International Symposium on Earthen Structures (ISES-2007)

22 – 24 August 2007, Indian Institute of Science, Bangalore, INDIA

INTRODUCTION

Earthen structures house a significant proportion of humanity, globally. Earthen structures adopt time-tested building techniques, are affordable, easily procurable and more responsive to the local environment conditions. In our current pursuit of Sustainable Development Earthen Structures have tremendous potential in providing solutions for energy efficiency, human-comfort, eco-architecture, and cost-effectiveness.

However, increasing modernisation of lifestyles and rapid pace of urbanisation have seen a steep decline in the acceptance and adoption of traditional or vernacular earthen structures. Architecture and buildings today are characterised by designs that are not climatically responsive and excessive use of exotic energy intensive building materials. Not only are modern building materials and techniques unsuited to local demands of climate and cultures, they place heavy demands on energy required to maintain required comfort levels.

Fortunately, in many industrialised countries interest in traditional and modern methods of earth building has been steadily growing as more sustainable and healthier buildings sought. The introduction and development of new affordable solutions to combat critical housing shortages, using earth based materials, such as compressed earth blocks, rammed earth, etc remains a primary focus for modern earth-based buildings. Recent developments include wide adoption of stabilised compressed earth blocks and rammed earth constructions.

Earth buildings offer many advantages, including opportunity to use locally available affordable materials, low environmental impact, improved occupant health, reuse and recyclable capabilities, and a favourable building environmental performance. Challenges include poor seismic resistance of vernacular construction, limited data on performance and building standards, uncertified products, lack of education and training, and poor regulatory mechanisms.

We have so far received contributions from more than 12 countries representing all five continents of the world

SYMPOSIUM OBJECTIVES

- *The symposium will provide an International Forum for information dissemination and exchange, discussions and debates on research and practice in the broad field of earthen structures, including building techniques and materials, earthquake resistance, architecture and building-comfort.*
- *The symposium aims to bring together practicing professionals (engineers and architects), manufacturers, artistes and designers, academicians, researchers and students keenly interested and engaged in the theory and practice of 'earthen structures'.*

THEMES

The following themes can include case-studies, R & D, designs and innovations pertaining to Earthen Structures

1. Materials
2. Technology (adobe, rammed earth, etc.)
3. Performance and durability (energy, seismic resistance, climate-response, structural, sustainability, etc.)
4. Design (architecture, code/regulations, etc.)
5. Heritage structures, conservation, repair and reuse
6. Traditional and non-traditional concepts and practices

KEY DATES and REGISTRATION

Paper Submission:

Full length papers can be directly submitted for review

Announcement of acceptance of paper with referee comments : 20th Apr. 2007

Submission of (revised) final papers : 18th May 2007

Venue:

J.N. Tata Auditorium, IISc, Bangalore, INDIA

Registration Details:

Registration form accompanied with registration fee should be payable as Bank Draft (Cheques NOT accepted please) favouring ISES 2007 payable at Bangalore, India.

The registration fees are as follows:

Author/Delegate from abroad	: €200 (US $275)
	[after June 30, 2007 - €225 (US $300)]
Accompanying Spouse from abroad	: €75 (US $100)
Author/Delegate within the country	: Rs. 4000
	[after June 30, 2007 – Rs. 4500]
Accompanying Spouse within the country	: Rs. 1500
Students from abroad	: €100 (US $135)
Students within the country	: Rs. 2000

The registration fee includes seminar materials, refreshments, working lunches and a banquet.

Organisers:

UNIVERSITY OF BATH

INDIAN INSTITUTE OF SCIENCE

ENTPE

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THE INTEGRAL MASONRY SYSTEM WITH EARTH-BASED MATERIALS: RUBBLE BASED EARTHQUAKE RESISTANT CONSTRUCTION

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ABSTRACT

The article presents an adaptation of the Integral Masonry System (IMS) developed in Europe under the trade name of the “AllWall System”, for concrete or clay, block or brick masonry walls using just mortar.

In this case the objective is a study in order to adapt the system in a new practical application technology to suit earthen or rubble material to allow the construction of housing in seismic areas, and take advantage of materials deteriorated by natural disasters.

When employing earth-based or rubble infill it is impossible to transfer reinforcement stresses through the bond due to the ensuing lack of mortar or concrete in these structures. It is then necessary for the reinforcement itself to transfer these stresses through the tying, threading or bolting of the reinforcement and to brace the panels at the corners, at the junctions of walls or at the floor slabs in order to reinforce the entire assembly.

The prefabricated reinforcement employed in the IMS is made from electro welded galvanized wire and comes in 5.85 m lengths arranged in the form of a 30 cm truss. This reinforcement may intersect in the three spatial directions, and allows the construction of reinforced walls and slabs with these very lightweight and manageable components. These then only require infilling with rubble or earth or floor boarding in order to provide the structure with sufficient rigidity.

The construction may be left exposed or covered with mortar reinforced by chicken wire, or with earth reinforced by vegetable fibre, as the truss reinforcement wires are galvanized to protect them against corrosion.

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ORGANIZATION OF STANDARD HOUSING

The design of the standard housing is based on the dimensions of standard prefabricated reinforcement which comes in 5.85 m lengths to allow ease of transport in the back of a small lorry (6m) or on the roof rack of a car, given its light weight (approx. 8 kg/piece).
One or two-storey houses are considered, taking full advantage of the nigh on 6m lengths of reinforcement and employing 30 cm thick walls. The structural modulation may be 30cm and the spatial modulation 90 cm, in order to give the following prototypes:

Bungalows				
Type 1	5.10 x 6.00m	30.6m^2 total area	24.3m^2 floor area	1 bed.
Type 2	6.00 x 6.00m	36.0m^2 total area	29.2m^2 floor area	1 bed.
Type 3	2 (5.10 x 6.00m)	61.2m^2 total area	51.3m^2 floor area	2 bed.
Two-storey houses:				
Type 4	2(5.10 x 6.00m)	61.2m^2 total area	51.3m^2 floor area	2 bed.
Type 5	2(6.00 x 6.00m)	72.0m^2 total area	58.4m^2 floor area	3 bed.
Type 6	2[2(5.10 x 6.00m)]	122.4m^2 total area	102.6m^2 floor area	4 bed.

Houses type 1 and Type 4 (Fig. 1) of rectangular plan, have a lean-to roof (single pitch) which extends out on one side and covers the entrance in the one-bedroom Type 1 bungalow (24.3m^2 floor area), and covering the balcony and the steep external stairway in the two-bedroom and two-storey Type 4 house (51.3m^2 floor area).

The square plan Type 2 and Type 5 houses (Fig. 2) may have a hip roof or a ridge roof (4 or 2 pitches). The one-bedroom Type 2 bungalow has a 24.2m^2 floor area and the two-storey Type 5 house (58.4m^2 floor area) has a steep rising staircase and may have up to 3 bedrooms.

The rectangular plan Type 3 and 6 houses (double Type 1 and Type 4) have a two pitch ridge roof following the longitudinal centreline and leaving two 90cm wide pilasters to support the longer walls. The two-bedroom Type 3 bungalow (51.3m^2 floor area) has an entrance set under the eaves of the roof. The four-bedroom Type 6 house (102.6m^2 floor area) has normal pitched internal stairs and two balconies on either side protected by the eaves of the roof (Fig. 3).

In all the houses it is considered that the toilets will occupy a minimum area, with shower trays in the one and two-bedroom houses and an additional bathroom in the three and four-bedroom houses.

All houses have a single living-dining area, which includes the kitchen in the one and two-bedroom houses and which may be separated from the same in the 2 and 4 bedroom houses.

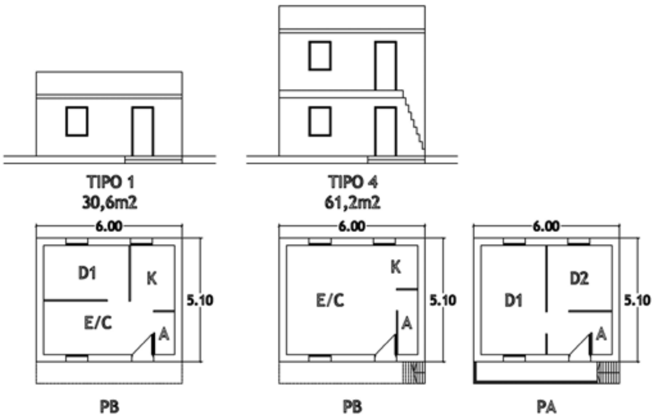


Figure 1. Type 1 Bungalow ($30.6m^2$) and two-storey Type 4 House ($62.2m^2$)

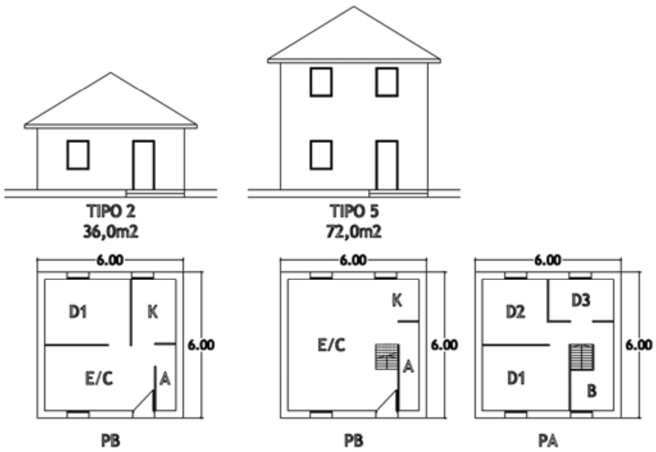


Figure 2. Type 2 Bungalow ($36.0m^2$) and two-storey Type 5 House ($72.0m^2$)

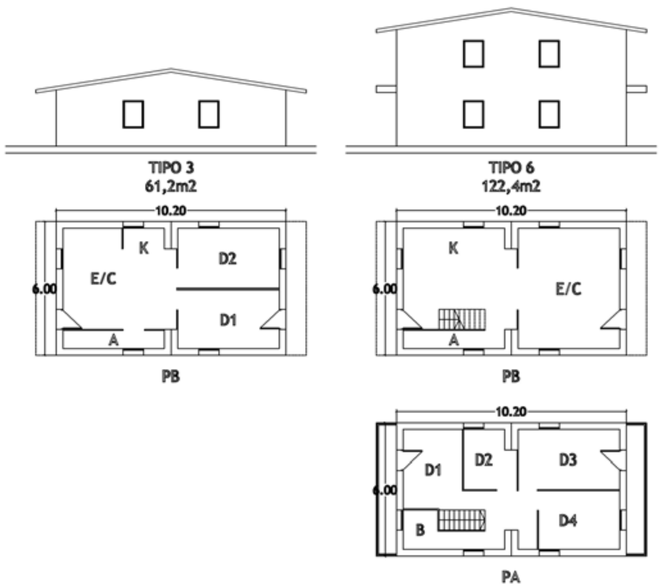


Figure 3. Type 3 Bungalow ($61.2m^2$) and two-storey Type 6 House ($122.4m^2$)

THE DOUBLE TRUSS-TYPE PREFABRICATED REINFORCEMENT

In order to obtain maximum economy in the manufacture of the steel elements, these have been standardized as far as possible and only one basic component will be manufactured and employed. This being a double-wire truss-type reinforcement which, when placed in different positions, serves as: vertical rib reinforcement, bed-joint reinforcement, beam or lintel, hoop or anchor reinforcement and beam reinforcement, and all cut-offs may be used for any of these applications.

To this end a single prototype has been designed for the prefabricated electrowelded and galvanized wire reinforcement. This is arranged in the form of a truss with four 8mm wires set, two and two, either side of a 6mm diagonal wire running zigzag between the same. The longitudinal wires are welded every 300 mm and the entire assembly is cut in 5.85m lengths to provide ease of transport. This reinforcement is a variation of the AllWall System truss: AW-RIB.

The area of triangulation and the wire sections, together with their weldings, allow the reinforcement to be threaded through others by setting the truss at an angle of 30º and then turning until both are set at right angles, with each node of the triangle on one side of the truss coinciding with the central point between triangles of the other truss (Fig. 4a).

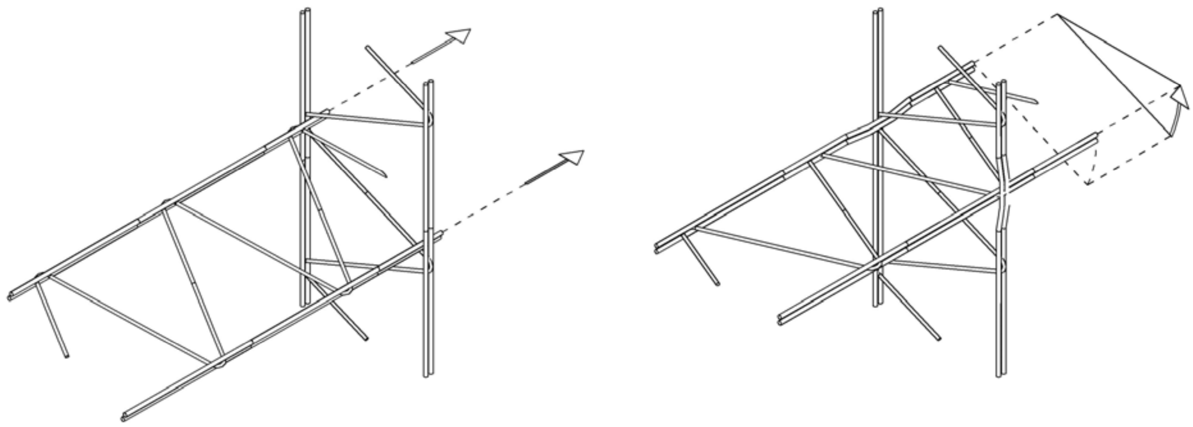


Fig. 4. Threading process of trusses set at right angles: a) Lateral access; b) Turn and curve

In order to set the trusses in their correct position it is necessary to apply a slight force to bend the 8mm diameter wires in the 300mm longitudinal span between weldings. Once the trusses are fully set at right angles to each other, these wires hold the trusses in position and allow the stress to be transmitted between the same more effectively and prevent possible lateral buckling (Fig. 4b).

With this process of threading ribs it is possible to form reticular space frames within the walls which may then be filled in with earth or adobe, and to tie these in with the reticular space frames of the floor slabs, which may be filled in mud and rattan infill (yet to ascertained) or to support wood boarding bolted to the trusses.

In accordance with the design, additional plates shall be placed to act as negative reinforcement at the joints between the beams of the floor slabs and the ribs of the walls, and further strips at the centre of the beam spans to act as positive reinforcement. These plates shall be supplied with their nuts and bolts to allow connection to the corresponding ribs and beams.

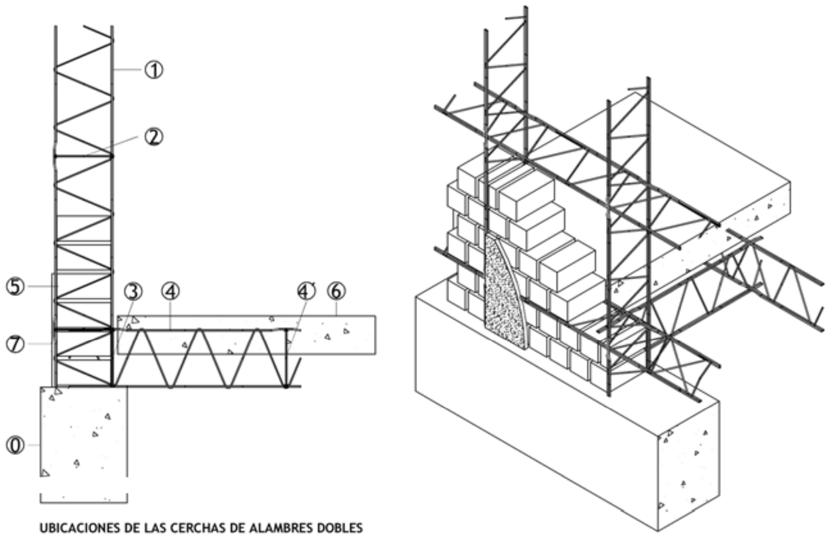
The spatial intersection of the bed-joint reinforcement, ribs, beams and anchor ties, while set flush for the graphical purposes of these drawings may, logically, be laterally overlapped where necessary. This would only produce a 1cm variation between the centrelines of the wires and would generate very little branch moment and not affect the transfer of stress, particularly in view of the fact that the earth infill would prevent any potential lateral buckling of these steel components.

Auxiliary components to the reinforcement such as bolted reinforcement plates, rib tie plates set at the corners of walls, tension wires to brace the infill panels between the trusses, etc., are not detailed here in order to simplify the description.

CONSTRUCTION ORGANIZATION OF THE HOUSES

All the houses are set on a well compacted earth perimeter (or a slightly reinforced concrete strip foundation) set under the walls. A floor slab is set on the ground floor which is tied in to the surrounding walls, so that these may be independent from the foundation itself, thereby ensuring smaller stress transfer in the case of earthquake. After preparing the base or foundations, the building work then consists of setting vertical ribs every 90cm, perfectly plumb and threaded in the first slab set over the soil and always starting with the same triangulation module. In two-storey houses, these ribs will extend the total height of the building. The 90cm horizontal modular spacing allows for openings such as doors and windows in the walls and for the passing of stairways through the voids in the floor slabs.

LOCATION OF DOUBLE WIRE TRUSS REINFORCEMENT



Figs. 5. Truss arrangement over the foundation of a single leaf compacted earth wall:

a) 1. Vertical rib truss; 2) Bed-joint reinforcement truss; 3. Anchor truss; 4. Beam truss; 5. Pressed earth brick; 6. Slab thickness; 7. Mortar rendering on chicken wire or vegetable fibre reinforced earth; b) Perspective of lower section of single leaf earth wall

Two vertical ribs are set at each wall panel. These ribs, for their corresponding wall panels, are tied together on the outer side by steel ties set at the level of the horizontal joints between the blocks or bricks. At all these corners the reinforcement of the corner panels shall be triangulated in 90 cm wide and 90 or 120 cm high modules. This will also be performed at the panels around wall openings. At the level of the ground floor slab, the upper floor slab (where existing) and the roof slab, the reinforcements of the slab beams are connected to the previously positioned and plumbed vertical ribs, together with an intermediate edge beam set on the perimeter of the wall (fig. 5a). The earth bricks or blocks shall be prepared in 30cm length modules when including the joint thickness, and so their real size will be approx 28x13x13cm, and may be laid in header bond to form a wall of uniform thickness (Fig.5b).

The earth (or adobe) shall be laid in successive courses as the wall rises and bed-joint reinforcement shall be set every 90cm approximately. This reinforcement threading in perfectly through the triangulations of the previously placed vertical ribs. According to the climate of the area where the house is to built, the wall may be arranged as solid uniform earth wall or, alternatively, as a cavity wall with the leaves tied together by double trusses every 90cm maximum and with a central air cavity or cavity wall insulation and/or damproofing.

The 80 cm wide door openings are arranged by setting a rib next to the each door jamb, which will be covered by the corresponding door frame. The window openings will similarly correspond to this 90cm modulation, it being possible to set two together where required, with a central mullion (rib), leaving a 1.80m apparent span. The façade shall be modulated in such a way that the bed-joint reinforcement coincides as a lintel over the door and window openings to support the weight of the earth wall. It is also advisable that bed-joint reinforcement be set at the level of the window sills.

The slabs may be formed as a segmental arch with mud and straw set between one way beams, or as mud vaults between two-way beams. The ribs of the beams shall be spaced a maximum of 90cm, and this may then be covered by paving, and where possible, an intermediate 5mm diameter 150mm x 150 mm electrowelded mesh.

Alternatively, wood floor boards may be set directly on the slab trusses to form the flooring. The slabs may leave the double trusses exposed or covered by a false ceiling in plasterboard or wood boarding, where light fittings may be housed. At the overhangs, the double trusses may be covered in wood boarding on each side, appearing as corbels at the roof eaves or slab overhangs. In this type of housing and particularly those with minimum floor area, it has been considered necessary to employ very steeply pitched stairs simply by employing a couple of double ribs set parallel and crossed with boards in the form of steps.

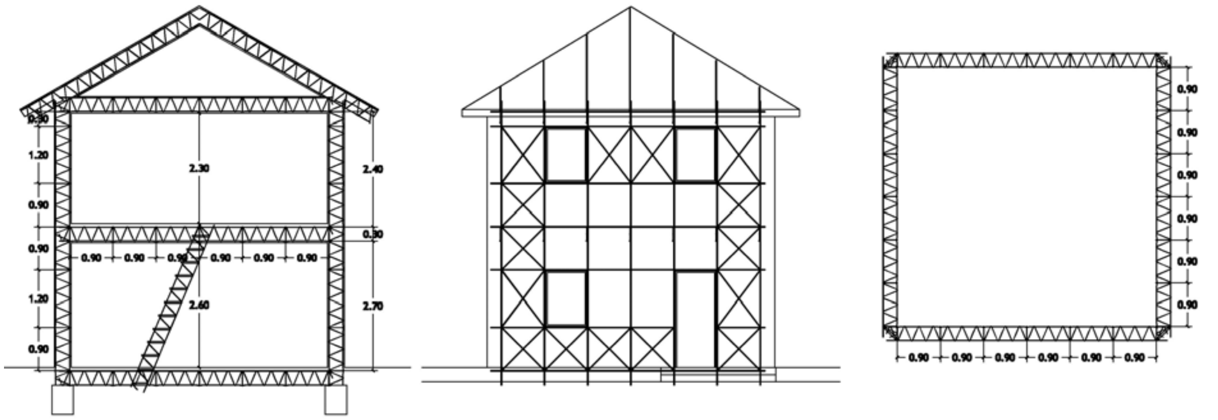


Fig.6. Construction of Type 5 house with two 6x6m^2 floors: a) Section with reinforcement trusses set in walls, slabs, roof and stairs; b)Elevation showing reinforcement prior to rendering; c) Plan showing wall reinforcement; d) Plan showing slab reinforcement.

BREAKDOWN OF COMPONENTS FOR STANDARD HOUSING

A calculation has been made of the number of 5.85m long truss units required for each of the proposed house types. The calculation individually adds the trusses required for wall reinforcements to that of the floor reinforcement, as there is the possibility of forming a composite construction using the Integral Masonry System for earth or adobe walls, and wooden joists, as indicated in the table below.

COMPONENTS OF EACH BUILDING TYPE			Wall Trusses	Slab Trusses	Total Trusses
Bungalows					
Type 1	1 bed.	5.10 x 6.00m	42	18	**60**
Type 2	1 bed.	6.00 x 6.00m	38	28	**66**
Type 3	2 bed.	2(5.10 x 6.00m)	65	38	**103**
Two-storey house:					
Type 4	2 bed.	2(5.10 x 6.00m)	54	27	**81**
Type 5	3 bed.	2(6.00 x 6.00m)	56	42	**98**
Type 6	4 bed.	2[2(5.10 x 6.00m)]	97	57	**154**

In order to illustrate the building organization of the Integral Masonry System (IMS), applied to both walls and slabs, for an earthquake resistant construction built with earth, we have used the example of the 6x6m² two-storey Type 5 house, with a total constructed area of 72.0m² and a free floor area of 58.4m², with internal stairs and three bedrooms. The construction of the 6x6m² two-storey Type 5 house is developed in elevation, plan and section in a way which clearly shows the threading of the orthogonal trusses. In the walls, the trusses employed as vertical stiffening ribs are threaded through the trusses employed as bed-joint reinforcement, while in the slabs, the trusses employed as beams or joists are threaded with the trusses used as anchor ties (Figs. 6a, b, c and d).

This house type has the maximum span of 6m (including the 30cm thickness of the walls) and it has, subsequently, been decided to place a reinforcement of two-way beams which will more efficiently absorb the effect of seismic action. This reinforcement being set at the ground floor, first floor and roof. In the construction of the earth IMS, the truss reinforcement is set on the outside of the rubble blocks and this ensures that the wall panels are very well encased and set against seismic action. In order to ‘dress’ the finishing of the building, and while this is not required to prevent the corrosion of the galvanized trusses, it is recommended that rendering be applied to a mesh of chicken wire fixed to the rib wires. In the case where an adobe finish is employed this should be reinforced with a vegetable mesh. The finish also cover the external braces of the wall panels set at the corners of the walls (Fig. 7).

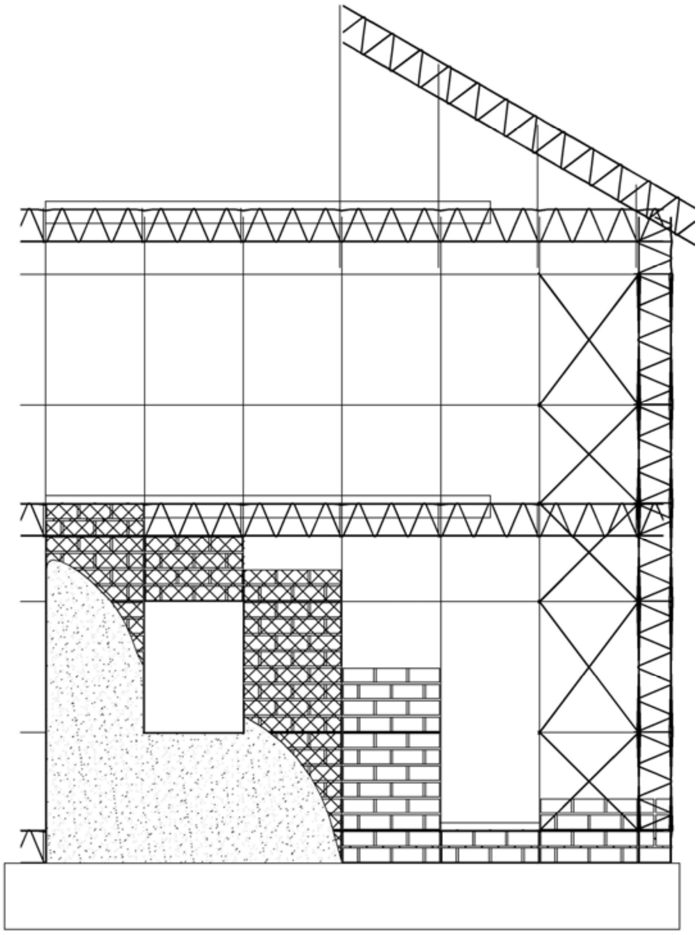


Fig.7. Elevation showing construction detail of Type 5 house: Vertical and horizontal ribs braced at the corners with diagonal wires. Earth infill between the vertical trusses and the bed-joint reinforcement. Rendering set on chicken wire fixed to the rib wires.

A finished version of the building is shown with all its reinforcements and reveals the homogeneous and interconnected reinforcement provided by the system in walls and slabs.

However, this view does not correspond to the reality of the construction process, as the 6m high vertical reinforcements are set in position at the start of the building process, and the earth block infill, the bed-joint reinforcement and the finishing of the slabs are all set at different stages of the construction process.

With regards to the corner detail, it should be clarified that the vertical ribs of the orthogonal walls are tied together and these are, in turn, braced by the bed-joint reinforcement in the same to ensure that the entire assembly works together against horizontal seismic action. This similarly applies to the equivalent detail at the meeting of the slab and walls.

ECONOMIC VIABILITY OF THESE EARTHQUAKE RESISTING HOUSES.

Building with mud, rubble or compacted earth mixed with straw to form earth blocks is usually applied in areas with underdeveloped economies and/or the third world. This solution is also ideal for using rubble from earlier buildings destroyed by natural disasters.

The building system proposed here may, in view of the ease of construction and lightweight building components, be performed by any person with a correct knowledge of this building techniques and suitably guided by the pertinent illustrations of each construction stage.

The building work may be performed by anybody, including those for whom the house it to be built, as each component marries in with the next and the reinforcements are laid out in all their length without overlaps (and only requiring ties and stiffening at the corners and joints, which for simplicity's sake are not illustrated here) and the entire process is accumulative with the placement of vertical trusses, an earth infill between the reinforcement and the tying of the same horizontal trusses. The main inconvenience lies in the cost of the truss type prefabricated reinforcement which cannot normally be paid by the owners of these houses.

In order to ensure the viability of earthquake resistant building in areas with little or no technology or the availability of reinforced concrete, and where many buildings may be formed with a cheap workforce unspecialized in this type of construction, it is only necessary to find a suitable means of funding the truss reinforcement which is the essence of the system.

As such it is necessary that the governments of these countries, the different international aid organizations and the NGOs find a way to fund the trusses as and when required by the different family groups.

CONCLUSIONS

The 'AllWall' Integral Masonry system, designed in Spain, may be efficiently applied to earthquake resistant construction with earth, adobe or rubble (in addition to traditional brick or block) in any country in the world, simply by using double electrowelded and galvanized trusses as the essential resisting element in both walls and slabs.

This is a new structural type which uniformly distributes reinforcement throughout the masonry, and requiring smaller diameters as this takes full advantage of the thickness of the wall, without requiring concrete or mortar to transmit the stresses in the steel (on account of the ties and bolts), and acting as a masonry panel which efficiently works under compression.

The IMS has the great advantage of ease of construction as it does not require experience or building control and may be built by following a practical guide provided together with the subsidised trusses.

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