), an assembly is prepared by connecting the footing to an anchor plate, which is located at the base of the granular pile, through a mild steel rod. This anchor system allows GAPS to be tension resistant in swelling clay.

In such situations when structures are required to resist tensile forces in addition to the compressive forces, steel anchors and RCC piles have been suggested as appropriate solutions. However, the problem becomes difficult when foundations are required to be laid in weak sub-soil deposits having in adequate strength to support the structure. This necessitates the adoption of some viable ground improvement foundation technique, which should also be economical. Granular Anchor Pile System suits such conditions.

Material Requirements

Size as per design	Stone aggregate Steel rod with plate

Tools and Equipments

a) Auger b) Annular hammer c) Footing plate
d) Anchor Rod e) Base/Anchor plate

Salient Features

1. Granular pile anchors are innovative and effective in resisting the uplift pressure exerted on the foundation in loose sands as well as in expansive or reactive clay beds.
2. The GAP System inherits all the advantages of GP System such as resistance to compressive load, restricting settlement by allowing the ground water to seep through the pile material thus reducing the pore water pressure of the soil and accelerating consolidation process.
3. No such special equipment's are required in excavating the ground and installing the pile material to the borehole.
4. Granular anchor pile also resists the liquefaction in the loose sands by providing an effective drainage conditions.
5. The other advantages of granular anchors include short construction time, lower costs, as well as the ability to resist applied loading immediately after construction.
6. Semi-skilled labor can be used in proving the employment opportunities.

Economic Aspects

1. It is 40% more economical than RCC pile due to less consumption of cement.

Sustainability Aspects

1. Surrounding materials such as rock, stone aggregate etc which are locally available is used in construction.
2. Zero carbon foot-print.

Limitations

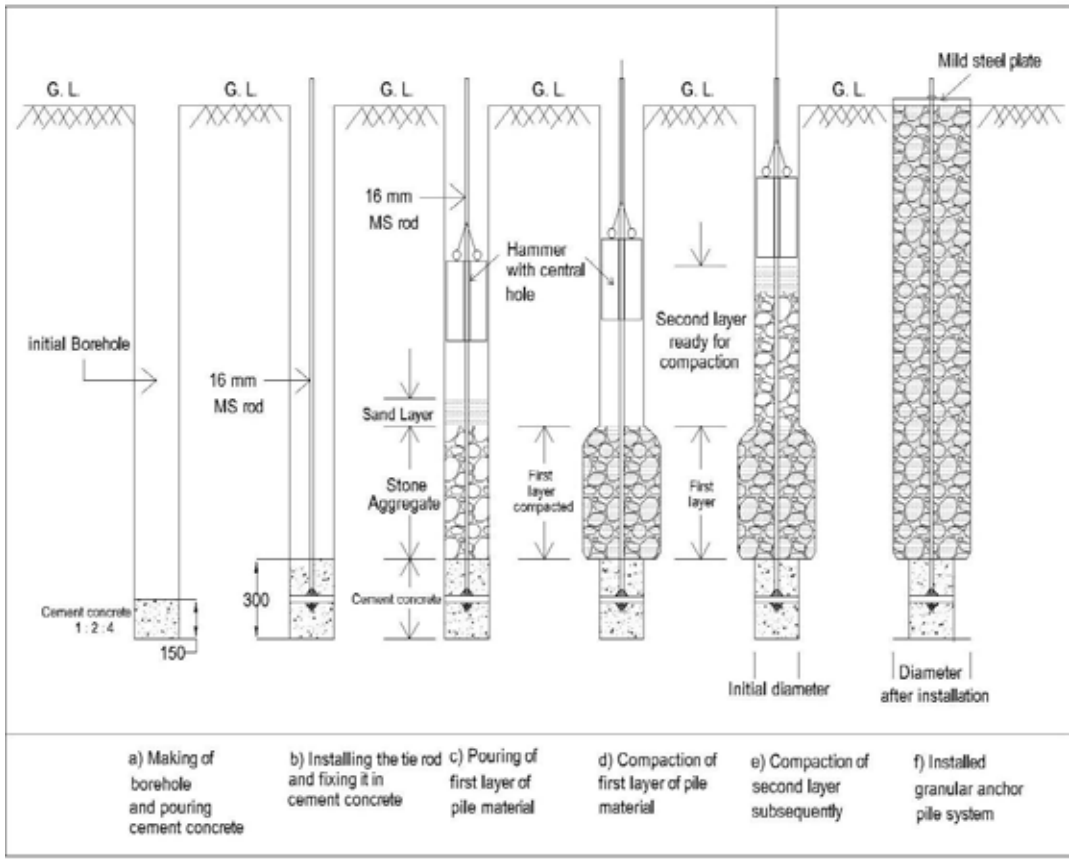
1. Not possible in areas where water table is high as it involves boring.

Market Linkages

1. Should be constructed at site using local labour as per design.

Cost

1. Cost of the Foundation depends totally on the type and design load.



Granular anchor pile foundation

Specifications

Construction	1. For granular anchor pile under tensile load, a uniform and straight borehole of suitable diameter and length is excavated inside the ground. Auger boring can be done for sufficiently low water table, but in case of high ground water table excavated borehole is needed to be provided with encasing. 2. Before casting of the granular pile, a 15 mm thick 1:2:4 cement concrete mix is placed in the borehole. 3. A mild steel anchor plate (generally 25 mm thick) of diameter less than the diameter of borehole, is connected with the mild steel rod with a nut on both sides. These bolt are welded with rod and plate, to make it stronger. Equally spaced mild steel support strips can also be welded around the nut connection to ensure the strength of the connection. 4. This Anchor plate – tie rod assembly is then lowered inside the excavated borehole. Subsequently another layer of 25 mm thick, 1:2:4 cement concrete mix is placed over the plate and thoroughly compacted by rodding. 5. The Anchor plate – tie rod assembly is left for 24 hours for curing. 6. Once the concrete is set, the next step is to fill the borehole cavity with granular pile material. The pile material is fed to the ground in several portions, i.e. feeding is followed by a thorough compaction. 7. GAP and soil behave as one single structure, when it is loaded. GAP system is mostly used in Grid system. The desired compaction as mentioned above is generally obtained by using the Vibro Replacement Technique.

Relevant Standards and References

1. IS 2911:2010, Design and construction of pile foundations — code of practice, Bureau of Indian Standards, New Delhi.

System Level Technologies

EPS Wall Panel System
(Scheme for Walls)

Suitable Regions

All parts of India

About the Technology

Expanded Polystyrene (EPS) core Panel system is a modern, efficient, safe and economic construction system for the construction of buildings. These panels can be used both as load bearing as well as non-load bearing elements. CSIR-SERC, Chennai has also undertaken extensive work on pre-engineered precast lightweight large wall and roof panels for mass housing that will contribute immensely towards urban infrastructure development in India. The light weight panels have a sandwich construction with expanded polystyrene as core and self-compacting concrete skins. The performance of these light weight panels as well as G+1 building assembled using these panels were evaluated for flexural, axial and seismic actions.

Mass Housing needs alternate technologies that enables faster construction than that achieved using conventional technologies.

The EPS panels consist of a 3-dimensional welded wire space frame utilizing a truss concept for stress transfer and stiffness. EPS panel includes welded reinforcing meshes of high-strength wire, diagonal wire and self-extinguishing expanded polystyrene uncoated concrete, manufactured in the factory and shotcrete is applied to the panel assembled at the construction site, which gives the load bearing capacity to the structure.

EPS panels after shotcrete have the following five components:

1. The outer layer of shotcrete, Welded reinforcing mesh of high tension GI wire
2. The core of expanded polystyrene sheet
3. Diagonal wire (stainless or galvanized wire)
4. The inner layer of shotcrete.

Material Requirements (per unit)

150 mm thick wall Size 3000 mm x 3000 mm	3 EPS panels with 70 mm EPS core and 40 mm M20 Shotcrete

Tools and Equipments

a) General construction equipment b) mason's tools
c) shotcrete machine

Salient Features

1. Two third weight reduction compared to conventional panels .
2. Low thermal conductivity, moderate compressive strength and excellent shock absorption ability.
3. Faster casting, better quality control for prefabrication.
4. Pollution free construction.

Economic Aspects

1. The EPS Core panel system is environment friendly and aesthetically appealing. It can be constructed quickly resulting in savings in construction time and money.

Sustainability Aspects

1. Low Carbon Foot Print. No large construction machines required. Amenable to manual labor construction.

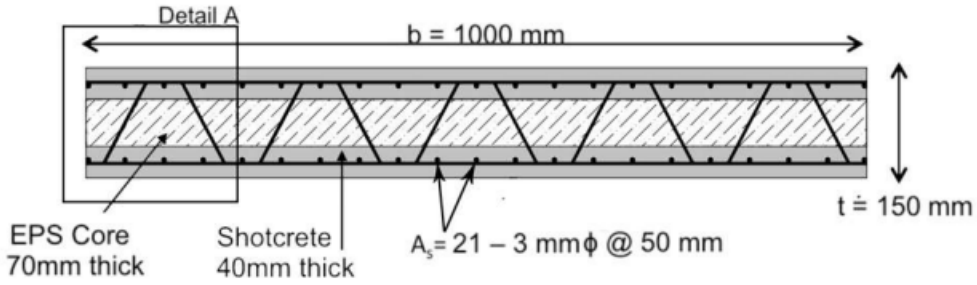
Limitations

1. Should be designed properly by a professional engineer
2. Concrete must either be applied by shotcrete dry or shotcrete wet.

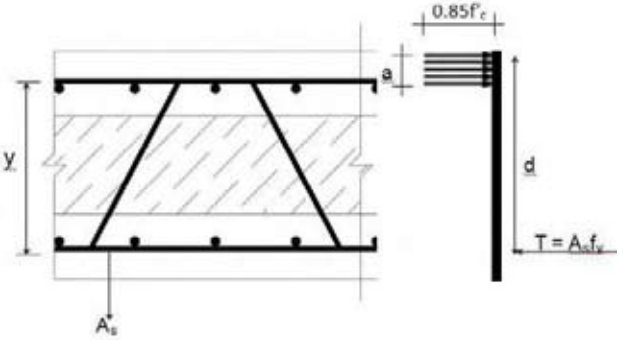
Market Linkages

1. Complete design and construction works undertaken by the manufacturers: M/s Synergy Trishlington, Mohali; M/s Consortium Techno Solution Pvt. Ltd., Hyderabad; and M/s. Level9 Biz Pvt. Ltd., Mohali

Walling system

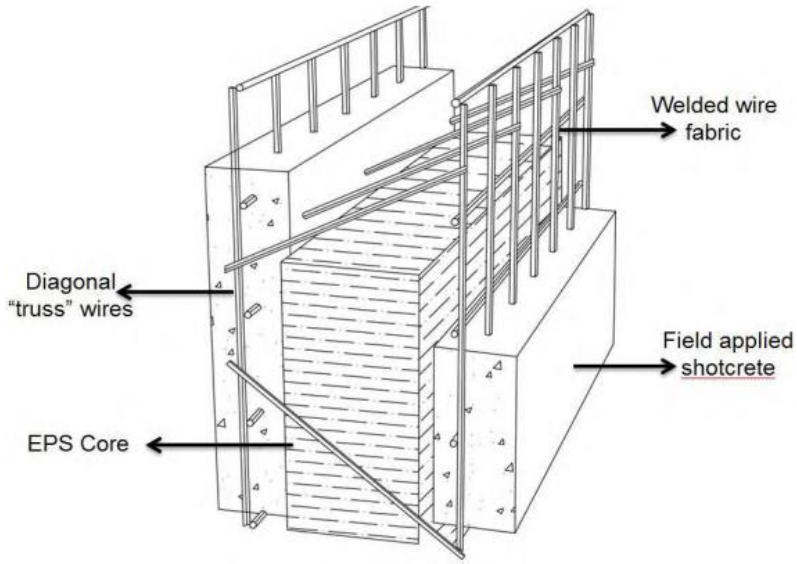


Cross Section of EPS Panel (source: refer 5)



β	Factor 0.85 for $f_c' \leq 4000$ psi ACI 10.2.7.3	Dimensionless
ε_c	Strain in Concrete	Dimensionless
ε_y	Yield Strain in reinforcement	Dimensionless
ϕ	Strength reduction factor 0.7 for combined axial load and flexure as per ACI 9.3.2	Dimensionless
a	Depth of the equivalent rectangular stress block as per ACI 9.3.2	mm
A_g	Gross area of concrete section	mm^2
A_s	Area of tensile reinforcement	mm^2
b	Width of compression face	mm
c	Distance from extreme compression fiber to neutral axis	mm
C_c	Compression force in concrete	N
C_s	Compression force in reinforcement	N
d	Distance from extreme compression fiber to centroid of tension reinforcement	mm
E_s	Modulus of elasticity of reinforcement 29,000,000 psi as per ACI 8.5.2	MPa
f_c	Specified compressive strength of concrete	MPa
f_y	Specified yield strength of reinforcement	MPa

Detail at A (source: refer 5)



3D Cross Section of EPS Panel (source: refer 5)

Specifications

Density	15, 20, 25, 30 or 35 kg/m^3
Compressive Strength	12 kg/m^3 - 50 kPa 33 kg/m^3 - 250 kPa
Poisson's Ratio	0.05 and 0.5
Water Absorption	3 – 5 % (variable with density)
Thermal Conductivity	0.28 - 0.37 mW/cm °C
Dead load	0.5 kN/m^2 to 2.5 kN/m^2

Relevant Standards and References

1. IS: 11447 – 1985, Code of practice for construction with large panel prefabricates , Bureau of Indian Standards, New Delhi
2. IS 13920 – 2016, Code of Practice for Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces , Bureau of Indian Standards, New Delhi
3. IS: 4671 – 1984, Expanded polystyrene for thermal insulation purposes, Bureau of Indian Standards, New Delhi
4. CSIR-SERC, Chennai, M/s Synergy Trishlington, Mohali; M/s Consortium Techno Solution Pvt. Ltd., Hyderabad; and M/s. Level9 Biz Pvt. Ltd., Mohali.
5. Manual for Expanded Polystyrene (EPS) Core Panel System and its field Application , CSIR-CBRI, Sponsored By Ministry of Housing and Urban Poverty Alleviation, Government of India.

Reinforced Concrete Framed Construction

(Cast-in-situ RC foundation, beam, column, floor/roof)

Suitable Regions

All regions except costal regions of the country

About the Technology

This is a cast-in-situ building technology for single and multi-storey buildings. It comprises framework of columns and connecting beams which forms the building's structural skeleton. The columns are supported by adequate foundation at appropriate depth and size. This grid of beams and columns supports the building's floors, roofs and walls. The infill walls can be of bricks/blocks/stone /panels, which principally do not participate in load transfer.

RC Foundation is the base of the structure which bears the load of superstructure, typically made of concrete and reinforcing bars. There are different types of foundation depending on the size, type of the building, load on the structure and type of soil. Shallow foundation includes Strip, Isolated, Combined footing, Raft or mat foundation up to 1.50 meter depth from ground level. Deep foundation are Pile and Pier foundation up to or greater than 3.50 meter deep from ground level. Typically the minimum size of a footing shall be 1 m x 1 m and minimum depth 1.20 m from ground level.

RC Columns are vertical member made of concrete and reinforcing bars. The minimum recommended size for a RC column is 230mmx300mm,M20 grade of concrete,4 bars of 12mm diameter, 8mm lateral ties at 100mm to 150 mm center to center spacing. However, it should be designed as per relevant standards.

RC Beam is a horizontal member made of concrete and reinforcing bars. The minimum recommended size for a RC beam is 225mm x 225mm .Two bottom bars of 12mm thickness and two top bars of 10 mm diameter with M20 grade concrete and 8mm steel rings at 100mm to 150 mm center to center spacing. RC beams should always be designed as per standards.

RC Slab horizontal member which makes the roof/floor of the building structure typically of thickness 120 to 150 mm with steel bars as per design.

Material Requirements

RC Column	M20 Concrete and Steel rebar
RC Beam	M20 Concrete and Steel rebar

Tools and Equipments

a) Excavator b) Concrete Mixer c) Steel/timber formwork
d) vibrator e) Bar bending Machine f) Wheel barrow

Salient Features

1. Reinforced concrete is a fluid material and can be economically moulded into a range of shapes.
2. Reinforced concrete has good resistance to damage by fire and weathering, if constructed properly
3. Low maintenance cost .
4. Earthquake resilient construction.
5. Reduced construction time and rapid site mobilisation.
6. Easily available construction Materials.
7. Easy in installation and can easily be adopted by semi-skilled labour.
8. Long and safe service life.
9. Easy alterations even after construction.

Economic Aspects

1. RCC construction work is costly with high labour cost, material cost and machinery cost.

Sustainability Aspects

1. Being large consumers of cement, RC structures are responsible for a sizable proportion of worldwide carbon emissions.

Limitations

1. High cost of formwork, casting for R.C. construction
2. Unsuitable construction system for coastal, low load bearing capacity soils.

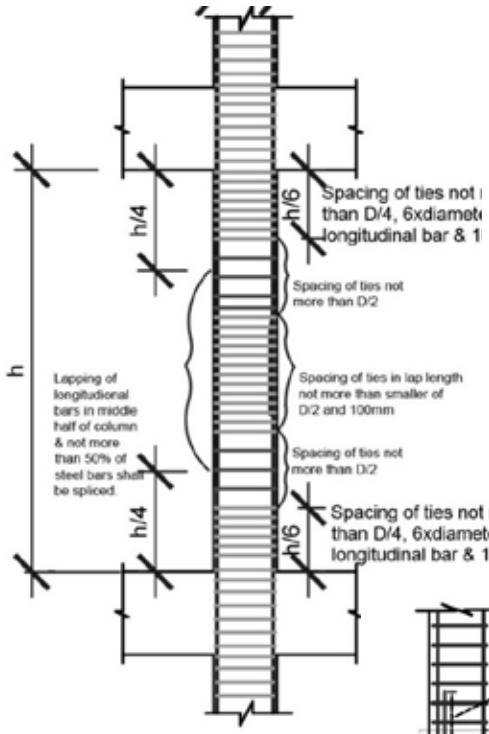
Market Linkages

1. Easily available construction materials and workmen.

System Level

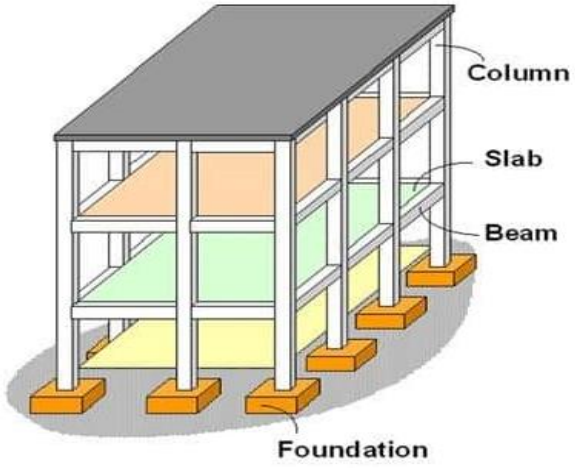
Specifications

Reinforced Concrete Foundation *(Refer IS 1080: 1982)*	**Size** : Length: 1000mm, Width: 1000mm, Depth: 1500mm **Concrete Mix** : M20, 1.5 m^3 **Reinforcement** : 240 kg
Reinforced Concrete Column *(Refer IS 456:2000)*	**Size** : Length: 225mm, Width: 300 mm Height: 3150mm **Concrete Mix** : M20, 0.212 m^3 **Reinforcement** : 12 mm dia. TMT- 4 Nos. longitudinal reinforcement, 8mm stirrups @150 mm c/c as per design. 23 kg
Reinforced Concrete Beam *(Refer IS 456:2000)*	**Size** : Length: 225mm, Width: 300 mm, **In-situ concrete mix** : **Concrete Mix** : M20, 0.216 m^3 **Reinforcement** : top 12 mm dia. TMT-2Nos., bottom 10 mm dia. TMT- 2 Nos. longitudinal reinforcement, 8mm stirrups @ 150mm c/c as per design. 18 kg
Reinforced Concrete Slab *(Refer IS 456: 2000)*	**Size** : Length:3000, Width:5000, Thickness:100 **In-situ Concrete Mix** : M20, 1.5 m^3 **Reinforcement** : 240 kg

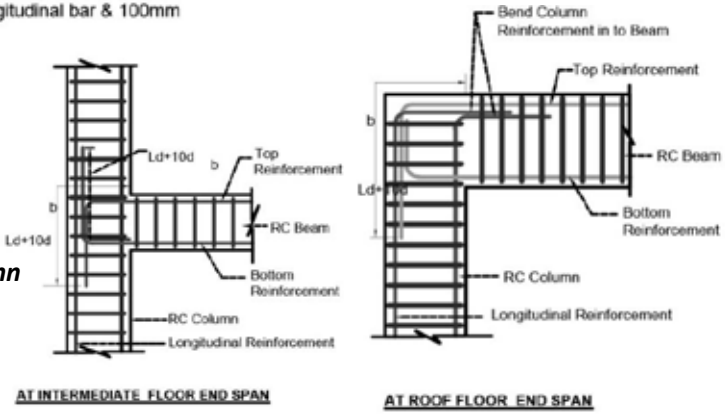


Typical detail:

reinforcement in the column



Typical RC frame building



Relevant Standards and References

1. IS 1080:1982-Code of practice for Design and construction of shallow foundations in soil (other than raft, ring and shell) (Second Revision), Bureau of Indian Standards, New Delhi.
2. IS 456:2000-Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Confined Masonry

(alternative to conventional masonry construction)

Suitable Regions

All parts of India

About the Technology

Confined masonry building technology is applicable for construction of low-to-medium rise building. This technology has excellent seismic resistance, cost-effective and make use of locally available construction materials and skills. During the construction nominal reinforcement are erected first at corners of room, and at intersections followed by masonry work up to 1000 mm height, by providing 25 – 40 mm toothing arrangement in masonry at interface of column and wall. The column are of 230X230 mm size for 230 mm walls with 4-12 dia. Bars (lightly reinforced) called as tie-column and beam of 230x230 mm at plinth and lintel level called as Bond-beam. Thus the construction masonry is bound by tie-column and bond beam.

Foundation: Based on soil condition different foundation types; cement concrete/masonry strip, pile, are adopted.

Masonry walls: Made up of brunt solid –clay or concrete block units built on top of plinth beam width 230mm.

RC Tie-Columns are small size cast in situ vertical confining elements around masonry wall construction. The maximum distance between two columns should be limited to 4000 mm. Makes use of 4 10/12 mm dia. longitudinal HYSD bars, and 6mm dia. tie bars @150-200mm center to center spacing.

RC Tie-beams, bands- plinth beam, sill band, lintel band, Roof band are cast-in-situ horizontal confining elements. Longitudinal reinforcement bars in horizontal RC bands run through all walls of the house. Plinth and lintel beam of 230mm x 150mm with 4 10mm dia. longitudinal bars and 6mm dia. ties at 150-200 mm centre to centre spacing for RC slab roof buildings. In case of truss roofing system eves and gables are also provided with similar size tie beams.

RC floor/roof slabs built monolithically with the confining elements. Roof slab is directly tied with the wall and transfer loads to walls and both elements are resistant against earthquake.

Material Requirements

Size as per design	M20 Concrete Steel reinforcements Bricks

Tools and Equipments

a) Steel/timber moulds b) Plate vibrator c)Light hoisting equipment

Salient Features

1. Superior seismic performance with higher strength, initial stiffness, ductility and energy dissipation capacity as compared to unreinforced and reinforced masonry.
2. Uses locally available material and skills
3. Economically viable for low-to-medium rise buildings in earthquake prone construction.
4. RC tie-beams and tie-columns are smaller in size and require less reinforcement compared to RC frame members.
5. Makes use of a well proportioned building layout.
6. Does not require any special construction skills.

Economic Aspects

1. About 30% cost reduction as compared to the construction cost of RC framed structure

Sustainability Aspects

1. Saves use of cement and steel.

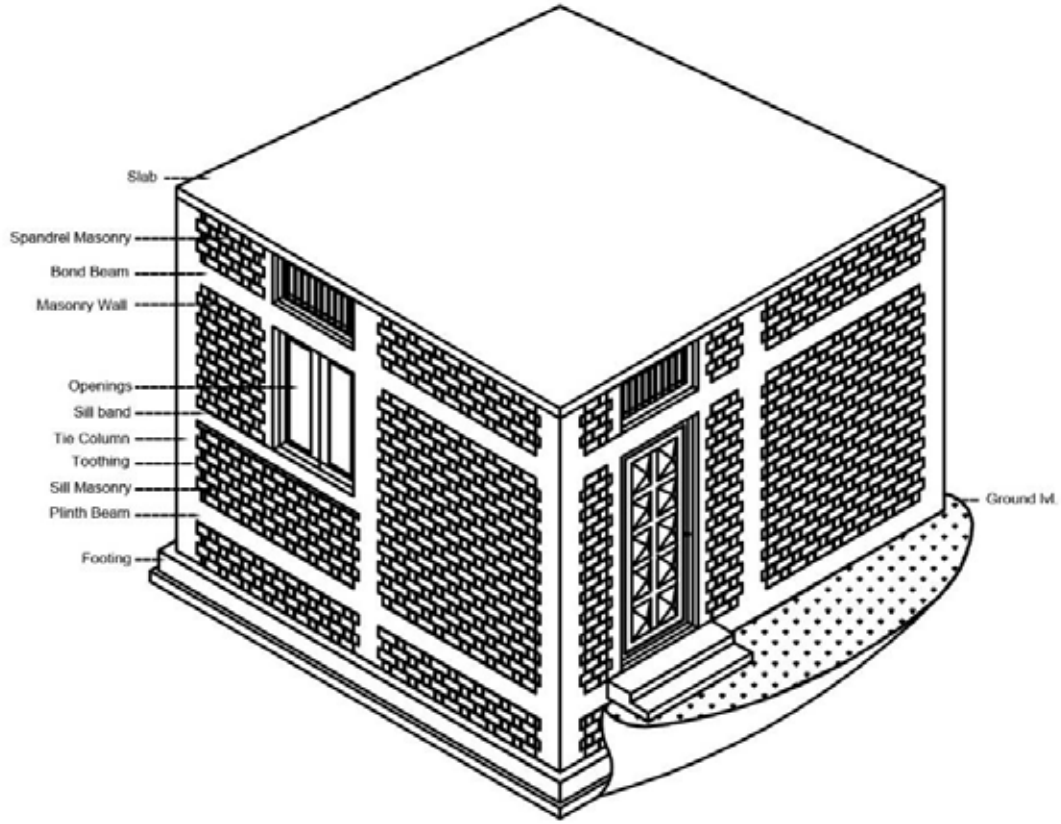
Limitations

1. Not suitable for more than 4 storey buildings.

Market Linkages

1. locally available construction materials and labours.

System Level



Confined masonry building

Specifications

Strip foundation	**Size** : as per design; D: 1500 mm **Concrete Mix** : M20, 1.5 m^3 **Reinforcement** : 240 kg
Masonry wall	**Size** : Length: 6000 mm, Height: 3100 mm, Thickness: 230 mm **Mortar:**1.49 m^3 **Bricks:** 2139
RC Tie-columns	**Size :** L: 225mm, W: 300 mm H: 3150 mm **Concrete Mix :** M20, 0.212 m^3 **Reinforcement :** 12 mm dia. TMT- 4 Nos. longitudinal reinforcement, 8mm stirrups @150 mm c/c as per design. 22 kg.
RC Tie-beam- plinth beam	**Size** : L: 3200 mm, W: 225 mm, D: 300 mm **Concrete Mix :** M20, 0.216 m^3 **Reinforcement :** Top 12 mm dia. TMT-2Nos., bottom 10 mm dia. TMT- 2 Nos. longitudinal reinforcement, 8mm stirrups @ 150mm c/c as per design. 18 kg.
RC Tie-bands- Sill band, lintel band, roof band	**Size** : L:90 m, W: 230 mm Depth:150 mm, **Concrete Mix** : M20, 3.10 m^3 **Reinforcement** : 500 kg.
RC floor/roof slabs	**Size** : L:3200 mm, W:3650 mm, T: 100 mm **Concrete Mix** : M20, 1.08 m^3 **Reinforcement:** 180 kg

Relevant Standards and References

1. IS: 4326 – 2013, Earthquake resistant design and construction of buildings - Code of practice, Bureau of Indian Standards, New Delhi.
2. IS: 1905 – 1987, Code of Practice for Structural use of Unreinforced Masonry, Bureau of Indian Standards, New Delhi.
3. Design Guidelines for Confined Masonry Buildings, Central Building Research Institute, Roorkee.
4. IS 456:2000-Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Precast Large Concrete Panel System

(alternative of conventional Cast-in-situ RC framed structure)

Suitable Regions

About the Technology

Precast Large Construction Panel system is a structural system comprising of various precast elements such as walls, beams, slabs, columns, staircase and other customized elements. There are two types of precast concrete elements, viz. Precast RC elements and precast pre-stressed concrete elements, prefabricated in a precast yard or site. The precast elements are installed on site and supported by temporary jacks. Shims are used to carefully align the elements and grouted after the final adjustments. This technology is suitable for construction of high rise buildings resisting seismic, wind and gravity loads. A typical construction involves design, strategic yard planning, lifting, handling, transportation, and assembly of precast elements.

Precast concrete wall panel resists axial lateral loads. The typical dimensions for precast concrete wall panel are 500 mm x 2850 mm x 120 mm.

Precast concrete column typical sizes are 900 mm x 350 mm x 2850 mm.

Precast concrete beam: typical sizes are 0.20mx0.40m

Precast concrete slab: typical sizes are 3mx5m. For reinforced concrete floors, concrete of minimum grade M 30 shall be used. The minimum thickness of concrete layer for cored slab is 50 mm. Panels shall be designed in accordance with the recommendations given in IS 456:2000 governing reinforcement and detailing.

Material Requirements

Size as per design	M20 concrete Steel Reinforcement

Tools and Equipments

a) Steel/Concrete moulds b) cranes c) Leveling Shims
d) Light hoisting equipment

Salient Features

1. Pre-casting of elements to substantial reduction in construction time.
2. Flexibility in design.
3. Strength gradually increases over time.
4. Precast concrete wall panels have passed impact testing, giving owners an added level of safety assurance in areas prone to severe weather.
5. Precast concrete products are typically produced in a controlled plant environment, they exhibit high quality and uniformity.
6. Due to non-modular nature of precast concrete products, buildings of nearly any size can be accommodated.

Economic Aspects

1. Precast concrete slabs are about 23.22% cheaper than cast-in-place concrete construction, precast columns are about 21.4% cheaper than cast-in-place concrete construction.

Sustainability Aspects

1. Optimum utilization of resources with no/minimum wastage.

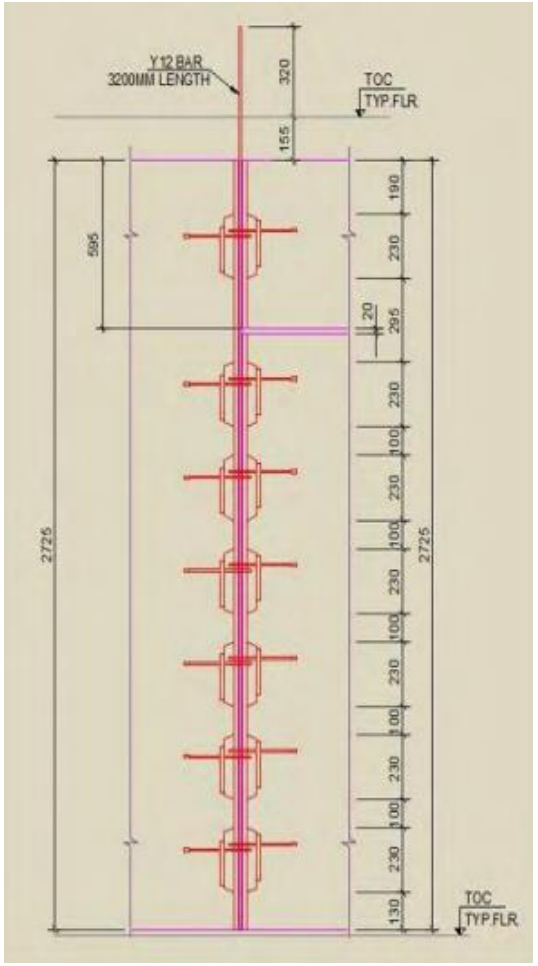
Limitations

1. Large and heavy precast components require cranes for lifting, positioning and placement.
2. The use of this technology is limited to multiple/mass scale housing units of repetitive types.

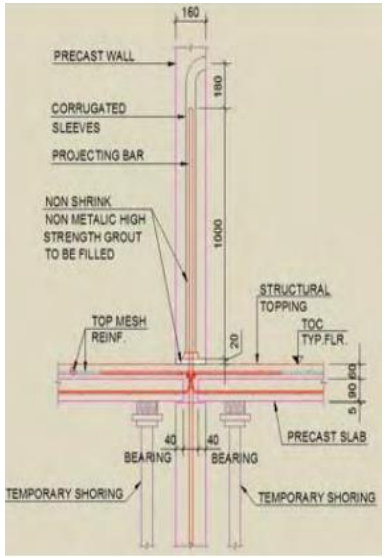
Market Linkages

1. The precast components can be cast at construction site or factory with specialized skills and assembled at site.

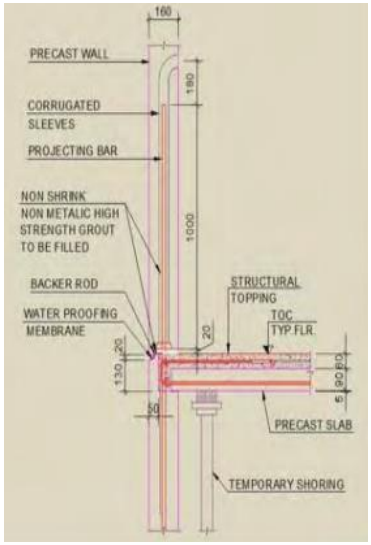
System Level



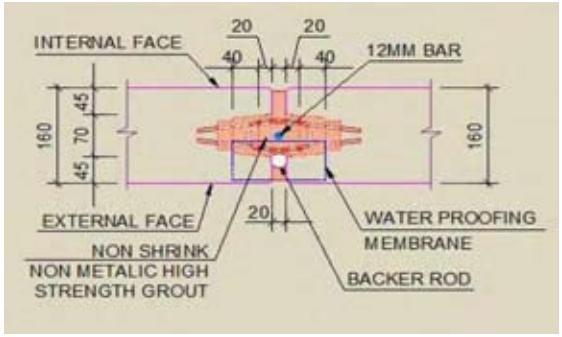
Wall to Wall Connection Elevation



External Wall Connection



Internal Wall Connection



Wall to Wall Connection Plan

Specifications

Precast concrete wall panel	**Size** : Length 5000 mm, Width 2850 mm, Thickness 120 mm **Concrete Mix** : M30, 1.71m^3 **Reinforcement** : 274 kg
Precast concrete column	**Size** : Length: 900 mm , Width: 350 mm , Height: 2850 mm **Concrete Mix** : M30, 0.89 m^3 **Reinforcement** : 144 kg
Precast concrete beam	**Size** : 200 mm x 400 mm x Length as per design **Concrete Mix** : M30, 0.256 m^3 **Reinforcement** : 41 kg.
Precast concrete slab	**Size** : 3m x 5m, Thickness: 50mm **Concrete Mix** : M30, 0.75 m^3 **Reinforcement** : 120 kg.
NOTE- Sizes of panel slabs may vary as per the architectural and construction requirement. The components of the structure shall be designed for loads in accordance with IS 875 (Parts 1-5):1987 and IS 1893 (Part 1):2016.	

Relevant Standards and References

1. IS 456:2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
2. IS 875 (Parts 1,2,4&5):1987 and IS 875 (Part 3) 2015, Code of Practice for Design loads (other than earthquake) of buildings and structures, Bureau of Indian Standards, New Delhi.
3. IS 15916:2010 Code of practice for building design and erection using prefabricated concrete (Reaffirmed 2013), Bureau of Indian Standards, New Delhi.
4. IS: 1893(Part 1): 2016, "Criteria for Earthquake Resistant Design of Structures", Bureau of Indian Standards, New Delhi

Monolithic Concrete Construction system

(alternative of conventional Cast-in-situ RC framed structure)

Suitable Regions

About the Technology

In this system, Aluminium or other type of formwork is used for RC reinforcement concrete element. Construction being modular predesigned formwork, it acts as a assembly line production and enables rapid construction of multiple/mass-scale units repetitive type. It is a fast construction technique where Walls, slabs, beams, staircases, balconies along with doors & windows can be casted at one single construction site or zone. This system comprised of panel with aluminium sections like beam, deck and wall components that are welded to an aluminium sheet. This system of formwork construction runs the structural system in one continuous pour. When the formwork is removed a high quality concrete finish is shaped with precise tolerances and verticality which invalidates the need for additional plastering. The size and design of formworks are based on the structural requirements of building units.

The Monolithic RC wall is considered as a shear wall. The maximum spacing between cross wall shall be limited to 1.5 times the floor height if supported on two edges and 2.0 times the floor height, when supported on all four wall. Thickness of the wall is generally minimum 100 mm with centrally placed reinforcement.

Aluminium formwork: The formwork systems used are made of light weight Aluminium. The recommended concrete forms generally use robotics welding system for manufacturing. A soft alloy weld wire is utilized in the concrete form weld process. Fixing of the formwork is done using tie, pin & wedges system which can be carried out by semi-skilled labour. The formwork can be designed based on requirements of dwelling unit and the project.

Material Requirements

Size as per design	M20 concrete Steel Reinforcement

Tools and Equipments

a) Aluminum/other formwork b) Light hoisting equipment

Salient Features

1. High quality and uniform finish.
2. Unsurpassed construction speed and require less manpower.
3. Total system forms the complete Concrete Structure.
4. Easy to handle.
5. On the structural front, the technology makes the buildings more seismic-resistant and durable. Since there is a lesser number of joints, hence requiring negligible maintenance.

Economic Aspects

1. Economy of scale depends upon the volume of work and number of repetition of the formwork. To achieve economy, minimum 100 repetitions are desirable. For very small project of less than 500 units, this system may not prove to be economical.

Sustainability Aspects

1. The aluminium forms can be reused at least 250 times, resulting in minimum waste from the construction sites.

Limitations

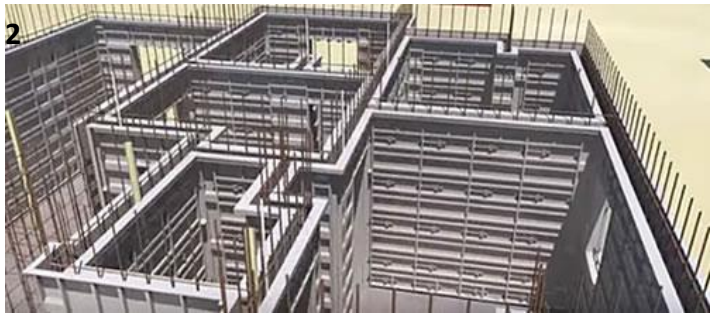
1. Post construction, on site alterations are not possible. Therefore all the service lines are to be pre-planned in advanced.
2. For very small project of less than 500 units, this system may not be economical.

Market Linkages

1. Modular size Aluminium/other formwork are commercially available. The precast components can be cast at construction site.

System Level

Setting up the wall Reinforcement steel –The wall reinforcing with steel is used to give a structure to the building and support the concrete until they gain half of the required strength. The aluminium formworks are cast around the steel mesh, which is factory made and directly erected on the construction site.



Placement of Aluminium formwork –Along the wall reinforcing steel, prefabricated room sized walls and floor slabs are erected. Spaces for windows, ducts, doors and other features are also integrated in these structures. The forms are joint together using the pin and wedge system, which can be dismantled quickly after the concrete structure is made.

Pouring of concrete – After casting the forms, concrete is poured This concrete takes the form and shape of the cast reaching nuke and corners of the form works easy, which is later removed.

Construction technique *(source: hombale group)*

Specifications

RC Structural wall *(Refer IS 875:1987)*	**Size** : Thickness is generally 100 mm with the reinforcement placed in the middle. Thickness of wall below plinth level should be minimum 200 mm with double layers reinforcement.
Concrete *(Refer IS 456:2000)*	Shall be of appropriate grade shall not be less than M20 as per IS 456:2000.
Reinforcement *(Refer IS 1786:2008)*	Shall conform to IS 1786:2008.

Relevant Standards and References

1. IS 456:2000-Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
2. IS 733 : 1983-Wrought Aluminium and Aluminium Alloy Bars, Rods and Sections (for General Engineering Purposes), Bureau of Indian Standards, New Delhi.
3. IS 1786:2008-High strength deformed steel bars and wires for concrete reinforcement, Bureau of Indian Standards, New Delhi.
4. IS 875 (Pt.3):1987 Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures- Part 3 : Wind Loads, Bureau of Indian Standards, New Delhi.
5. IS 13920:1993-Code of Practice for ductile detailing of reinforced concrete structure, Bureau of Indian Standards, New Delhi.
6. Building Materials & Technology Promotion Council Guidelines : 2011

Glass Fibre Reinforced Gypsum (GFRG) Panel System

(alternative of conventional wall & roof system)

Suitable Regions

All parts of India

About the Technology

GFRG panel, also known as Rapid wall, is a composite building system which uses prefab load bearing panels and cast in-situ RC infill for walling and floor/roof slabs, suitable for single storey to ten storey building. The panel is made of calcined gypsum plaster reinforced with glass fibres manufactured to a thickness of 124 mm, length 12 m and height 3 m under carefully controlled conditions. It contains cavities which maybe unfilled, partially filled or fully filled with reinforced concrete as per structural requirements. Each one metre length of GFRG panel has four cavities of 230 mm x 94 mm x 3 mm dimension, with two reinforcements in each cavity of 8mm in low rise buildings. These cellular cavities are formed between 15 mm thick outer skins (flanges) and 20 mm thick interconnecting ribs at 250 mm spacing. If the cavities are appropriately filled with plain reinforced concrete, GFRG possesses substantial strength to act as load bearing as well as shear wall, capable of resisting lateral loads. For low rise GFRG buildings (up to three storeys), there is no structural requirement to infill all cavities with reinforced concrete, although it is desirable to fill cavities with plain concrete or quarry dust with cement to facilitate nailing, drilling, fastening of non-structural components.

Walls: Load bearing wall panel with RC infill is suitable for multi-storeyed housing. In single or two storeyed construction the cavities can remain unfilled or partially filled with non-structural core filling such as insulation, sand, quarry dust or light weight concrete. Can also be used as partition walls in multi storeyed framed buildings.

Floor/Roof slab by providing embedded micro beams, top flange of the respective cavity is cut and removed in such a way that minimum 25 mm flange on both end is protruded. RC concrete screed of minimum 50 mm thickness is provided above the GFRG floor panel, which is reinforced with weld mesh of minimum size of 10 gauge 100 mm × 100 mm. This RC screed and micro beam act together as series of embedded T-beams.The system can also be used in inclined configuration such as staircase waist slab and pitched roofing.

Material Requirements

GFRG Panel	Calcined gypsum plaster Glass fibres

Tools and Equipments

a) lifting jaws & spreader bar b) Crane for loading unloading and erecting the panels

Salient Features

1. Flexible use of panels as load bearing walls, partition or infill walls in multi-storeyed RC framed structures; as shear walls to resist both gravity load and lateral load from earthquakes and wind; as floor/roof slabs, pitched roof slabs and also as staircase waist slabs and mid-landing slabs.
2. Low construction cost and savings in materials.
3. Less building weight, thereby, reduction in design for seismic forces and savings in foundation, especially in multi-storeyed buildings.
4. Low maintenance cost with high speed of construction.

Economic Aspects

1. This system results in 50.8% in cement, 35.2% in steel, 76% in sand, 75% in water consumption, 67.59% in labour, 82% in construction time.

Sustainability Aspects

1. It is 100% recyclable as it makes use of industrial waste gypsum and does not requires any plastering. GFRG has 61.5% less embodied energy as compared to RC system.

Limitations

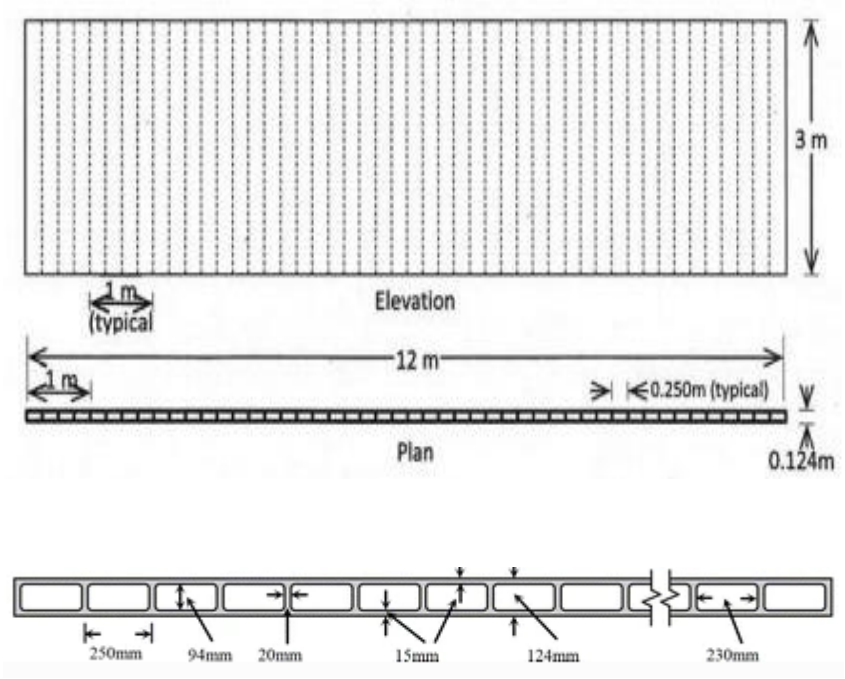
1. Ideal only if same floor/roof is replicated for all floors in a multi storeyed structure.
2. Cannot be used for wall with circular or higher curvature.
3. The electrical/plumbing fittings should go through the cavities (in order to facilitate minimum cutting of panel).

Market Linkages

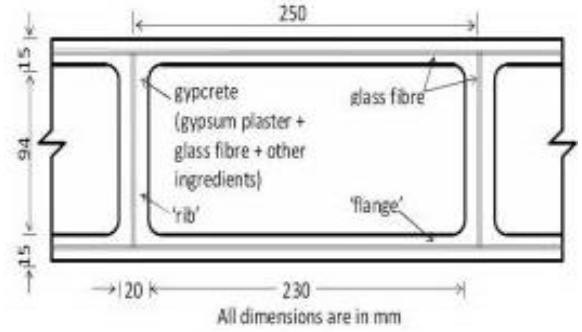
1. Manufacturing and test facilities available in the factory are found to be suitable to produce these panels as per the specifications.

Cost

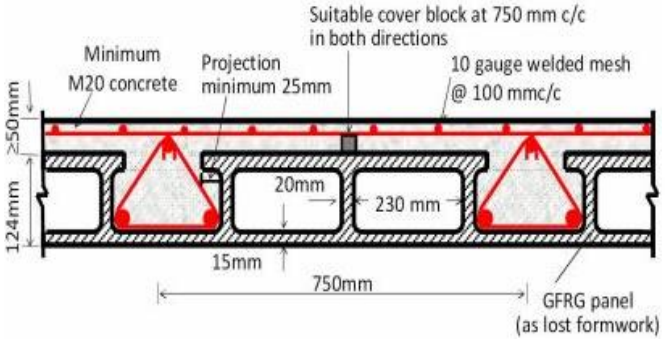
1. This scheme results in 50% savings in overall cost as compared to conventional cast in-situ RC system.



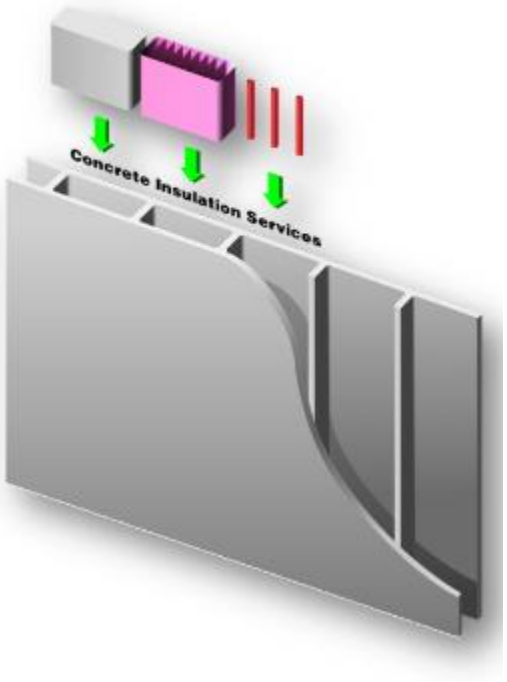
Typical elevation and cross section of GFRG panel



Enlarged view of a typical cell



Typical cross section of GFRG-RC slab (with concealed RC Beams)



A typical GFRG panel

Specifications

GFRG Panel	**Size** : Length: 12 m, Width: 3 m, Thickness: 124mm **In-situ concrete mix:** M20 **Concrete Mix**: M20 **Reinforcement**: Glass fibres **Weight** :Shall be 40 Kg/m² ± 6% (Class 1 & 2), Shall be 40 Kg/mm²±15% (Class)

Relevant Standards and References

1. Report by IIT, Madras on Testing of GFRG panel dated 20.07.11.
2. GFRG/Rapid wall Building Structural Design Manual, IIT Madras.
3. ISO 9004.1 Quality Management and Quality System Elements, Part 1:Guidelines.
4. BMBA PC-3: 2011, Clause10.4.4 – Specifications for Glass Fibre Reinforced Gypsum panel.
5. IS 456:2000-Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.

Light Gauge Framed Structural (LGFS) System

(alternative of conventional wall & roof system)

Suitable Regions

About the Technology

Light Gauge Framed Structures is based on factory made galvanized light gauge steel components, designed as per code. The system is produced by cold forming method and assembled as panels at site forming structural steel framework of a building of varying sizes of wall and floor.

The basic building elements of light gauge steel framing are cold formed sections which can be prefabricated at site using various methods of connection. The assembly is done using special types of screws and bolts.

LGSF is typically ideal for one to three storey high buildings, especially for residential and commercial buildings. LGF can be combined with composite steel/concrete deck resting on light steel framing stud walls. Advisable maximum span for LGSF buildings should be 7.5 m.

Due to its flexibility, fast construction and durability, this technology has great potential for counties like India. Apart from having potential for mass housing, modular buildings can be used for long term temporary or permanent structures such as schools and classroom, military and civil housing needs, post – disaster relief structures and industrial buildings.

Construction phases resembles the phases of conventional RC buildings. The sections manufactured as per design are numbered properly. The profiles are sent to site considering the distance of the construction site and transportation conditions. Profiles are assembled at the construction site in line with the architectural plan. Only special studs are used during assembly, no welding is done. Once the assembly is done, the frame is filled with insulation materials (fibreglass, Rockwool etc). Walls are then covered with standard boards or similar approved materials.

Material Requirements

Structural framework	Steel
Wall cladding	Gypsum board or Heavy duty cement particle board

Tools and Equipments

a) Screws and bolts b) Light hoisting equipment/Crane

Salient Features

1. LGSF structural system possess high strength to weight ratio. Due to low weight, significant reduction in earthquake forces.
2. Construction speed is high, where a typical four storeyed building can be constructed within one month.
3. The superstructure being light, does not requires heavy foundation.
4. Structural materials are easily transportable including hilly areas.
5. The wastage of material during construction is minimum.

Economic Aspects

1. This construction technology results in saving cement, water consumption, labour as well as construction time.

Sustainability Aspects

1. Saves use of cement.
2. Steel used can be recycled when required.

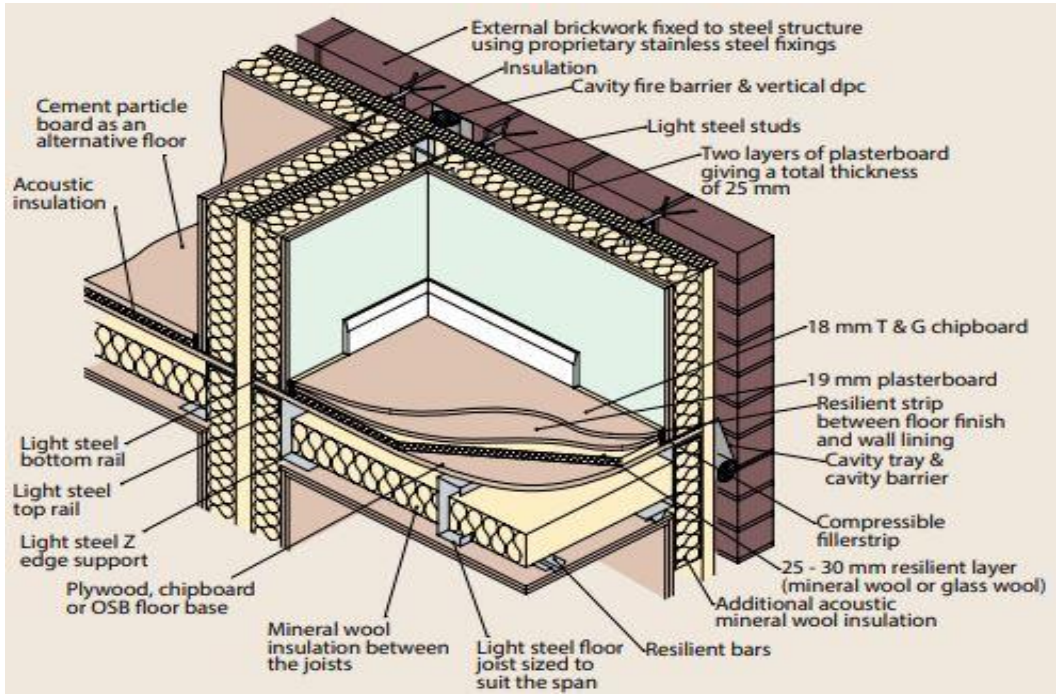
Limitations

1. LGF may be used only up to G+3 level, and above with composition of hot rolled structures.
2. Steel framing can loose strength during fire thus proper insulation is required.

Market Linkages

1. The sections are manufactured using Centrally Numerical Control (CNC) automatic four Pinnacle Roll Forming machine having production speed of 450-900 m/hr with very high precision.

System Level



Light Gauge Framed Structural System

Specifications

Stud & Track	Load bearing steel framing members shall be cold – formed to shape from structural quality sheet steel complying with the requirements of either ASTM A 653 M -13 or ASTM A 792 M -13 or ASTM A 875 M-13.
Wall frame	Consists of top track (U shape configuration) with a depth compatible with that of the studs of the same nominal size. Minimum height of track flanges shall be 19 mm.
Load bearing Walls	C section studs with depth of 90 and 200 mm and thickness between 2.7 mm and 2.0 mm shall be provided at a distance of 300 mm / 400 mm / 610 mm to ensure efficient use of cladding material.
Wall cladding	Shall be designed to resist wind load. Sheet has to be screwed to the joist with a spacing of 300 mm c/c with a minimum lap of 150 mm.
Floor frame	Steel joists are generally positioned at 300, 400 & 600 mm centres, depending on the spacing capabilities of the floor materials used.
Roof frame	Flat roof is made up of joists, where steel decking form a flat roof, a minimum fall of 1:4 should be introduced to ensure that any moisture runs off.
Wire Mesh	4 mm dia. wire of UTs 480 MPa with spacing 150 mm x 150 mm or 1.4 m dia. of spacing 40 mm x 40 mm.
Shotcrete	minimum grade M 25

Relevant Standards and References

1. IS 801:1975 – Code of practice for use of Cold Formed Light gauge Steel structural members in General building construction, Bureau of Indian Standards, New Delhi.
2. IS 456:2000 –Code of practice for Plain & Reinforced concrete (fourth revision), Bureau of Indian Standards, New Delhi.
3. IS 2095 (Part1):2011 –Specifications for Gypsum plaster boards – plain, Bureau of Indian Standards, New Delhi.
4. IS 14862 : 2000 Specification for Fibre Cement Flat Sheets (Reaffirmed 2015)
5. ASTM – A653/ A 653 M -13 Specification for steel sheet, zinc coated (galvanized) on zinc – iron alloy coated by hot dip process.
6. ASTM – A 792/792 M -13 Specification for steel sheet, 55% aluminium zinc alloy coated by hot dip process
7. ASTM – A 875/875 M -13 Specification for steel sheet, zinc 5% aluminium alloy coated by hot dip process

Speed Floor Construction System

(alternative to conventional RCC beam)

Suitable Regions

About the Technology

The Speed floor system is a suspended concrete flooring system using hot rolled steel joist galvanised (Z275) high tensile (350MPa) as an integral part of the final concrete and steel composite floor & is a hybrid concrete/steel tee-beam in one direction and an integrated continuous one-way slab in other direction. The joists of different depths are manufactured from pre-galvanized high tensile steel in a one pass roll former, where it is roll formed, punched, pressed and slotted in a fully computerized machine. Using plywood formwork over the joists, reinforcement is placed and concrete is poured for the final finish.

Joist The joist is manufactured from G 350 Z 275 pre-galvanized steel conforming to AS 1397:2001. Sizes are 200 mm, 250 mm, 300 mm, 350 mm and 400 mm, depending upon the design requirements. Concrete thickness may be 75mm or 90mm as required. The top section of the joist is embedded in concrete .The mid section or web of the joists has the flanged service hole and the lock-bar hole punched into it. The bottom triangular section of the joist acts as a tension member both during construction phase and when the joist is acting compositely with the slab.

The Lock bar locks the joists in their positions and support the temporary plywood formwork between the joists during construction. It is spaced 300mm c/c. The standard lock bars when installed will position the joists 1230mm, 930mm or 630mm apart.

Temporary Plywood formwork is high density paper overlaid 12mm shuttering plywood conforming to IS 4990:2011 or equivalent is used as formwork to produce a good finish to the underside of the slab.

Reinforcing mesh Welded reinforcement mesh made of 8mm diameter bar (fy 415 N/m^2) placed @ 200mmc/c in both directions, is laid and tied into place.

Material Requirements

Speed floor system	Pre-galvanized steel Plywood Mesh reinforcement

Tools and Equipments

a) Edge angles b) Jointers c) Lock bar Hanger Angles

Salient Features

1. Suitable in all types of construction buildings including Steel frames structures, RCC frame buildings, Light gauge steel frames, Conventional Structural brick wall constructions .
2. Easily accommodates services through pre-punched holes.
3. No need of propping and requires less crane handling
4. Can work parallely in more than one floor at a time, leading to speedy const.

Economic Aspects

1. 20 to 30% reduction in construction time relative to site-intensive construction.
2. 30% reduction in overall foundation loads.

Sustainability Aspects

1. No wastage of material.

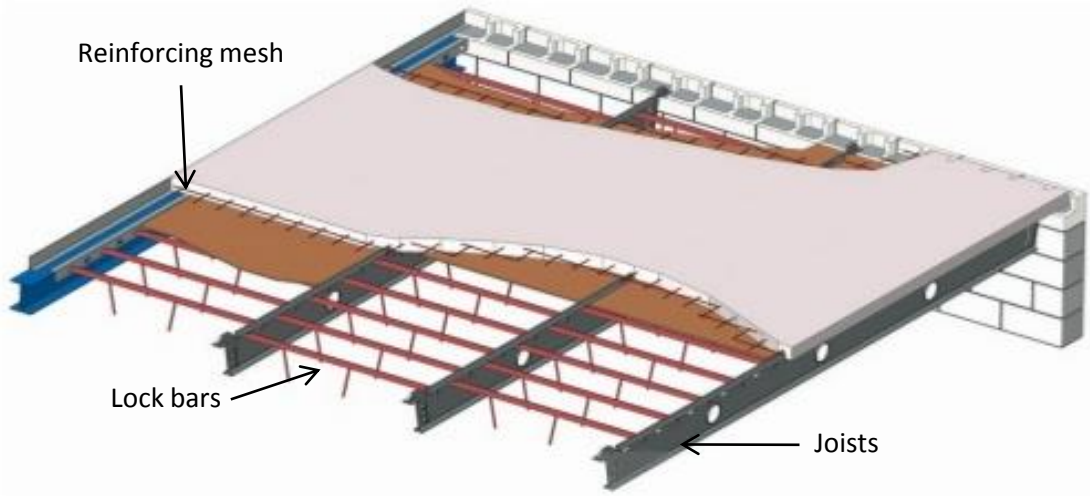
Limitations

1. Maximum length of joist which can be used is 10m.
2. Demands industrial set-up for manufacturing steel beam and other components.

Market Linkages

1. Medium or large scale industry is required for manufacturing of components.

System Level



Speed floor construction system

Specifications

Design *(Refer IS 875: 2015, IS 1893:2016, NZS 3404 and NZS 4600)*	The design of the speed floor system is based on NZS 3404 (Part 1 &2), AS/NZS 4600 and the Australian Composite Standard AS 2327 (Part-I). The design load shall be taken as prevalent in IS 875 (Part 1 & 3). Earthquake forces shall be taken in accordance with IS 1893 (Part-1).
Steel Joist *(Refer IS 2062:2011)*	**Depth**: 200mm, 250mm, 300mm, 350mm and 400mm as per requirements **Weight(kg/ In m)** : 9.41, 10.59, 11.76, 12.94, 14.12 according to the depth respectively.
Steel Lock bars *(Refer IS 2062:2011)*	They shall be spaced approx. 300mm apart and engage in the slotted holes punched in the top section of the joist maintaining the exact spacing of the joists.
Plywood Formwork *(Refer IS 4990:2011)*	High density paper overlaid 12mm shuttering plywood conforming to IS 4990:2011 or equivalent is used as formwork to produce a good finish to the underside of the slab.
Reinforcing mesh	8mm dia. bar (fy 415 N/m2) placed @ 200mm c/c in both directions.
Concrete Mix	Minimum grade of concrete shall be M25as per IS 456:2000.

Relevant Standards and References

1. AS/NZS 4600:2005 – Design of cold formed steel structures.
2. AS/NZS 4671: 2001 – Specifications for steel reinforcing materials.
3. NZS 3101(Part1):2006– Design of concrete structures.
4. NZS 3404 (Part1):1997 – Design of steel structures.
5. AS1397—2001: Steel sheet and strip—Hot-dip zinc coated or aluminium/zinc-coated.
6. AS/NZS 1170-2 (Parts 0 & 2) :2002 Structural Design Actions—General principles and Wind actions.
7. IS 456:2000 –Code of practice for plain & reinforced Concrete (fourth revision), Bureau of Indian Standards, New Delhi.
8. IS 2062:2011– Specifications for hot rolled medium & high tensile structural steel , Bureau of Indian Standards, New Delhi.
9. IS: 1893(Part 1): 2016, " Criteria for Earthquake Resistant Design of Structures." Part-1, Bureau of Indian Standards, New Delhi, 2016.

Cyclone Shelter

Suitable Regions

All regions except costal regions of the country

About the Technology

The coastal line of Bay of Bengal in South Asia has a maximum length of 5000 km (approximate) and the weather conditions there are often brutal due to heavy monsoon rains, both summer and winter. About 2 to 3 tropical cyclones form every year, bringing intense winds and severe flooding. Water produced directly by the strong winds, from 8 m to 10 m high .

At the request of Indian and German Red Cross and KfW, Germany, CSIR-SERC has designed a stilted cyclone shelter for use in Orissa coast with specialized foundation. The 23 cyclone shelters constructed at Orissa have saved nearly 46,000 people during the Super Cyclone which hit Orissa in 1999 and many of these structures are still in service, withstanding the recently hit 'Phailin' cyclone in October 2013.

The cyclone shelter has rectangular shape and aerodynamically rounded at the four corners to reduce wind load effects. The overall length of the building between the end frames is 21 m. The radius of the circular curve at the inner edge is 1000 mm. To reduce the effects of storm surge/flooding, the ground level in the area is raised by 1050 mm and with a stilt height of 3500 mm. The building has a corridor of width 1950 mm at first floor level (+4650 mm). A wide staircase with a width of 2000 mm is provided to reach the corridor from the raised ground level. The overall dimensions at the roof level are 7650 mm x 23000 mm, which includes an overhang of 1950 mm in front and 900 mm at the rear of the building. The columns of the frame are circular in shape. Since the ground floor is left open, there tends to be additional wind loading on the bottom floor slab, which has been duly considered in the design.

Material Requirements

Cyclone shelter	Concrete Steel reinforcement Bricks

Tools and Equipments

a) Masonry Hammer b) Scaffolding c) Trowel
d) Reinforcing steel fabrication e) Concrete vibrators
f) Trowel g) Concrete mixer h) Mason's tools

Salient Features

1. Easy, efficient, economic and durable structure.
2. Flood resistant design with capability of high wind resistance.
3. 23 cyclone shelters were built along the coast of Odisha based on the CSIR-SERC design.
4. Each of these shelters saved nearly 2,000 people during the super cyclone which hit Odisha in the year 1999.
5. 75 such cyclone shelters cover about one lakh people during Hudhud cyclone in October 2014.

Economic Aspects

1. As it saves the lives of the people we can't measure economic aspects.

Sustainability Aspects

1. Withstood the fury of many severe cyclones.

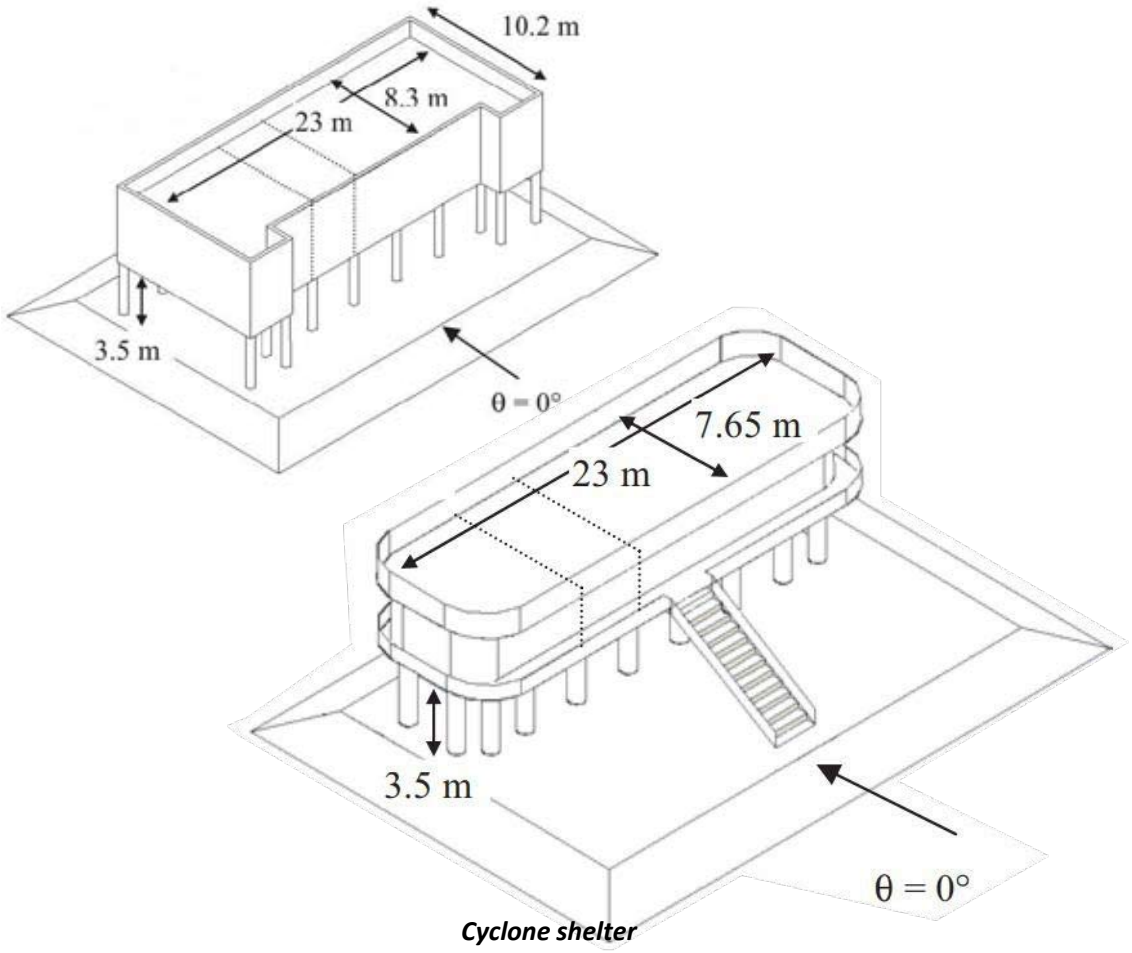
Limitations

1. Present design can accommodate only 1000 People / Shelter.

Market Linkages

1. The design of the multi-purpose cyclone shelter is transferred to The Indian and German Red Cross Society for constructing cyclone shelters in Odisha Coast.

System Level



Cyclone shelter

Specifications

Capacity	Shelters at least 1000 people.
Size	7650 mm x 23000 mm aerodynamically rounded at the four corners
Stilt	Provision of stilt, and sloping ground to satisfy functional requirements against storm surges/flood. The stilt height is about 3500 mm. circular curve at the inner edge is 1000 mm.
Shape	Aerodynamic shape effectively resist cyclonic wind forces.
Features	Continuous RC hand rails (GI), lintel and loft. 2000 mm wide staircases at both eds.
Footing	Under-reamed pile/strip footing as per design load.
Parapet	1200 mm high R.C. parapet wall.

Relevant Standards and References

1. IS: 456 – 2000, Criteria for design of plain and reinforced concrete structures, Bureau of Indian Standards, New Delhi.
2. IS: 13920 – 1987, Ductile detailing of reinforced concrete structures subjected to seismic forces, Bureau of Indian Standards, New Delhi.
3. IS: 875 (Part3) – 2015, Code of Practice for(other than earthquakes) Wind Loads for Building and Structures, Bureau of Indian Standards, New Delhi.
4. IS: 15498 – 2004, Guidelines for improving the cyclonic resistance of low rise houses and other buildings/structures, Bureau of Indian Standards, New Delhi.

Services

Rain Water Harvesting

Suitable Regions

All regions of the country

About the Technology

Rainwater harvesting refers to collection and storage of rainwater and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage, and all other hydrological studies and engineering interventions that are aimed at conservation and efficient utilization of the limited water endowment of physiographic unit such as watershed.

In general, rainwater harvesting is the activity of direct collection of rainwater. The rainwater collected can be stored for direct use or can be recharged into the groundwater. While measures should be taken voluntarily, the authority should also encourage appropriately to provide rainwater harvesting in outdoor built environment.

The system of collection of rainwater and its conservation for future needs has traditionally been practiced in the country through baoris, step wells, lakes, tanks, roof top collection systems, etc, to meet the domestic and irrigation demands. This also helps to arrest groundwater decline and enhance groundwater table, beneficiate water quality in aquifers, conserve surface water runoff during monsoon, reduce soil erosion and inculcate a culture of water presevation.

Two broad approaches to rainwater harvesting are:

a) **Storing rainwater for direct use**: suitable for domestic and irrigation purposes, the rainwater is directly collected either in the natural or man-made structures such as nadi, tanka, kund, sand filter bed, pond, rooftop rainwater collection structure, etc.

b) **Recharging groundwater aquifers:** this approach involves use of various kinds of recharge structures, which not only arrest the water but also promote water percolation through soil strata to recharge the depleting aquifers. Structures like percolation tank, anicut, gabion, etc, facilitate the recharge of underground aquifers. However, meteorological and hydrological investigations along with geo-technical investigations shall be carried out before selecting the best suited method for groundwater recharge.

Components

Catchments area receives rainfall directly. It can be paved like a terrace or courtyard of a building, or unpaved like lawn or open ground. A roof made of RCC, galvanised iron corrugated sheets can also be used for water harvesting. **Coarse mesh** is provided at the roof to prevent the passage of debris.

Gutters are channels all around the edge of a sloping roof to collect and transport rainwater to the storage tank. It can be semi-circular or rectangular and could be made using plain G.I. sheet (20-22 gauge), PVC & Bamboo/betel trunks cut vertically in half. Size should be according to the flow during the highest intensity rain. It is advisable to make them 10 -15% oversize. Rainwater is carried from the catchment area to storage through PVC or G.I. pipes/drains called **conduits**.

Salient Features

1. Storing rainwater helps in recharging the aquifers.
2. It helps in preventing urban flooding due to excess rain.
3. The stored water can be used for irrigation practices in farming region.
4. The water can be used for daily use and help in reducing water bills in the towns and cities.

Economic Aspects

1. Rainwater harvesting methods are site specific. Depending on tank size and climate. Additional expenditure on RWH is essential for future generations.

Sustainability Aspects

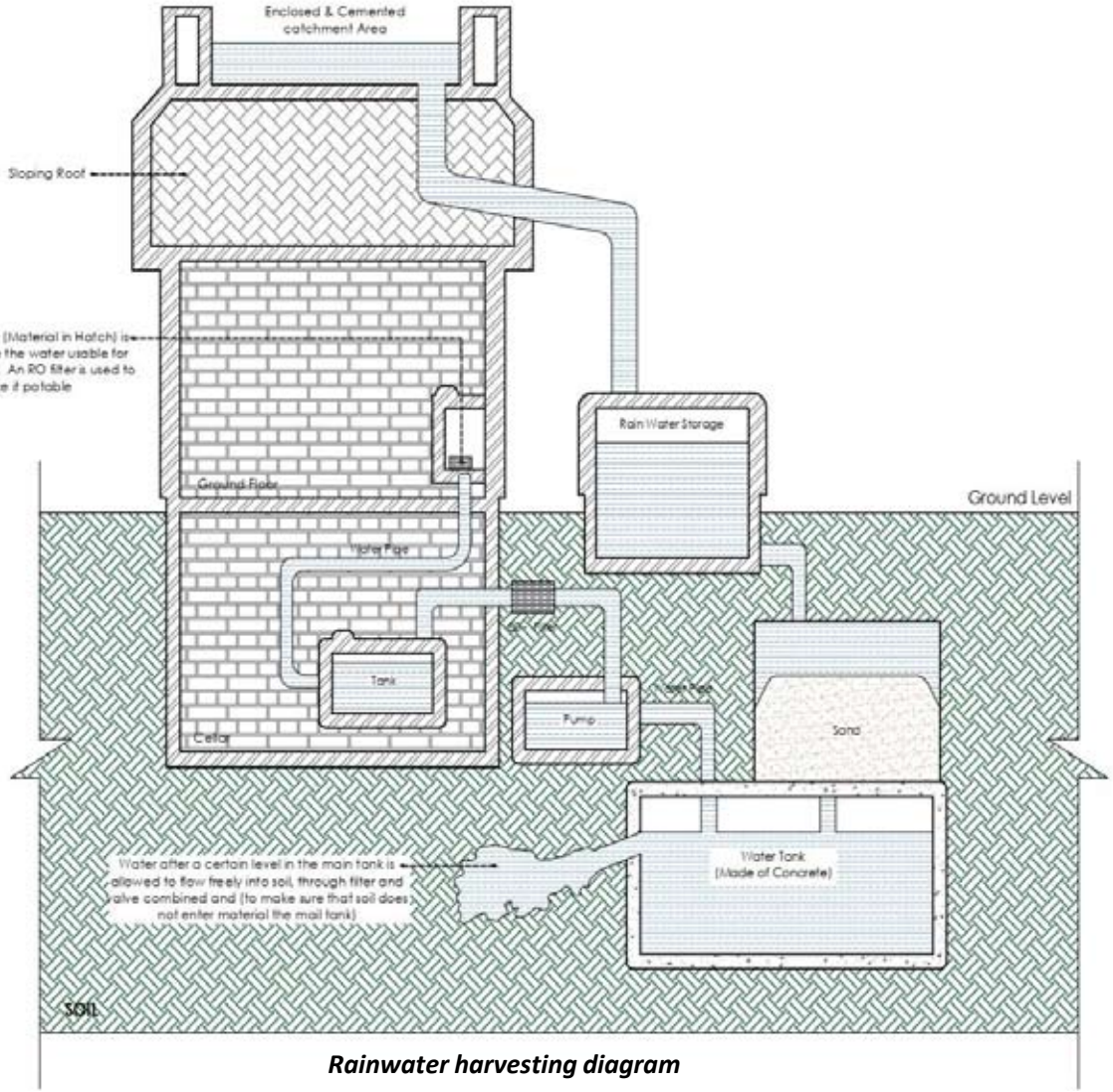
1. It is the most traditional and sustainable method that can be used for potable and non-potable purposes both in residential and commercial buildings.

Limitations

1. All places do not receive the same amount of rainfall.

Market Linkages

1. Components of a rainwater harvesting system are easily available.



Rainwater harvesting diagram

Specifications

Sizing of Rain-Water Pipes for Roof Drainage *(Refer NBC 2016)*						
Diameter Of pipe (mm)	**Average rate of rainfall in mm/h (millimetres per hour)**					
	50	**75**	**100**	**125**	**150**	**200**
	Roof Area (square meters)					
50	13.4	8.9	6.6	5.3	4.4	3.3
65	24.1	16.0	12.0	9.6	8.0	6.0
75	40.8	27.0	20.4	16.3	13.6	10.2
100	85.4	57.0	42.7	34.2	28.5	21.3
125	-	-	80.5	64.3	53.5	40.0
150	-	-	-	-	83.6	62.7

NOTE — *For rain-water pipes of other materials, the roof areas shall be multiplied by (0.013/coefficient of roughness of surface of that material) or refer IS 15797:2008.*

Relevant Standards and References

1. National Building Code Of India (2016), Volume-2, Part- 7.2 of Chapter 11- Approach to sustainability, Bureau of Indian Standards, New Delhi.
2. IS 15797:2008, Roof top rainwater harvesting – Guidelines, Bureau of Indian Standards, New Delhi.

Plumbing and Drainage System

Suitable Regions

All regions of the country

About the Technology

Plumbing and drainage system refers to the entire system of pipeline for providing water supply to the entire building and disposal of waste water from the building.

Plumbing System includes the water supply and distribution pipes; plumbing fittings and traps; soil, waste, vent pipes and anti-siphonage pipes; building drains and building sewers including their respective connections, devices and appurtenances within the property lines of the premises; and water-treating or water-using equipment. It shall be designed, installed and adjusted to use the optimum quantity of water consistent with proper performance and cleaning.

Drainage System consists of construction and maintenance of drains for foul water, surface water, subsoil water and sewage together with all ancillary works, such as connections, manholes and inspection chambers used within the building and from building to the connection to a public sewer/private sewer/individual sewage-disposal system/cesspool/soak away or to other approved point of disposal/ treatment work. A sanitary drainage system consists of a building sewer, a building drain, a soil and/or waste stack, horizontal branches or fixture drain, and vents. The sanitary drainage of a large building may have a number of primary and secondary branches, and several soil and/or waste stacks, each of them in turn may have a number of horizontal branches.

Types of Plumbing and Drainage system

a) **Two-pipe system** is ideal when the location of toilets and stacks for the WCs and waste fittings is not uniform or repetitive. It consists of two sets of vertical pipes, one soil pipe and one waste pipe. Both pipes are separately ventilated by providing separate vent pipe or anti-siphonage pipe and hence has four vertical pipes.

b) **One-pipe system** is suitable for buildings where the toilet layouts and the shafts are repetitive. It requires less space, & is economical. Here, only one pipe is provided which collects both night soil & sullage water

The main pipe is ventilated at the top, in addition to that a separate vent pipe is also provided. Hence, this system has two vertical pipes.

c) **Single stack system** is ideal when the toilet layouts are repetitive and there is less space for pipes on the wall. This system has a single pipe for soil, waste and vent without any separate ventilation pipe. The pipe is extended up to 2m above roof level, capped with a cowl to act as vent pipe. Deep seal traps are used.

d) **Single stack system (partially ventilated)** is an improved form of single stack system, where the traps of the water closets are ventilated by a separate vent pipe called relief vent pipe. Both the pipes, soil pipe and waste pipe, are connected to vent pipe and thus cost is reduced.

Salient Features

1. Two pipe system ensures segregation of sewage from waste water without danger of backflow and hence enables direct use of waste water for gardening.
2. One pipe system requires less shaft space, quick to construct and more economical than two pipe system for multi-storey buildings.

Economic Aspects

1. Ease of construction, lesser space requirements makes one pipe system more economical than two pipe, especially in high rise buildings.

Sustainability Aspects

1. Grey water recycling is a way of reusing the grey water for flushing purposes after it has been filtered and disinfected.

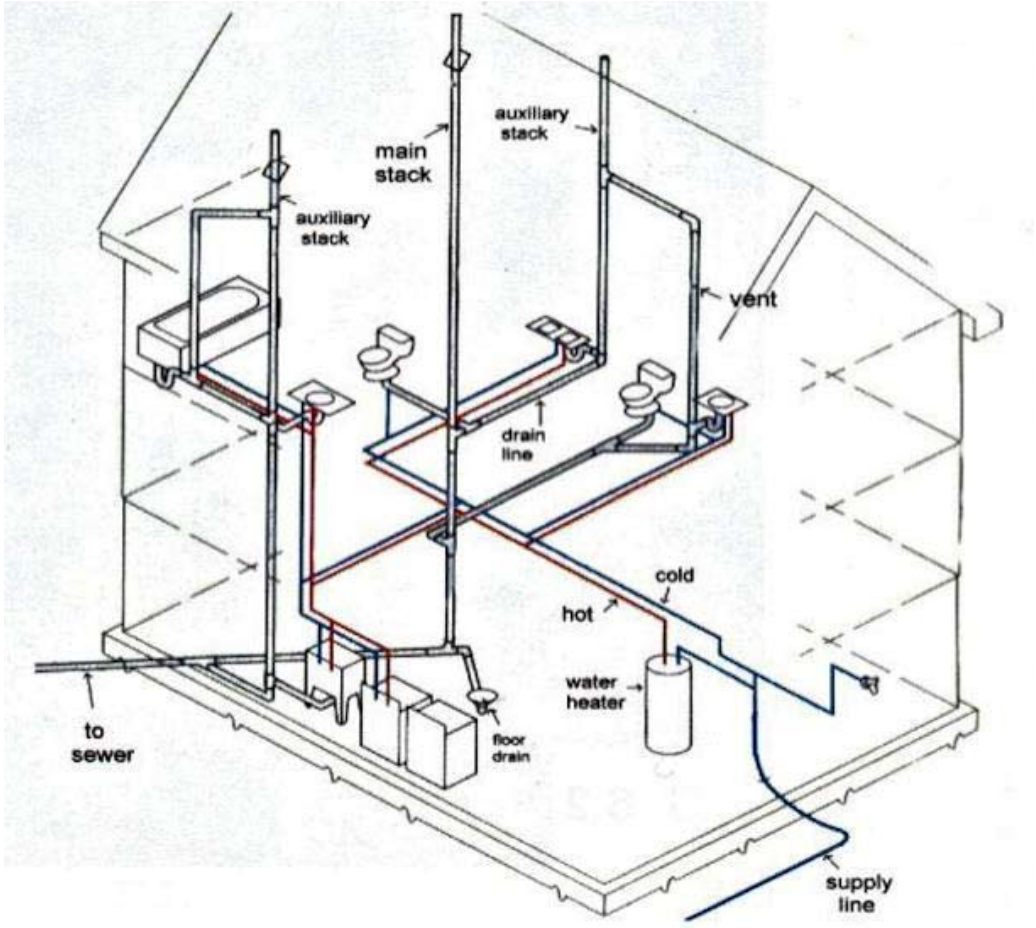
Limitations

1. Two pipe system is difficult to construct in multi-storey buildings.
2. There is danger of backflow in one pipe system.

Market Linkages

1. Components of plumbing & drainage system are easily available in different sizes.

Services



Drainage and plumbing system diagram

Specifications

Size of Drainage and Plumbing pipes *(Refer NBC 2016, IS 1747:1983 and IS 12183:1987)*	
Type of pipe	**Diameter Of pipe (mm)**
Soil pipe	100
Waste pipe (horizontal)	30-50
Waste pipe (vertical)	75
Vent pipe	50
Rain water pipe	75
Anti-siponage pipe	50

Relevant Standards and References

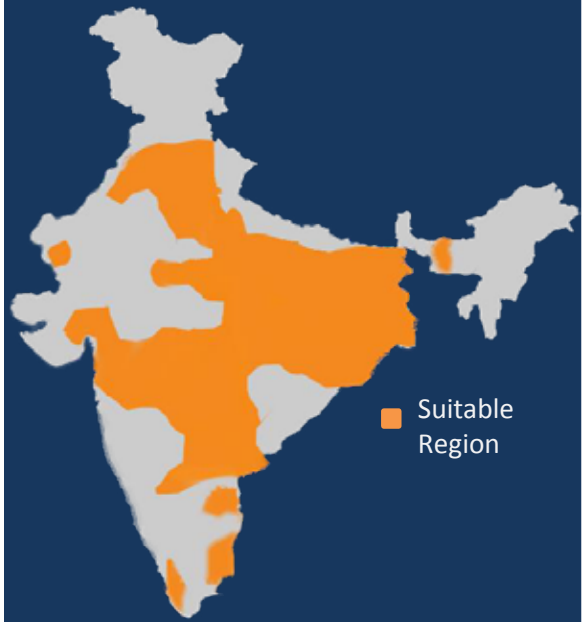
1. National Building Code Of India (2016), Volume-2, Part-9 Plumbing Services, Bureau of Indian Standards, New Delhi.
2. IS 1172 : 1993, Code of basic requirements for water supply, drainage and sanitation (fourth revision), Bureau of Indian Standards, New Delhi.
3. IS 1742 : 1983, Code of practice for building drainage (second revision), Bureau of Indian Standards, New Delhi.
4. IS 12183 (Part 1) : 1987, Code of practice for plumbing in multi-storeyed buildings: Part 1 Water supply, Bureau of Indian Standards, New Delhi.

Materials

Fly Ash Brick

(alternate of conventional Burnt Clay Bricks)

Suitable Regions



Predominantly within 100km radius of a thermal power plant.

About the Technology

A fly ash brick is one, in which min. 50% fly ash has been used as the input material. A fly Ash brick is thus, a brick made up of min. 50% fly ash, the rest is Cement/lime and sand. Water is added to prepare the mix and to perform curing of bricks. It is a masonry unit, and is a 100% replacement/alternative to conventional bricks/red bricks. Government has provided guidelines to all the construction agencies working in the radius of 100km from any coal/lignite based thermal power plant, it is a must for them to use only fly ash based products/components. Fly ash being an industrial waste, is cheaply available in abundance. It is also hazardous to health and environment when loosely dumped in open areas. Thus, utilisation of the same in construction materials, save environment and health of people living in surrounding areas. For details, IS:12894 may also be referred. Being an engineered material it is easy to control the quality of fly ash bricks and get the desired strength and properties.

Material Requirements

Fly Ash	Min. 50% of total input material
Cement	As per the desired properties/strength (usually 6-8%)
Sand	Max 42% (Depends on the desired mix properties)
Water	For mix preparation and curing purpose

Tools and Equipments

a) Pan Mixer b)Moulds c) Vibro Compactor d)Curing tank/equipment

Salient Features

1. A well proven building material and can be used as an 100% replacement of burnt clay bricks
2. Bricks of desired strength can be designed, as per the requirement
3. BIS have issued an Indian Standard code IS:12894-2002 for fly ash bricks
4. Use of fly ash bricks is a part of CPWD specifications
5. These bricks are a part of DSR
6. Fly Ash bricks are environment friendly
7. Can be manufactured right at the construction site
8. Major constituent material being fly ash, these bricks are economical as compared to burnt clay bricks

Economic Aspects

1. Fly Ash bricks are 20% cheaper than regular burnt clay bricks

Sustainability Aspects

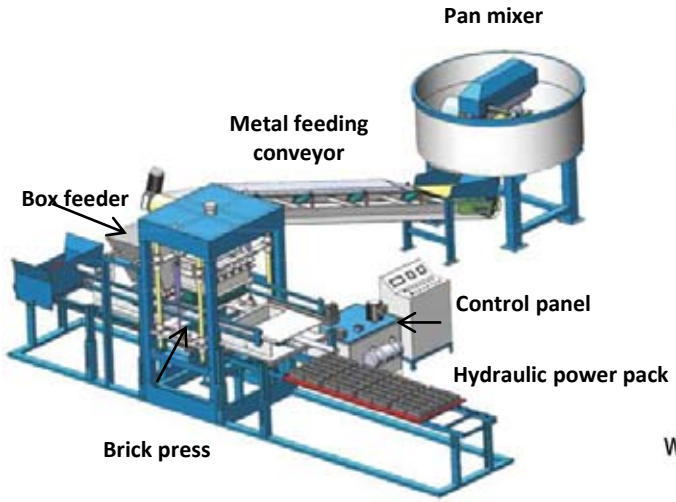
1. Made up of industrial waste material.
2. Carbon footprint is very less than the conventional bricks.

Limitations

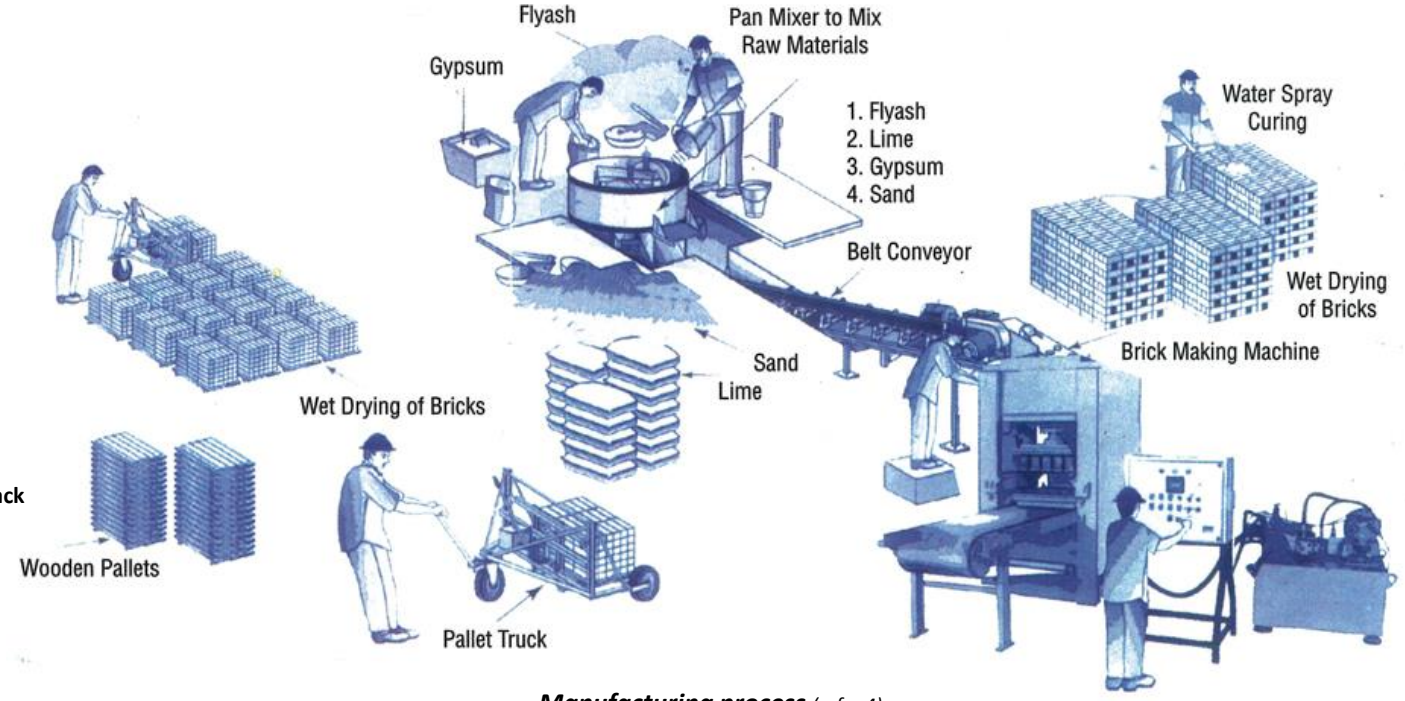
1. May not be easily available in areas where thermal power plants are at a very far distance.

Market Linkages

1. Fly ash bricks can easily be cast at construction site.
2. It can also be produced by small entrepreneurs and supplied to consumers at State/ Block/village level.



Fly ash brick making machine *(refer 3)*



Manufacturing process *(refer 4)*

Specifications

Fly Ash Bricks *(Refer IS 12894)*	**Size** Regular brick size 190mm x 90mm x 90mm (can be moulded in any size to meet specific requirement)
Fly Ash *(Refer IS 15648)*	Grade 1 fly ash only must be used for preparation of such bricks

Relevant Standards and References

1. IS 12894: Pulverized fuel Ash-Lime Bricks-Specifications, Bureau of Indian Standards, New Delhi.
2. IS 15648: Pulverised fuel ash for Lime-Pozzolana Mixture Applications, Bureau of Indian Standards, New Delhi.
3. Fly Ash Brick Machines Manufacturers Suppliers Exporters, http://www.punebusinessdirectory.com/product/fly-ash-brick-machines.html
4. B & B Machines, https://www.bandbmachines.com/.

Rice Husk Ash Concrete
(alternate of cement concrete)

Suitable Regions

Predominantly in regions where rice is grown.

About the Technology

Rice husk is an agricultural residue which is renewable and available in significant amounts. With the annual rice production of 500 million tonnes in developing countries, approximately 100 million tonnes of rice husk is available annually for utilization in these countries alone. RHA, produced after burning of Rice husks (RH) has high reactivity and pozzolanic property. Indian Standard code of practice for plain and reinforced concrete, IS 456- 2000, recommends use of RHA in concrete but does not specify quantities. Chemical compositions of RHA are affected due to burning process and temperature. Silica content in the ash increases with higher the burning temperature. Rice husk is unusually high in ash: close to 20%. The ash contains 92 to 95% silica, highly porous, and lightweight and has very large external surface area. The use of ashes by the grinding process in cement concrete generally improves the properties of concrete. The concretes containing ground RHA are of good quality with reduced porosity and improved resistance to sulphate attack and chloride penetration as well as high strength.

Material Requirements

Rice Husk Ash	Varies, typically 10-20% of total cement requirement
Cement	Depends on quality of RHA and the Grade of concrete being designed
Sand	
Aggregate	

Tools and Equipments

a) Roller Pan Mixer b) concrete pump c) needle vibrator
d) Moulds e) Mixing, casting & handling equipment

Salient Features

1. Utilises Agricultural waste material.
2. Better stability and workability as compared to conventional concrete.
3. RHA concrete has better impermeability and durability because of strengthened transition zones.
4. RHA minimizes alkali-aggregate reaction, reduces expansion, refines pore structure and hinders diffusion of alkali ions to the surface of aggregate by micro porous structure.
5. Environment friendly.

Economic Aspects

1. Studies reveal that RHA Concrete provides an economy of 10%-15%.

Sustainability Aspects

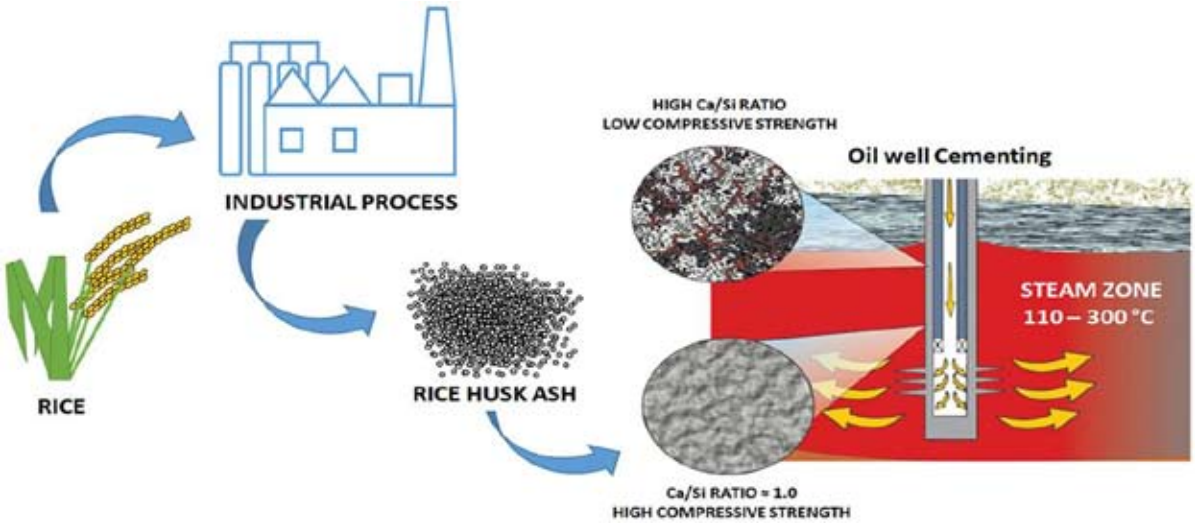
1. Utilization of agricultural waste.
2. Reduced carbon foot print.

Limitations

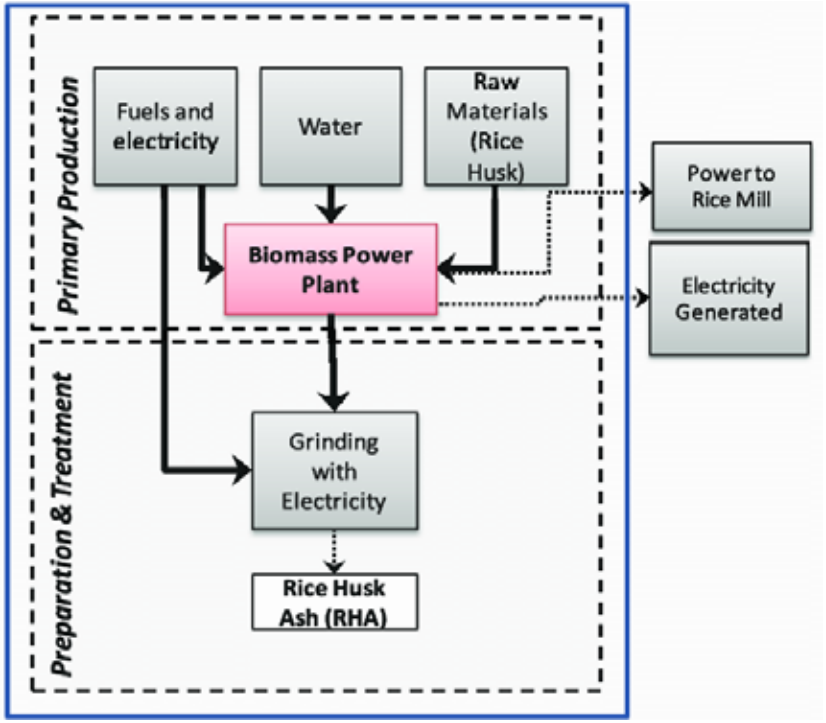
1. May be difficult to get in the parts where rice cultivation is low.

Market Linkages

1. Prepared at the site itself.
2. Beneficial for construction agencies.



Manufacturing process *(refer 3)*



Schematic representation of RHA production. Black arrows represent process flow and dotted arrows show the transportation.
(refer 4)

Specifications

RHA Concrete *(Refer IS 456:2000)*	Suggests the utilisation of RHA in concrete

Relevant Standards and References

1. IS 456-2000, Code of practice for plain and reinforced concrete (Reaffirmed 2016), Bureau of Indian Standards, New Delhi.
2. IS 15648:2006, Pulverized fuel ash for lime-pozzolana mixture applications-specifications, Bureau of Indian Standards, New Delhi.
3. Sustainable cement slurry using rice husk ash for high temperature oil well, Journal of Cleaner Production, Volume 204, 10 December 2018, Pages 292-297.
4. A life-cycle approach to environmental, mechanical, and durability properties of “green” concrete mixes with rice husk ash

Cellular Light Weight Concrete

(alternate of conventional Burnt Clay Bricks)

Suitable Regions

All parts of India

About the Technology

Cellular concrete is a mixture of cement, water, and preformed foam. The purpose of the foam is to supply a mechanism by which a relatively high proportion of stable air voids can be induced into the mixture and produce a cellular or porous solid upon curing of the mixture. Cellular concrete is produced with various densities (volume weights) from 250 kg/m³ to 1600 kg/m³. CFC is harder in comparison with traditional insulation materials, especially when chemical and fire resistance is needed. A light weight cellular concrete is that Solid or hollow concrete blocks, density of which does not exceed 1000 kg/m3 conforming to IS: 3590. formation of cellular concrete require a all the relevant materials and equipment that are required to form conventional concrete, in addition to that we also will need foam concentrate, foam generator and foam injector. Cellular concrete are typically divided into 3 types based on their densities High Density Cellular concrete (Density ranging from 1200 kg/cum to 1800 kg/cum) Medium Density Cellular concrete (800-1000 kg/cum) and light density Cellular concrete (400-600 kg/cum). Portland cement is the normal cementing material. When Portland cement mixes rich in lime are used, very finely ground pozzolanic material, such as scoria, cinders, burnt clay or shale, diatomite or crushed brick, in the proportion of up to 25% by weight of the cement and lime, should be used.

Foam concrete of density less than about 600 kg/m³ is made with neat cement, but when a denser concrete is required, aggregates are included in the mix. Examples of suitable aggregates are sand, stone dust, brick dust, fine gravel, granulated cinders, fly ash. To produce uniform, low density products, sand should be of even particle size and, for the lower densities, relatively fine (passing 0.6 mm mesh).

Material Requirements

Cement concrete	Fly ash	Foaming agent

Tools and Equipments

a) Pan Mixer b) Concrete Pump c) Foam Generator and d) Foam Injector

Salient Features

1. Light in Weight
2. Easy handling
3. Better Fire Resistance
4. Better Thermal Insulation
5. Better acoustic insulation
6. If fly ash based-Eco friendly
7. Cost efficient
8. Better termite resistance
9. Better resistance to freezing issues

Economic Aspects

1. Production cost is comparable to conventional concrete, however, transportation cost is lesser.

Sustainability Aspects

1. Lesser carbon foot print.
2. Low life cycle cost.

Limitations

1. Low compressive strength as compared to conventional concrete.

Market Linkages

1. Ready availability of the technology.
2. Widely accepted technique and products worldwide.

Materials

Manufacturing process *(source: iyantra|CLC)*

Specifications

IS 6042:1969	Code of practice for construction of light weight concrete block masonry
ASTM C 869:2016	Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete
ASTM C 796:2019	Standard Test Method for Foaming Agents for use in Producing Cellular Concrete using Preformed Foam
ASTM C 495:2019	Standard Test Method for Compressive Strength of Lightweight Insulating Concrete

Relevant Standards and References

1. IS 6042:1969, Code of practice for construction of light weight concrete block masonry, Bureau of Indian Standards, New Delhi.
2. ASTM C 869 :2016, Standard Specification for Foaming Agents Used in Making Preformed Foam for Cellular Concrete.
3. ASTM C 796 :2019, Standard Test Method for Foaming Agents for use in Producing Cellular Concrete using Preformed Foam.
4. ASTM C 495 :2019, Standard Test Method for Compressive Strength of Lightweight Insulating Concrete

Bamboo May Corrugated Sheet

(alternate to CGI/Asbestos roofing sheets)

Suitable Regions

North-east India and some other parts of country where structural grade bamboo is available.

About the Technology

Bamboo Mat Corrugated Sheet are an excellent alternative to corrugated metal, plastic or asbestos roofing sheets. They are produced from a natural and sustainable resource and can be used to cover homes, storage facilities, animal pens and many other temporary or permanent structures. Bamboo Corrugated Sheet is made from several layers of woven bamboo mats. These woven mats are impregnated with an adhesive resin and pressed together between two specially designed corrugated pressing plates. The sheets can be produced in a range of sizes to suit particular requirements and can easily be trimmed for special applications. The main materials used are bamboo slivers to produce the mats, and adhesive resin in which to soak the mats. A resin applicator is needed, and a drying chamber is optional. Corrugated pressing plates for the hot press are essential.

The process of producing Bamboo Corrugated Sheet involves 6 steps:

1. Bamboos are split into thin slivers.
2. Slivers are woven into mats.
3. Mats are soaked in adhesive resin.
4. Mats are allowed to drain and dry.
5. Mats are glued together under high temperature and pressure.
6. Sheets are trimmed to shape.

Essentially the process is identical to the production of bamboo mat board, except that the sheets are formed by pressing the mats between corrugated rather than flat pressing plates.

Material Requirements

Bamboo mat	Bamboo slivers
Phenol formaldehyde resin	For soaking mats
Polyurethane	For coating purpose

Tools and Equipments

a) Band Dryer b) Thermic fluid boiler c) Storage tank d) screw compressor e) Resin applicator f) glue spreader, g) Dust extractor e) corrugated pressing plates

Salient Features

1. Better Thermal Comfort than other sheets.
2. Better Appearances.
3. Better flexural strength.
4. Better Impact resistance.
5. Better Noise insulation performance as compared to plastic/zinc sheets.
6. Better thermal insulation.

Sustainability Aspects

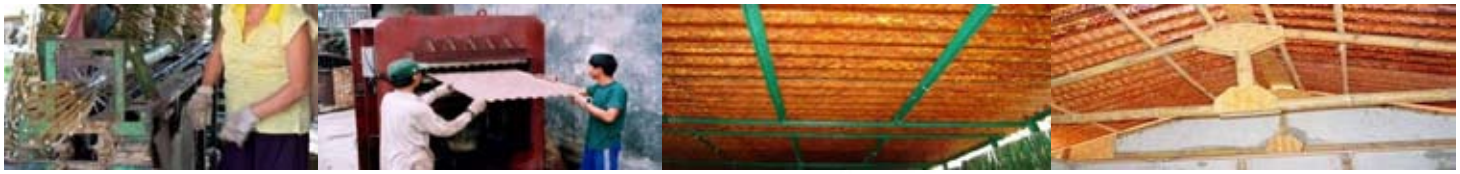
1. Eco Friendly.
2. Very less carbon footprint.
3. Local employment generation.
4. Utilisation of local resources.
5. Bamboo is available in abundance.
6. Energy efficient.

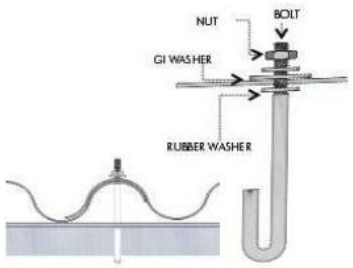
Limitations

1. May not be economical at places where bamboo is not easily available.

Market Linkages

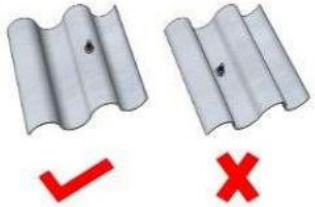
1. Beneficial for MSME.
2. Low investment-High return.
3. Can be produced locally.
4. Easy availability of raw material.
5. Availability of up to 75% working capital loan.





BMCS are anchored to bamboo purlins Using J bolts

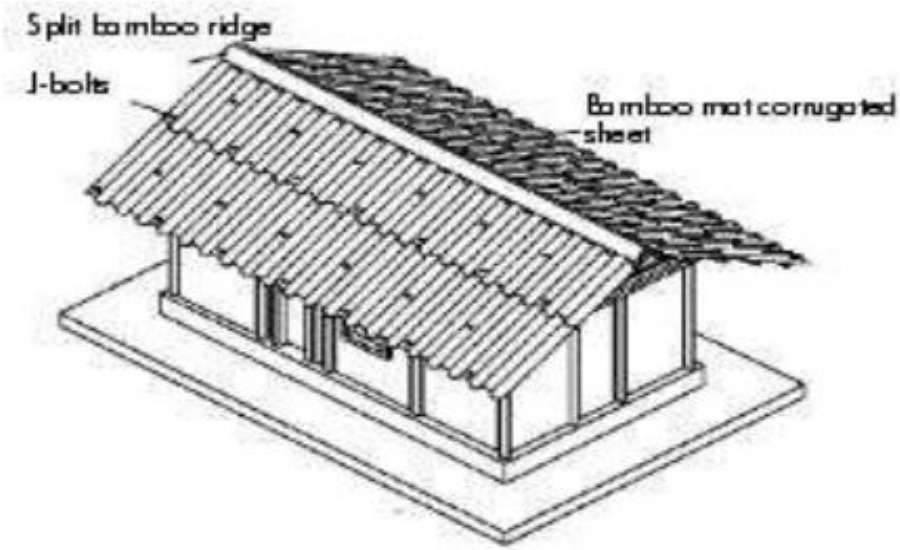
Detail showing how BMCS are joined to bamboo purlins using J bolts at the crest



BMCS should be bolted at crest not trough.

Detail showing overlap of BMCS .

Joinery details of Bamboo mat corrugated sheet
(source: Corrugated Bamboo Roofing Sheets*)*



Complete house with Bamboo mat corrugated sheet roofing
(source: Corrugated Bamboo Roofing Sheets*)*

Specifications

IS-5476:1986	Bamboo Mat corrugated sheet-specifications
IS-13958:1994	Bamboo mat board for general purposes– Specification
IS 1902:2006	Code of practice for preservation of bamboo and cane for non-structural Purposes
IS 4905:1968	Methods of random sampling

Relevant Standards and References

1. IS-5476:1986, Bamboo Mat corrugated sheet-specifications, Bureau of Indian Standards, New Delhi.
2. IS 13958:1994, Bamboo mat board for general purposes – Specification, Bureau of Indian Standards, New Delhi.
3. IS 1902:2006, Code of practice for preservation of bamboo and cane for non-structural Purposes, Bureau of Indian Standards, New Delhi.
4. IS 4905:1968, Methods of random sampling, Bureau of Indian Standards, New Delhi.
5. Corrugated Bamboo Roofing Sheets, INBAR technology pages.

Compressed Earth Brick/Block

(alternate of conventional Burnt Clay Bricks)

Suitable Regions

All parts of India

About the Technology

Compressed earth blocks have been in use since hundreds of years, The first steel manual press which has been produced in the world in the 1950's was the Cinvaram. It was the result of a research programed for a social housing in Colombia to improve the hand moulded & sun dried brick (adobe). This press could get regular blocks in shape and size, denser, stronger and more water resistant than the common adobe. Since then many more types of machines were designed and many laboratories got specialized and skilled to identify the soils for buildings. Many countries in Africa as well as South America, India and South Asia have been using a lot this technique.

The soil, raw or stabilized, for a compressed earth block is slightly moistened, poured into a steel press (with or without stabilizer) and then compressed either with a manual or motorized press. CEB can be compressed in many different shapes and sizes.

Not every soil is suitable for earth construction and CSEB in particular. But with some knowledge and experience many soils can be used for producing CSEB. Topsoil and organic soils must not be used. Identifying the properties of a soil is essential to make good quality products. Some simple sensitive analysis can be performed after a short training. Cement stabilization will be better for sandy soils. Lime stabilization will be better suited for clayey soils.

Material Requirements

Good Soil	Gravel= 15%
	Sand= 50%
	Silt= 15%
	Clay= 20%
Stabilizers	**Proportion**
Cement (sandy soil)	3% (min.)to 5%
Lime (clayey soil)	2% (min.)to 6% (10% max.)

Tools and Equipments

a) Mixer b) Moulds c) needle vibrator d) Compressors

Salient Features

1. CSEB uses a biodegradable material that is locally available. Thus, it saves the transportation, fuel, time and money.
2. Firewood is not needed to produce CSEB, thereby limiting deforestation.
3. Produced locally, with a natural resource and semi skilled labour, it is a cost effective material.
4. Being produced locally it is easily adapted to the various needs: technical, social, cultural habits.

Economic Aspects

1. CSEB are cheaper than fired bricks, offering an economy of approximately 20%.

Sustainability Aspects

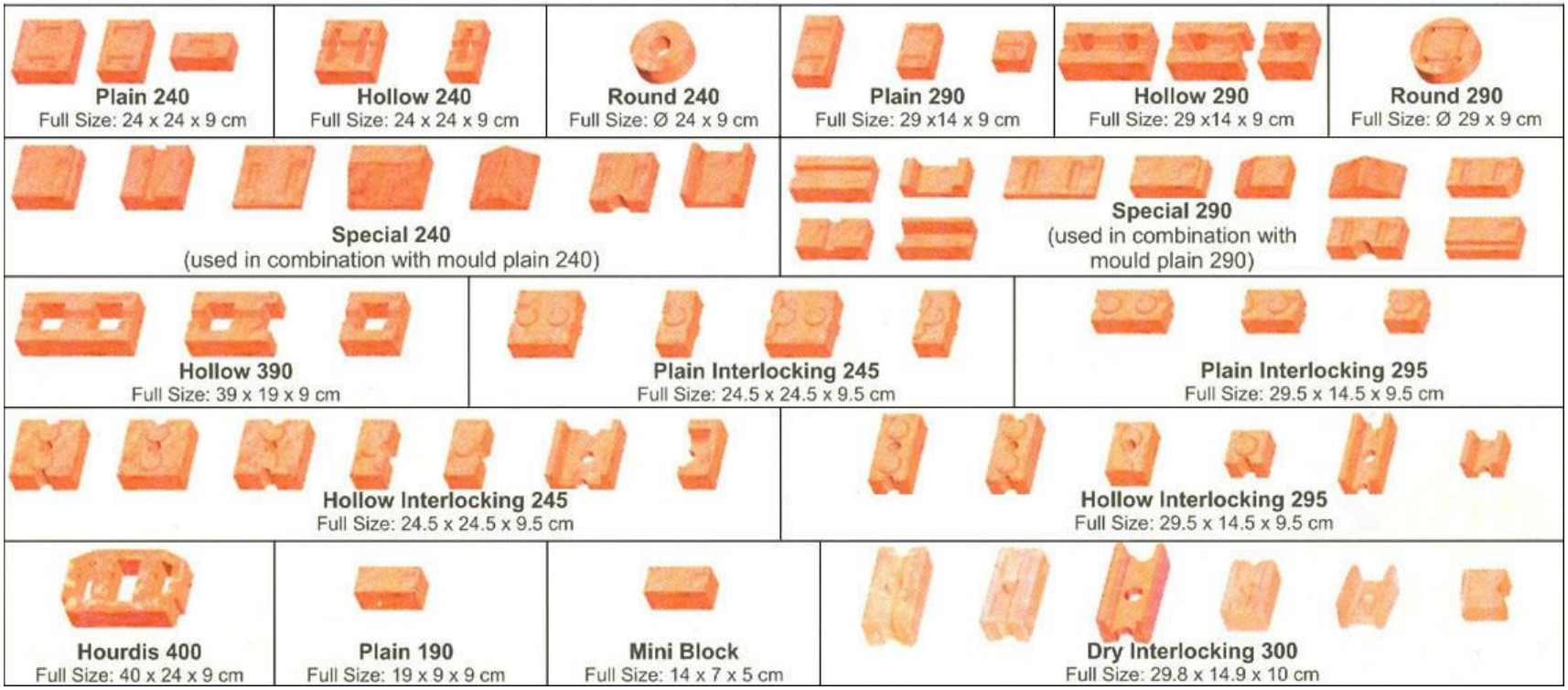
1. The production of earth-based materials consumes much less energy (15.1 times less than country fired bricks) and pollutes much less than fired bricks (7.9 times less), thus, are much more eco-friendly.

Limitations

1. Wide spans, high & long building need special considerations.
2. Low technical performances compared to concrete.
3. Under-stabilization resulting in low quality products.
4. Proper soil identification is required.

Market Linkages

1. Prepared at the site itself.
2. It can also be produced by small entrepreneurs and supplied to consumers at State/ Block/ village level.



Different sizes of compressed earth blocks *(source: Auroville Earth Institute)*

Specifications

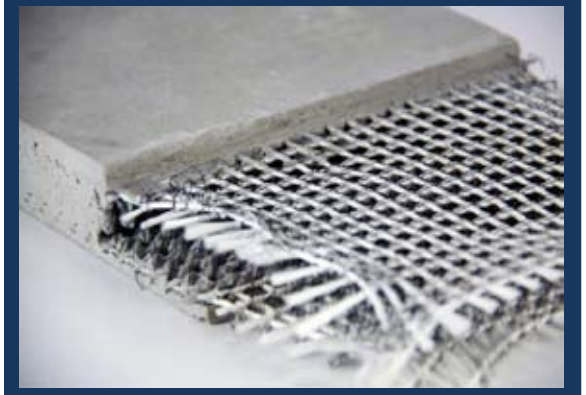
ARS 680:1996	Production of Compressed earth blocks
ARS 681:1996	Preparation of earth mortars for Compressed earth blocks
ARS 682:1996	Assembly of Compressed earth blocks masonry

Relevant Standards and References

1. ARS 680: 1996 - Compressed earth blocks - Code of practice for the production of compressed earth blocks.
2. ARS 681: 1996 - Compressed earth blocks - Code of practice for the preparation of earth mortars.
3. ARS 682: 1996 - Compressed earth blocks - Code of practice for the assembly of compressed earth block masonry
4. Auroville Earth Institute, http://www.earthauroville.com/auram_earth_equipment_introduction_en.php

Textile Reinforced Concrete

(alternate of conventional cement concrete)



Suitable Regions

All parts of India

About the Technology

Reinforced concrete (RC) is one of the most widely used building materials in the construction industry in the past and present century. However, the major disadvantage of RC is that its steel reinforcement is prone to corrosion. Textile reinforced concrete (TRC) is an innovative composite material that is making rapid strides in the construction industry, across the globe.

TRC comprises of fine-grained high quality cementitious matrix and non-metallic alkali-resistant textile as reinforcement. The reinforcing textile can be of alkali resistant glass, carbon, polypropylene, aramid and so, which are economically and/or functionally superior to classical steel reinforcement in many applications. The textile made of treated coir, bamboo, jute, etc. are also the potential candidates for textile reinforcement. High corrosion resistance of non-metallic fibres and low self-weight of textile allows production of lightweight and thin walled elements. With excellent material properties, most notably freedom from corrosion, lightness and flexibility, textile reinforcements have the potential to greatly transform the construction industry. TRC is also expected to revolutionize the rehabilitation and maintenance of structures, as the corrosion damage and the subsequent high maintenance costs were the major challenges with the steel reinforced concrete.

TRC products developed by CSIR-SERC, Chennai, can be used for a variety of applications in roofing, walling and flooring. A novel technology was also developed to produce light-weight TRC tiles of different shapes and sizes for wall/flooring applications. Besides these, TRC can also be used as a repair, rehabilitation and retrofit material.

Material Requirements

TRC Panels for walls, floors and roofs TRC tiles	Cement concrete Alkali-resistant textile

Tools and Equipments

a) Mortar mixer machine b) MASS TRCPT unit

Salient Features

1. Completely avoids the conventional way of concrete construction, which makes use of moulds.
2. Various products for structural and non-structural applications can be produced from this single technology.
3. Less fabrication cost with increased production rate.
4. Flexible and light weight material which is non-corrosive and durable.
5. Unskilled manpower can be deployed for production of TRC panels.
6. TRC panels can withstand rough weather conditions.
7. Formwork not required for TRC panel casting.
8. TRC panels can be aesthetically designed without any additional cost during fabrication.

Economic Aspects

1. TRC is cheaper as it consumes approximately 60% less concrete than steel reinforced concrete.

Sustainability Aspects

1. TRC offers enhanced environmental performance as it requires less concrete.

Limitations

1. The alkali resistant textile should be carefully selected based on the quality of bond with concrete, corrosion and temperature resistance, cost as well as environmental impact.

Market Linkages

1. Using TRCPT, TRC sheets are prototyped to produce products of various shapes and forms by appropriately choosing the cementitious matrix and textile combinations.
2. Technology is available for transfer to interested players in the industry.

Materials



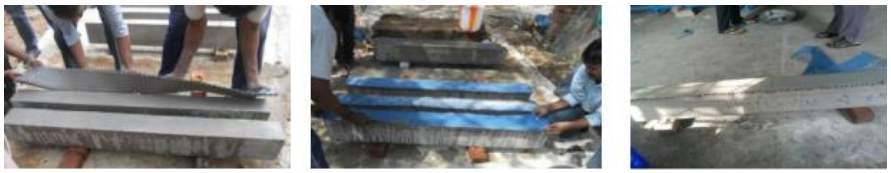



Plinth Panel ***Wall Panel*** ***Crash barrier*** ***Door Panel*** ***Roof Panel*** ***Tiles***

TRC products developed at CSIR-SERC*(source: CSIR-SERC)*

Construction of TRC toilet - various stages *(source: CSIR-SERC)*

Lining of a damaged canal using TRC produced from TRCPT *(source: CSIR-SERC)*



Demonstration of strengthening of RC beam using TRC produced from TRCPT *(source: CSIR-SERC)*

TRC products produced using TRCPT *(source: CSIR-SERC)*

Specifications

Precast TRC Panels for wall, floor and roofing applications	**Size**: custom-made to any shape and size without using moulds. Thickness Varies from 15mm to 25mm.
TRC tiles for industrial flooring	**Size**: 300 x300x 15mm. **Abrasion resistance:** 1.9mm **Water absorption**: 6% **Wet transverse strength**: 4.8MPa.

Relevant Standards and References

1. CSIR- Structural Engineering Research Centre, Press-Release-TRC-16.6.2017, https://serc.res.in/sites/default/files/Press-Release-TRC-16.6.2017.pdf
2. Textile reinforced concrete prototyping technology, CSIR- Structural Engineering Research Centre, https://serc.res.in/sites/default/files/TRCPT.pdf

CSIR-Central Building Research Institute, Roorkee
Ministry of Science and Technology, Government of India

Building Materials & Technology Promotion Council,
Ministry of Housing & Urban Affairs, Government of India