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DEVELOPMENT OF A NEW LOADBEARING MASONRY WALL SYSTEM FOR BUILDING CONSTRUCTION IN HOT CLIMATE

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Abstract

Traditional loadbearing masonry has proven to be thermally inefficient in hot desert climate. A team from the Housing and Building Research Center, Cairo, Egypt and university faculty and headed by the author conducted a study to develop an efficient building system for the Toshki project in Egypt. A key component in the proposed system is a new interlocking concrete block developed by the author for residential construction in hot desert climate. The new block, which is made of lightweight concrete, has three chambers: an outer chamber to accommodate insulation, a middle chamber to accommodate reinforcing steel and grout and an inner chamber to accommodate electrical conduits and pipes. The main criteria used to develop the new system are thermal and structural efficiencies, minimum quality control on the job site and speed of construction using unskilled labor. This paper describes the unique features of the new block and presents results of physical and structural tests on wall assemblies conducted at the Building Research Center. A full scale prototype building was constructed in Toshki using the proposed new building system and its response to thermal loads was monitored. The unique design features of the building are discussed. The study demonstrates the potential of the proposed new system for efficient use in building construction in hot desert climate.

Key Words

Hot climate, Interlocking blocks, loadbearing walls, thermal response,

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1 Introduction

The desert area exceeds 90 percent of the total area of Egypt. Most of the population is concentrated in a narrow strip around the River Nile. National projects are currently considering developing new communities in the desert areas. Toshki is an example of this type of mega projects to expand the cultivated and inhabitant regions of the nation (HBRC,1999). Toshki region is located south of the valley as shown in Figure 1. Because of the significance of this project the study reported herein is directed to be applied to Toshki region.

Traditional building construction in desert areas has called for the use of available local stone to construct loadbearing walls. It has been demonstrated that this system does not provide acceptable level of indoor comfortable environment in hot climate. This has pointed out to the need to develop non-conventional building systems with high thermal efficiency and at the same time is easy to build with unskilled labor and minimum quality control critical for construction in remote areas.

A team from Housing and Building Research Center and university faculty and headed by the author conducted a study to develop an efficient building system for Toshki project. This project is funded by the Egyptian Ministry of Housing. The outcome of this study is presented in the following sections.

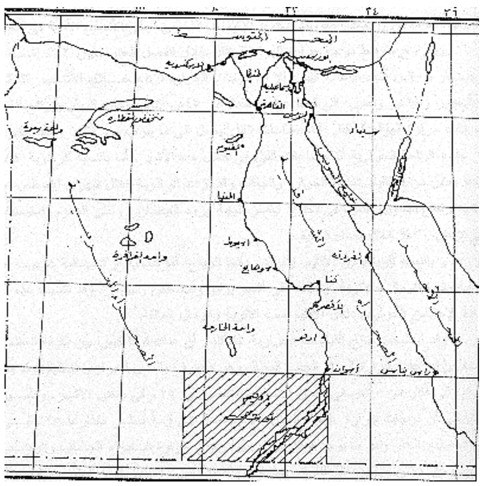


Figure 1 Map of Egypt Showing the Location of Toshki Region

2 Development Criteria for Building Systems in Hot Climate

Current challenges in design and construction in hot climate point out to the key elements in selecting a suitable criteria for developing the new system. These challenges are:

1- Traditional loadbearing masonry walls built with limestone locally available does not provide adequate thermal resistance.

2- In hot climate with day temperature reaching over 45 degrees it is difficult to cast in-situ concrete and ensure good quality.

3- Availability of skilled labor is scarce.

4- There is a need to reinforce the walls to provide adequate resistance to seismic loads.

5- Because mechanical air-conditioning is not affordable high thermal resistance of exterior walls, natural ventilation and air circulation are essential to achieve comfortable indoor temperature.

In light of the above four challenges the following features for developing an efficient building system have been identified:

1- Use of manufactured material with high thermal resistance such as insulation boards.
2- Use of precast small units that are easy to handle and place such as concrete masonry units.
3- Select a system that can be built with unskilled labor such as interlocking dry stack (moratless) loadbearing masonry system.
4- Walls have to be built with units that can accommodate reinforcing steel.
5- The system has to be designed to allow natural ventilation and air circulation. Use of vaults and open court concept can be utilized.

3 Description of the New Block Wall System

Considering the above features, the research team has developed a new building system made of insulated concrete masonry units that interlock without the need of mortar and can be reinforced. A new block developed by the author has been utilized in the wall system proposed for Toshki project.

The new block, shown in Figure 2, has three chambers: an outer chamber to accommodate insulation, a middle chamber to accommodate reinforcing steel and an inner chamber to accommodate electrical conduits and piping. The block is 390 mm long by 190 mm high by 300 mm thick. The faceshell thickness is 30 mm and the web thickness is 30 mm. The thickness of the inner and outer chambers is 40 mm whereas the thickness of the middle chamber is 100 mm. Tongue and groove concept was utilized for interlocking of the blocks in the vertical plane. There is no interlocking in the horizontal plane of the block. Staggering was used to provide continuity.

Figure 2 The New Interlocking Concrete Masonry Unit

Figure 3 shows an assembly of blocks to form a wall structure. As shown, staggering of the units is provided for wall continuity in the horizontal direction. Continuity along the vertical plane is provided by vertical interlocking using tongue and groove at the ends of the faceshells. To seal the joints and provide resistance to moisture and air flow a thin layer of plastering (5 mm thick) will be applied to the wall surface.

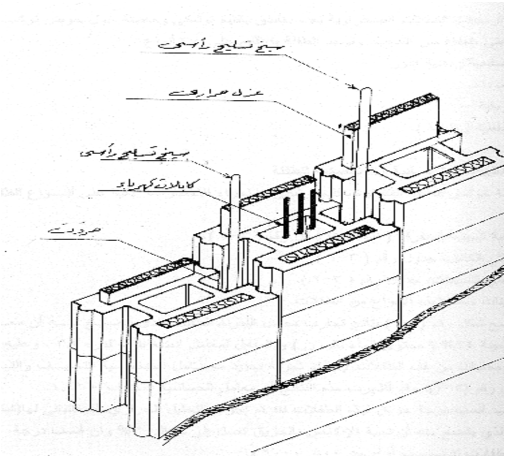


Figure 3 Wall Assembly Showing Unit Interlocking, Insulation, Piping and Reinforcing

4 Block Production

Three different materials were originally considered for block production: normal weight concrete using locally available crushed stone, lightweight concrete using lightweight leeka aggregate and silt available locally in Toshki region. Great difficulty was experienced in manufacturing the units with silt because the expansion of the material. Therefore, it was decided to eliminate the silt at least in this trial study. The lightweight block, because of its high insulation, it was selected as the best material for manufacturing the units. The dry density of the lightweight concrete using leeka aggregate is about 1.5 gm/cm^3. The average 28 days compressive strength of the trial mix is 14 MPa.

Wooden molds were originally used to produce the blocks. However, because dimensional accuracy of the produced units was not acceptable steel molds was used to meet targeted dimensional tolerances.

5 Mechanical Properties of Wall Assemblages

5.1 Compressive Strength

Tests were conducted to determine the mechanical properties of masonry needed to perform structural design. Prisms three courses high with different bond patterns were tested under axial compression to determine masonry compressive strength. These prisms were grout solid. The average compressive strength of prisms ranged from 3 to 5 MPa depending on the prism bond pattern.

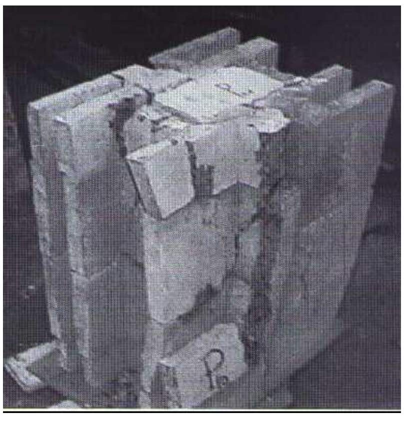
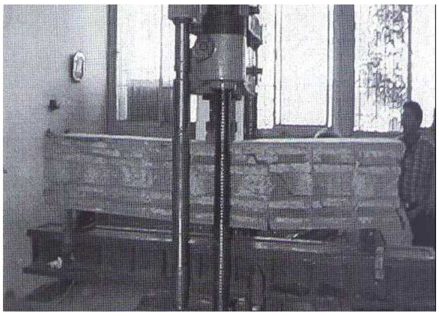


Figure 4. Three Course Prism Tested Under Axial Compression

5.2 Flexural Tensile Strength

Wall sections eight courses high were built and tested under mid-span load (Figure 5) to determine flexural strength. Two types of walls were tested: one without plastering and the other with plastering on both sides. As shown in Figure 5, plastering significantly increased wall flexural stiffness and cracking stress (modulus of rupture).



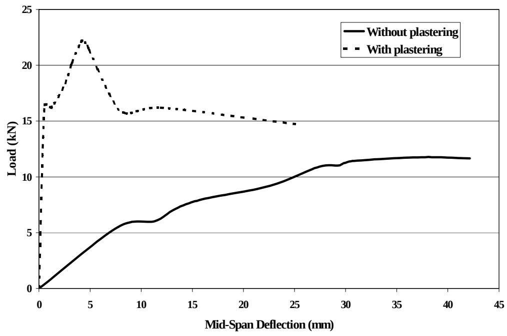


Figure 5 Flexural Test of Wall Segment

6 Thermal Testing of Wall Panels

Wall assemblies made of concrete and silt units were tested for thermal response in the laboratory of the Building Research Center using a hot box [1]. The panel dimension s are 2m by 2 m, see Figure 6.

Figure 6 Wall Panels for Thermal Testing

The results of the thermal testing of the concrete block panel is shown in Figure 7. The graph shows the heat flow with time at different distances through the wall thickness. The results show the thermal efficiency of the insulation demonstrated by the increase of the thermal gradient through the wall. It is also shown that, because of the 40 mm insulation in the outer chamber, the steady state heat flow through the wall was only 19 w/m^2. This amounts to 0.375 w/m^2 ^{o}C which satisfies the target thermal design

requirements for a comfortable interior temperature without the need of mechanical air-conditioning.

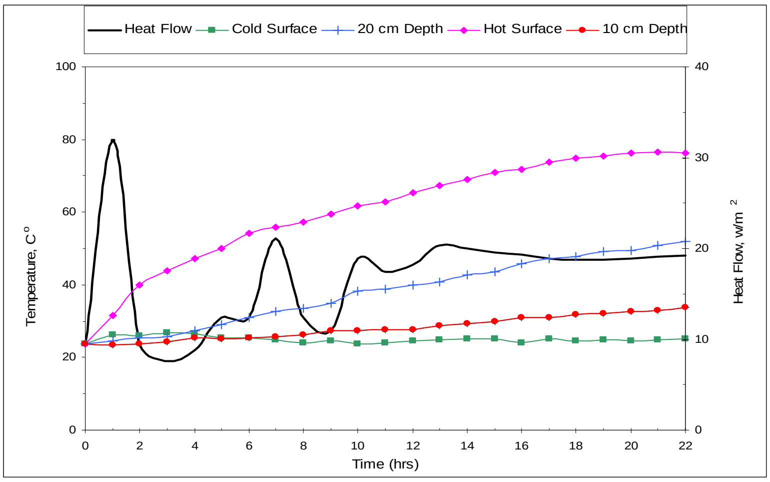


Figure 7 Thermal Response of Tested Wall Panels

7 Design of the prototype Building

Because of the encouraging results of the proposed wall system it was decided to build a prototype test building in Toshki. The building will be continuously monitored for its thermal response over an extended period of time during the summer months of the year 2001.

7.1 Design Considerations

In designing the building the following design considerations were taken into account:

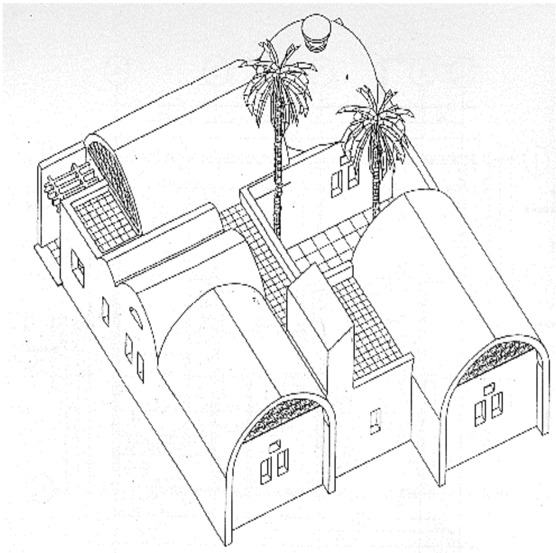
1- Aesthetics and environmental considerations,
2- Structural considerations,
3- Economical considerations, and
4- Social considerations

7.1.1 Architectural Considerations

Figure 8 shows 3-D view of the building. It is a one-story building with an inner open court. Vaults and domes were chosen for the roof to minimize direct exposure to sunlight. Also, small openings in the vaults and domes are provided to obtain effective ventilation and air exchange.

Figure 9 shows the floor plan of the building. It consists of two bedrooms, a family room, a dinning room, a kitchen and two bathrooms. The insulated concrete block masonry walls serve as the building envelope to separate the interior environment from the exterior hot climate, the loadbearing to carry the roof and the separator between different rooms. The building dimensions are set to match a grid system designed to fit the unit basic dimension. This is important to minimize block cutting to accommodate wall openings and intersections during construction.

The new insulated block will be used to build the exterior walls to provide targeted thermal efficiency. Interior walls were built using conventional concrete masonry blocks available in the market. The exterior walls were designed to resist the thrust horizontal forces from the dome and the vaults. Tie beams were used to carry the tension force and reduce the bending moments in the walls.



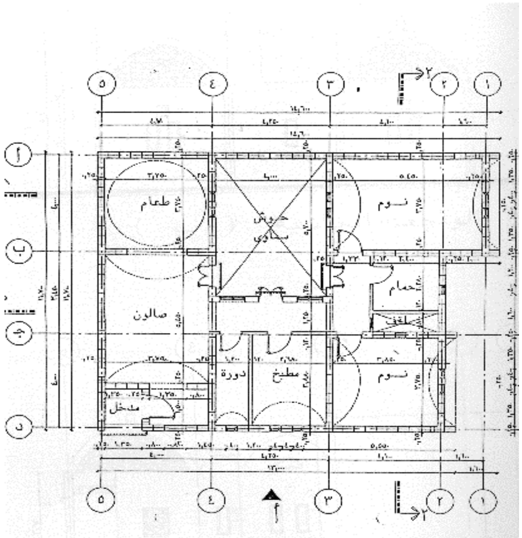


Figure 8 Proposed Prototype Building

Figure 9. Plan View of the Prototype Building

7.1.2 Structural Considerations

The walls were reinforced vertically and horizontally and grouted to provide adequate tensile and shear resistance to lateral loads (Drysdale et al 1999). The reinforcing steel was designed to carry lateral seismic forces for zone 3 as per the Egyptian code for loads and zone 2A as per the UBC code (1997).

The design is based on a net block compressive strength of 10 MPa, a type S mortar and a minimum grout compressive strength of 15 MPa. Minimum reinforcing rods with a 13-mm diameter were used at a maximum spacing of 1.2 m, at window and door openings and at wall intersections to satisfy code prescriptive reinforcement requirements for seismic areas. Horizontal reinforcing steel rods were provided at wall intersections to carry interface shear.

The masonry walls has to carry, in addition to roof vertical loads and lateral seismic loads) horizontal thrust forces from the vault. Horizonatl ties were provided to support the walls.

7.2 Computer Simulation of Building Thermal Response

A computer model has been developed to predict the thermal response of the prototype Building (HBRC 1999). The computer code predicts the dynamic thermal response taking into account the thermal inertia and the solar energy on horizontal and vertical surfaces. Input data includes a selected temperature profile within a 24 hours period and the thermal properties of the walls and the roof elements. The computer code was used to study the thermal efficiency of the proposed prototype building and how it is compared with conventional solid stone buildings. An example of the computer output is shown in Figure 9. This graph shows the variation of the thermal loads during a 24 hours period for an eastern wall during the month of July. As clearly demonstrated, the building with the proposed insulated interlocking blocks shows a superior thermal performance compared to other conventional systems.

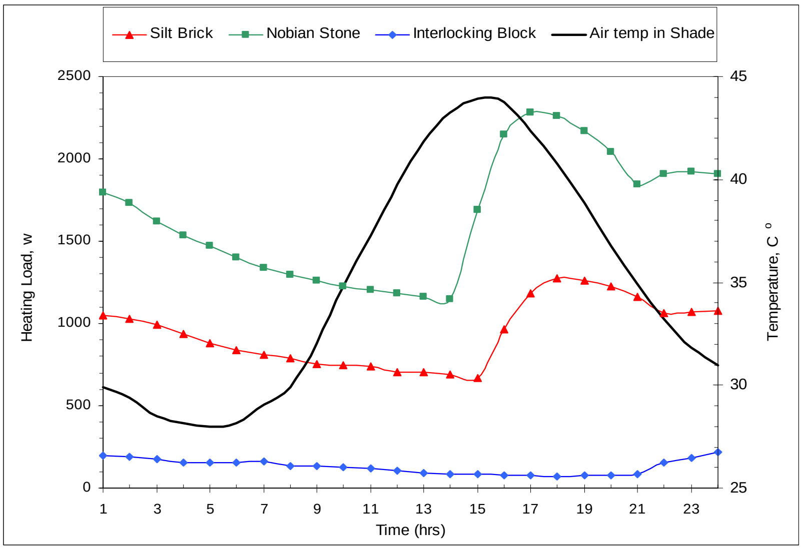


Figure 9   Analytical Thermal Response of An Eastern Wall in the prototype Building

8   Construction of the Prototype Building

A site was chosen in Toshki to build the prototype building. The new block was used to build the walls which were grouted and reinforced. Strip reinforced concrete footings were used. Steel dowels were installed to provide continuity between the footing and the bearing walls. The dome and the faults were constructed with clay masonry. The photographs of Figure 10 show the stages of the building construction. Figure 11 shows the finished building. White cement plaster was used on the exterior of the building.

Construction of the walls

Construction of the walls

Construction of the roof

Construction of the roof

Figure 10   Construction of Prototype Building in Toshki

Figure 11 The Finished Prototype Building

9 In-Situ Thermal Response of the Prototype Building

The prototype building was instrumented by thermo-couples to measure indoor air temperature at key locations. Weathering station was installed to provide climatic data for the outdoor air temperature, relative humidity and wind speed. As shown in Figure 12, the indoor temperature was within the identified comfort zone (between 25 And 32 degrees C). These results clearly demonstrate the effectiveness of the proposed system in maintaining comfortable indoor temperature.

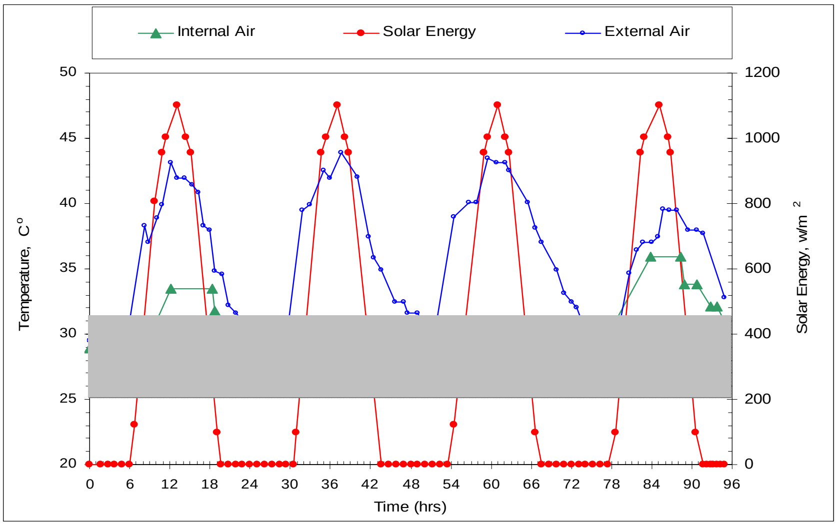


Figure 12 Thermal Response of the Prototype Building

10 Conclusion

The study presented in this paper has demonstrated the potential of the proposed concrete masonry system for use in hot desert climate such as the Toshki region in Egypt. Experimental and analytical studies demonstrated that the building with the proposed insulated interlocking blocks showed a superior thermal performance compared to other conventional systems. Actual thermal measurements of the prototype building affirm the thermal efficiency of the proposed building system. Interior comfortable temperature around 25 ^{o}C can be naturally achieved using the proposed insulated interlocking concrete masonry wall system without the need of mechanical air-conditioning. Phase two is currently underway to fine-tune the system for mass production of the masonry units and actual residential building construction in Toshki.

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