<u>**RELIABLE ICF**</u>

Suitable for low rise to medium rise buildings
(4 storey showroom, Indore)

ICF Technology
This technology replaces the RCC framed construction method of columns and beams . Instead, f**ully load bearing, monolithic, fire and disaster resistant walls with 150 mm monolithic concrete core sandwiched inside two layers of 50 mm thick, high density panels molded from EPS (Expanded Polystyrene cellular plastic foam).**

Lightweight, inter-locking forms molded from high density, non toxic and self extinguishing grade EPS are held together with hard plastic ties. These are easily assembled on site to hold reinforced concrete. Thus, a speedily erected shuttering system later provides a high degree of thermal and acoustic protection, making the structure 60-80% energy efficient when compared with un insulated masonry.

A high thermal resistance (R-value), above 3 K·m^2/W, results in saving energy throughout the building life that spans generations.
The insulation ensures further protection of the building against cracks and damages due to weathering and ageing caused by thermal stress.

As sound penetrates ICF walls only 1/8 to 1/4 as compared to conventional walls and an unbroken exterior envelope results in fewer cold spots and drafts, ICF structures provide comfortably quieter interiors.

There are no constraints related to design, render, cladding and finish.

Buildings go up faster and with fewer safety concerns as compared to other wall systems. Requirement of less skilled workers, reduce worker injuries with lightweight materials , no specialised equipments or heavy tools are added bonus.

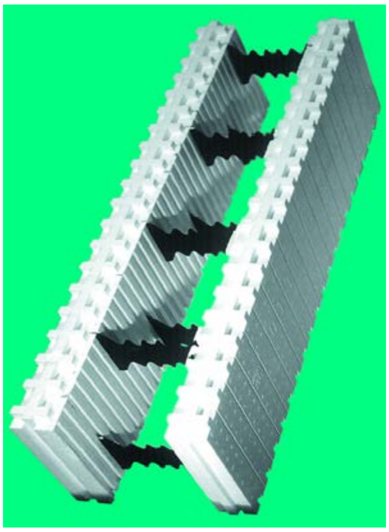
The unique combination of time and resource conservation at all stages with very low embodied energy for an extremely strong construction makes it an ideal 'green building' system.

1. Basic Requirements

(Ground Floor Walls at Theog, near Shimla)

Formwork

Formwork is interlocking and lightweight, to ensure ease of transportation, handling and assembly.



Hard plastic ties are in situ

molded to hold the EPS panels in place. Edges are sealed with EPS molded end pieces and Lintels over openings encased in insulating Lintel ICF for complete thermal protection and zero thermal bridges.
The forms can be cut to facilitate any design requirement such as arches or high ceilings.

Footings

The footings for ICF buildings are usually reinforced concrete rafts or strips that are flat and even enough to enable stacking of the EPS molded panels, with reinforcement starter bars set ready to connect with the concrete when poured into the formwork.

Concrete

Walls are strong due to 150 mm concrete Core, designed as per IS456:2000 and IS:875 for earthquake resistant design . Concrete poured is of grade M-20 inside 50 mm hollow panels of EPS formwork on both sides.
RMC, whenever used is as under the Indian Standard Specification IS4926:2003

(Concrete Pouring in ICF walls at New Delhi site)

Reinforcement

Steel bars of dimensions conforming to structural design as per IS456.

Accessories

Trestles designed for support from inner side during concrete pouring to ensure straight walls are used every 1-1.5m apart.

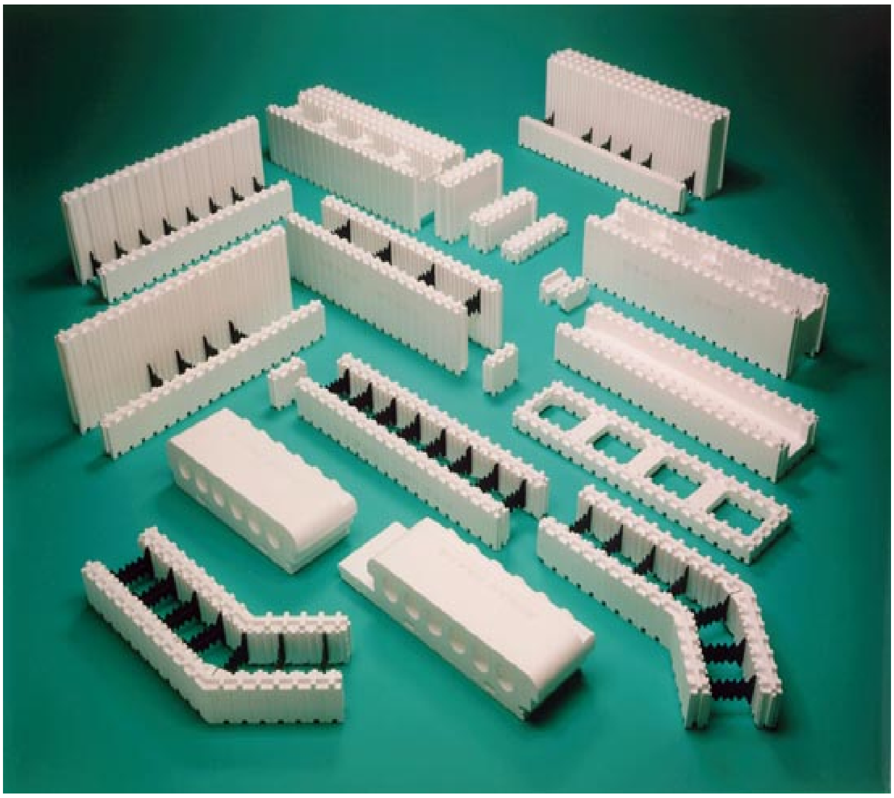
2. Details of formwork

6 different molded insulating building blocks (designed for use in all types of structures) that have different applications during wall erection.

Specifications Chart :
Dimensions (mm)

Name	***L***	***H***	***W***	***Function***
Standard	1000	250	250	makes up the basic formwork for wall construction
Lintel	1000	125	250	placed above doors and windows to make thermal bridge free buildings and to hold concrete above lintel
Half height	1000	150	250	used together with lintel for covering openings in walls and to hold Steel rebars
Floor edge	1000	375 / 125	250	used for seamless insulation of roof/floor concrete
Corner	750 /500	250	250	placed at all corners for straight and smooth edges . Result, strong buildings.
End piece	150	125	50	seals all openings for ensuring zero heat infiltration

ICF building blocks



3. Structural Details

Load bearing walls

All external walls made from ICF are fully load bearing walls. To prevent voids and fast curing without any additional water, specifications for slump and aggregates are Slump 130 to 150 and aggregates size < 10mm.

During concrete pouring, vibrators are used to further consolidate the concrete.

Resultant walls are smooth and straight, require only 5-8 mm plaster finish instead of the commonly seen undesirable thickness to hide structural blemishes or undulations.

(Basement, Gr. Noida)

Non load bearing walls

These are internal partition walls that can be either brick masonry or drywall.

Wall cladding

All standard cladding, render or finishing products can be applied on the smooth EPS surface, over a fibre glass reinforced base coat and waterproof cement plaster finishing top coat.

(Guard House with slip bricks)

Roof

Either flat RCC slab or sloping. It is also uniformly insulated on the external surface for 100% structural protection.

Final finishing layer is a fibre reinforced waterproof plaster on sloping roof or tiles grouted over suitable gradient provided on terrace.

(Sloping Roof on Cottage, Theog)

Doors and windows

Insulated doors and UPVC frame with double glaze glass to maintain high insulation value of structure.

Once openings have been made during the formwork assembly & concrete poured, they can accommodate window and door frames of any type.

Finishes

Typically, the main finish is a render or render-equivalent covering or paint. Any additional cladding can be added to the ICF walls subject to making appropriate supports for it, although many sheet finishes, such as plasterboard, can be glued directly to the surface of the formwork.
External renders require a base or skim coat embedded with fibreglass mesh, followed by a second coat and then a texture coating, finally finished with an 'top coat'.

4. Installation process

After foundation, footers and rebars as per the required design specifications are in place, the forms are assembled and horizontal and vertical rebars are put into place to build the walls.
Trestles for bracing is installed for secure and plumb walls, before the cavity is filled with poured or concrete pumped in.
When the ICF walls reach the desired height, the roof, windows and doors are ready to be installed.
Wiring is installed using a hot-knife, interior drywall and exterior finishes are done at this stage.

(Double height Godown Walls,Gr. Noida)

Utilities installation

The points at which utilities connect to the building needs to be identified prior to the pouring of concrete. This allows for conduits to be placed through the wall so that the utility can enter.

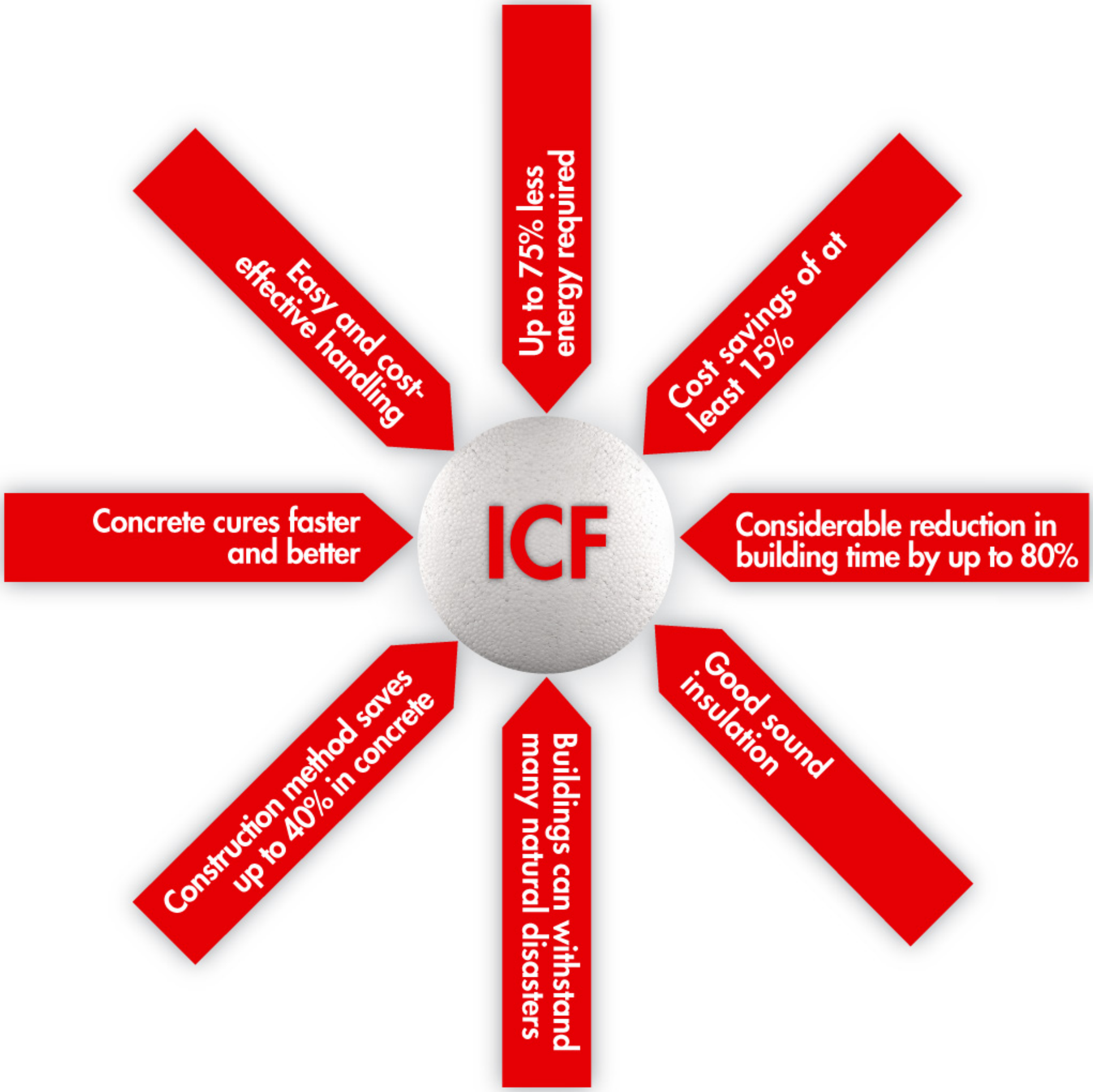
Once the concrete is poured and cured, channels or grooves are cut directly into the form using and electric hot knife or router. Plumbing and electrical lines are then inserted into the grooves and covered by drywall.

5. Manufacturing

Manufacturing process is environment friendly and product foam conforms to IS4671. Standards and procedures as per ISO 9000 and ISO 14000 are strictly followed to ensure consistently high quality levels.

RELIABLE ICF MOLDING MACHINE

6. Performance Evaluation



Green technology

Judging by the parameters of sustainability and energy efficiency
the embodied energy of ICF is known to be substantially low when compared to other methods for attaining similar levels of energy saving.

Sustainability criteria for selection of building materials is that they should score well in most or all of the following areas.
Materials should be :

- Low energy
- Low CO_2 emissions
- Sourced locally
- Reusable and recyclable
- Minimum waste generating

• Non-polluting
• Renewable

The use of ICF for buildings fits well with all of the above criterion.
The monolithic concrete core forms a tight air barrier, with penetrations (e.g. windows and doors) which are easy to identify and seal.
Time has no impact on these materials. EPS has a consistent R-value for the full service life of the wall and the concrete core inside is prevented from all cracks and ageing due to zero thermal stress.

Environmental Impact

Construction with ICF is a highly responsible way of using limited resources with concrete, insulating foam and steel for long-life, energy efficient structures.
As ICF has a very long life, the energy investment is recouped over many decades. The energy saving attributable to ICF means that, compared with conventional construction methods, ICF effectively recoups its own energy cost of manufacture within 12 months. The reduced consumption of steel and concrete (very high embodied energy) further improves the sustainability of ICF buildings in comparison to conventional ones.

Thermal behaviour

The energy effectiveness of an ICF wall is due to three important factors :
Continuous R-value, Reduced air infiltration, and Thermal mass moderation.
ICF exterior walls typically require 80% less energy to heat and 60% less energy to cool than comparable frame houses .
Insulation is permanent as the R-Value of EPS formwork does not degrade with the passage of time. Starting from R-18, the range can be further increased to R-26.

Thermal Properties of ICF Insulation & Concrete

Property	Insulation	Concrete
Thickness (each layer)	50 mm	150 mm
Density	24 kg / m^3	2,350 kg /m^3
Thermal Conductivity	0.034 W / mK	1.4 W / mK
Specific Heat	1,210 J / m^3	880 J / m^3
Volumetric Heat Capacity	19,360 J / m^3	20,68,000 J / m^3
Thermal Resistance	1.8 m^2K / W	0.1 m^2K / W

Mechanical Properties

With the combination of a heavy, high-strength material (reinforced concrete) between two layers of a light, high-insulation panels, the ICF buildings enjoy a unique set of desirable properties -
air tightness, strength, sound attenuation, insulation, and mass.

7. Significant features

Wall strength

The structural details for the test specimens were adopted based on design recommendations and guidelines for typical exterior wall panels in earthquake zones 1 or 2, and for minimum wind speed of up to 70 miles per hour. The test setup and procedure followed general guidelines of ASTM E564-95, Standard Practice for Static Load Test for Shear Resistance of Framed Walls for Buildings.
The amount of load was gradually increased while any major distress, cracking, or damage was observed and recorded. The loading was typically continued beyond the peak loading capacity of each wall and testing terminated when the strength of each wall was significantly reduced due to excessive damage to the wall specimens.
The frame walls showed initial damage at relatively light loading and had a much lower maximum lateral resistance. The ICF walls resisted a maximum lateral load 6 to 8 times the maximum loads resisted by the frame wall panels. Under lateral loads of about twice as much as the maximum resistance of the frame walls, the ICF panels were still very stiff, with extremely small deformation, and showed no damage.

In-Plane Shear Wall Testing and Loading Results :

Global Lateral Stiffness at 1/3 the maximum lateral force resistance for the wood and steel frame, at a lateral load of 5,000 lbs. for the ICF walls.
When subjected to lateral in-plane loading from sources such as wind or earthquake, the ICF wall panels are not only considerably stronger but also much stiffer than the framed wall panels.

Wall Panel	Global Lateral Stiffness (lbs/in)1	Load at First Major Damage (lbs)	Displacement at First Major Damage (in)	Maximum Lateral Resistance (lbs)	Displacement at Maximum Lateral Resistance (in)
Wood Frame	18,500	3,500	0.51	4,553	0.89
Steel Frame	30,000	3,500	0.54	4,004	0.76
ICF Flat	708,000	8,500	0.06	34,245	2.66

The higher strength of ICF walls enable concrete homes to resist winds and earthquakes of much higher magnitudes.
The higher stiffness demonstrated by the ICF wall panels at the loading limits of the frame wall systems, would result in smaller lateral deformation and prevention of potential

damage to non-structural elements of a home such as finishes and trim. In the case of moderate earthquakes, the repair cost of the damaged non-structural components is usually the major, and sometimes the only part of the restoration costs. ICFs offer great potential for reduced property loss from strong wind and earthquakes.

Load bearing capacity

The solid concrete core provides greater impact resistance and will withstand winds of up to 402 kph (250 mph) ensuring that safety and security in almost any situation.

Thermal mass advantages

Concrete mass in exterior walls reduces annual energy costs.
The ICF concrete core offers the characteristic thermal mass qualities of heat absorption and thermal lag.
The additional insulation further delays the transfer of heat to the inside of the building. This combination serves to reduce and delay peak loads, which may result in lower off-peak energy pricing and reduced HVAC equipment size.
In climates with large diurnal temperatures swings, the mass wall can release absorbed heat energy to the cooler night air, a process called heat flow reversal.
The ICF wall moderates indoor temperature swings and reduces the amount of heating/ cooling needed.

Durability and safety

Withstanding earthquakes, high speed cyclonic winds and floods.
ICF builds are built to last, and retain its value longer.
The main structural element is reinforced concrete which offers substantially better durability and requires less maintenance and repair over its lifetime compare to other structures that require regular maintenance over limited life span.

Fire Resistivity

Concrete is one of the most resistant building materials to heat and fire.
They are more resistant to allowing fire to pass from one side of the wall to the other.
The fire wall test confirms this, it measures how well the wall slows the passage of heat and fire from the side with the flame to the other side.
The ICF walls did not allow flames to pass directly through. It also took 2-4 hours before the ICF walls allowed enough heat through to start a fire on the cool side.
The insulation in ICFs are manufactured with flame-retardant additives. These prevent it from burning by themselves. If you hold a match to the material, it will melt away.

8. Impact and Natural Disasters Resistance

Wind Resistance

ICF wall was undamaged by the direct impact of the debris at over 100 mph.
The concrete stopped the debris from travelling through the wall. Exterior finishes were damaged by the impact, but the concrete walls themselves remained unscathed. The strength and durability of concrete walls formed with ICFs offer unmatched resistance to the devastation of major storms.

Table : Concrete Wall Test Results

Wall Type	**Test Wall Description**	**Speed of Debris**	**Results**
Concrete	6" thick reinforced concrete wall, #4*(D12)* vert. reinforcing bars, 12" *(300mm)*o.c., no finishes.	109.0 mph	No cracking, front face scabbing, or back face spalling of concrete observed.
Concrete	6*" (150mm)*thick reinforced concrete wall, #4 vert. reinforcing bars, 24" o.c., no finishes.	102.4 mph	No cracking, front face scabbing, or back face spalling of concrete observed.
ICF	Block ICF forms, 6" thick flat concrete wall, #4 vert. reinforcing bars, 12" o.c., vinyl siding. (Tested a second time with similar results)	103.8 mph	Debris penetrated vinyl siding and foam form. No cracking, front face scabbing, or back face spalling of concrete wall observed.
ICF	Block ICF forms, 6" thick flat concrete wall, #4 vert. reinforcing bars, 24" o.c., 3" brick veneer with ties spaced 1'-0" each way.	99.0 mph	Debris penetrated and cracked brick veneer. EPS form dented. No cracking, front face scabbing, or back face spalling of concrete wall observed.

Note : All concrete tested : 3000 PSI *(210 Kgf/cm^2)* compressive strength, maximum aggregate size ¾", 6" slump.

9. Seismic Performance

In reinforced concrete construction, the combination of concrete and steel provides the three most important properties for earthquake resistance : stiffness, strength, and ductility.
Reinforced concrete walls are a composite system: Concrete resists compression forces, and reinforcing steel resists tensile forces produced by an earthquake.
The concrete is cast around the bars, locking them into place. The exceptional ductility of the steel to resist tensile forces, coupled with the rock-like ability of concrete to resist compression.
Studies of earthquake damage consistently show well-anchored shear walls are the key to earthquake resistance in low-rise buildings.
In ICF walls, these elements are designed to survive severe sideways (in-plane) forces, called racking and shear, without being damaged or bent far out of position.
Shear walls are well anchored to the foundation structure to work effectively. Properly installed steel reinforcing bars extend across the joint between the walls and the foundation to provide secure anchorage to the foundation.

A research was carried out in order to asses an ICF tilt-up wall system with regard to the requirements of the actual earthquake resistant design of reinforced concrete wall systems and reinforced concrete wall equivalent dual systems.
A simple comparison of the resistant bending moments with the values of the design bending moments reveals that for low values of the normalized axial force, with a correspondent small number of floors, up to 7 storeys for concrete wall 150 mm thick concrete walls, even in the

most powerful seismic region of the country, characterized by a ground acceleration of 0.32g, the ordinary primary wall structures behave in the elastic range under the design earthquake spectrum.

10. Blast Resistance

Concrete has demonstrated blast resistance through tests.
The blast-resistant properties of ICF building systems have been successfully demonstrated in tests in the US, including those carried out in Marine Corps Base.
Eleven separate ICF boxes, weighing 13 tons apiece and with walls measuring 8 feet tall and 6 inches thick were subjected to explosion from 50 lbs of TNT at differing distances (3.5 feet to 10 feet) and to pressures from 300 pounds per square inch (psi) to over 7,000 psi.
Known for decades for its impact resistant properties, expanded polystyrene (psi), the primary material in ICFs, has recently shown great potential as a blast-resistant product. In each instance during six different blast demonstrations, EPS compressed against the face of the concrete wall and reduced the pressure of the blast.
The concretes in ICF often have a compressive strength exceeding 14,500 psi *(1020 Kgf/cm2)* and contain steel fibers. These blast-resistant structures are often used in bank vaults and military applications.

11. High Humidity and Wind-Driven Rain

Concrete is not affected by wind-driven rain and moist outdoor air in hot and humid climates because it is impermeable to air infiltration and wind-driven rain. Moisture that enters a building must come through joints between concrete elements. Interlocking insulation layer without any leaks minimizes this potential. More importantly, if moisture does enter through joints, it will not damage the concrete.
As EPS is water impermeable it is an effective vapour barrier.

12. Acoustic behaviour

The level of sound attenuation achieved is a function of wall thickness, mass, component materials and air tightness.

ICF walls have much lower rates of acoustic transmission.
Standard thickness ICF walls have shown sound transmission coefficients (STC) between 46 and 72. This Sound reduction within the structure and airborne external source compares favourably againt Standard delivery of a sound transmission class (STC) rating of around 36 for standard fiberglass insulation and drywall.

Sound transmission loss measurements conducted on similar ICF constructions using ASTM E966-92 “Standard Guide for Field Measurement of Airborne Sound Insulation of Building Facades and Facade Elements,” and ASTM E1332-90 “Standard Classification for Determination of Outdoor-Indoor Transmission Class.

The rooms were evaluated for sound transmission both from inside-to-outside and outside-to-inside to calculate an average transmission loss for each wall assembly.
The ICF walls provided higher (better) field sound transmission coefficients than other walls.

13. Ease of installing service connections

Service lines can be easily installed with pre planned design. Electrical conduit and plumbing is generally run in chasing in the depth of the insulation formwork.

14. Cost effectiveness

Economical in the long run as energy savings are from the very beginning.

15. Speed of installation

With little need for on-site adjustment and change, ICF construction is generally faster than most other building methods.

16. Health & Safety

The insulation does not allow moisture or air penetration. Because there are no cavities or other voids in ICF construction, there is no potential for moisture penetration or condensation in any structural elements.
The advantage with ICFs is that the termites can't affect the structural integrity of the building since it is made of concrete.

17. Ease of transportation, handling and assembly

No on site construction required to put the blocks together - this saves time and insures quality of the end product.

18. Versatility

Easy design - any shape , any size - for new build one can take an original drawing and convert them to ICF construction easily.

19. Compatibility with other systems and materials

ICF projects can be designed using ACI 318 and are designed like any other steel reinforced concrete wall.
Fastening strip for mechanical attachments, such as exterior siding, brick ties and drywall
In all cases, most exterior and interior cladding can be installed with common attaching screws.
Exterior acrylic systems are perfectly suited to ICFs, as the preparation for applying an acrylic system to the ICF typically requires only rasping the foam before application.

A vapor-permeable, water-resistant building paper separates the plaster and lath from the ICF. It's a proven system that works in all climates.

20. Limitations

Major openings for doorways, windows, etc., need to be set out in the formwork as it is relatively difficult to make changes later, owing to the fundamentally monolithic nature of the structural elements.

Building with ICF is a precise process with smaller margins for error than conventional or traditional construction allows

Completed Projects

1. 4 storey car showroom for M/s Rajpal Autolinks, Indore, MP
2. 2 storey cottage for Mrs. Tilottama Verma, Theog, HP
3. Guard House for Reliable Insupacks' plant, Gr. Noida, UP
Ongoing Projects
1. Basement+Stilt Parking+3 floors Residential project, New Delhi
2. Basement, Tool Room, Godown & Company's Office, Gr. Noida
3. 2 storey Residence for Mr. G. Pandya, Ahmedabad.

Standards / Guidelines referred

http://www.huduser.gov/Publications/pdf/icfperf.pdf

http://www.concretethinker.com/solutions/Disaster-Resistance.aspx

http://www.yourhome.gov.au/materials/insulating-concrete-forms

http://www.buildicf.co.uk/products.php

http://www.forms.org/index.cfm/durabilitystrength