USE OF AZAR INTERLOCKING SYSTEM FOR HOUSING CONSTRUCTION IN EGYPT

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ABSTRACT
There is a huge shortage of low-income housing in Egypt. In 2009 the Egyptian government has committed to build 500,000 apartments in the next five years. Use of conventional building systems such as skeleton reinforced concrete frame construction with infilled masonry walls may not satisfy the high demand for shelters in short time. Mortared concrete masonry has been used and cost saving has been achieved due to elimination of exterior plastering and formwork. However, many problems have been encountered in this type of construction due to lack of skilled masons. Azar interlocking concrete masonry has been introduced by Arab Contractors of Egypt to overcome problems encountered in mortared construction. Azar system is 5-8 faster than conventional masonry construction, eliminates the need for exterior plastering and does not required skilled labor. Tests reported in this paper demonstrate that compressive and diagonal tensile strength of fully grouted Azar specimens are comparable with conventional mortared fully grouted masonry. It is therefore concluded that code's provisions for conventional mortared concrete masonry are equally applicable to fully grouted Azar system. Limitations and recommendations for successful future implementation of this building system are presented.

KEYWORDS: concrete blocks, loadbearing masonry, low-income housing, reinforced concrete masonry, residential construction

INTRODUCTION AND PROBLEM STATEMENT
Egypt's population will grow from 70 million today to 95 million in 10 years. There is a huge shortage of housing for this fast growing population. This is particularly true for low-income housing. The Egyptian government has committed to build 500,000 apartments in the next five years. Use of traditional skeleton infilled reinforced concrete frame construction will not meet the goal of this national mega project because of the high cost and slow construction time of this conventional building system. It becomes obvious that there is an urgent need to develop and utilize non-traditional building materials and systems that will ensure cost efficiency and speed of construction.

PROBLEMS WITH CONVENTIONAL INFILLED REINFORCED CONCRETE FRAME CONSTRUCTION
The most common type of building construction in Egypt is skeleton reinforced concrete frame with 10 cm weak infilled exterior and interior walls. Low-strength concrete or shale units are usually used in constructing the infilled walls. Thick expensive plastering is used to provide

acceptable final finish surface. In addition to the major problem of slow of construction, two key problems are evident: durability problems (spalling, cracking, delamination and corrosion, see Fig. 1) and inadequate seismic resistance, particularly for low to mid-rise buildings in moderate seismic areas in Egypt.

(a) Spalling and Cracking of the Building Envelope

(b) Corrosion Problem in RC Structures

Figure 1: Durability Issues in Reinforced Concrete Construction

For non-ductile frames, beam-column connections are highly vulnerable to failure (Figure 2-a) under seismic forces. A common practice in Egypt is flat plate floor construction. This system is highly vulnerable to punching shear failure under vertical forces from earthquakes (Figure 2-b). Infilled walls alter the lateral stiffness and may cause significant damage due to overstressing from torsion-induced shear forces. Being unreinforced, infilled walls are highly vulnerable to damage due to in-plane seismic shear forces (Figure 2-c) and out-of-plane flexure (Figure 2-d).

PROPOSED SOLUTION: USE OF LOADBEARING MASONRY

Loadbearing stone and brick masonry is one of the oldest building material employed by man as it is evident from the historic remains of the Egyptians and the Greece. Traditional Loadbearing masonry was the most common building system in Egypt (Figure 3-a) until the turn of the century when reinforced concrete frame with infilled walls became the dominant system because of speed of construction, flexibility and lack of skilled masons. Recently, modern reinforced concrete masonry has been used to a limited extent in hotels and commercial buildings, see Figure 3-b. Until today, in remote areas, limestone units cut from local quarries have been used with mortar and light metal roofing for one story housing application by unskilled individuals, see Figure 3-c.

(a) Failure of Beam-Column Connection

(b) Punching Shear Failure of Flat Plate

c) Infill failure due to In-Plane loads

(d) Infill Failure due to Out-of-Plane Loads

Figure 2: Poor Seismic Performance of Reinforced Concrete Frames

(a) Traditional Masonry

(b) Contemporary Masonry

(c) Primitive Masonry

Figure 3: Application of Loadbearing Masonry in Egypt

Contemporary reinforced concrete loadbearing masonry buildings have been successfully used in building construction in North America for over 50 years [1]. Concrete masonry has the following multifunctional characteristics that make it an attractive and cost-efficient alternative to conventional frame construction:

1- Structural framework
2- Defining geometric space
3- Variety of durable architectural finishes
4- Thermal insulation
5- Acoustical enclosure
6- Fire proofing

7- Dimensional tolerance

8- Simple erection techniques

Advances in masonry materials, block manufacturing techniques, design methods and construction techniques [2] result in a competitive market for loadbearing masonry particularly for residential and commercial construction.

A building system, composes of hybrid exterior reinforced concrete masonry walls (acting as the building enclosure) and interior reinforced concrete columns with lightweight partitions, offers an attractive alternative system. This system has the advantage of protective energy efficient building enclosure with flexibility of floor space offered by infill non-loadbearing walls.

CASE STUDY: USE OF MORTARED CONCRETE MASONRY SYSTEM RESPONSE TO NATIONAL NEED

In response to the national needs 8,000 housing units were built in 6^{th} of October City. It was decided to build 1,000 units using loadbearing reinforced concrete masonry. The construction started in June 2010. Figure 4 shows masonry buildings under construction. The rest of the units are built using conventional infilled reinforced concrete frame (see the background of Figure 4).

Figure 4: Loadbearing Masonry Buildings under Construction

CONCRETE BLOCK PRODUCTION

Two-cell hollow concrete blocks having nominal dimensions of 20 by 20 by 40 cm were used in this project. Figure 5 shows a sample of such blocks. Three different colors; namely gray, red and yellow, are produced and used in the project to decorate the front view as shown in Figure 4. The face shell thickness is only 20 mm which does not meet ASTM C90 minimum thickness requirement of 30 mm. The block compressive strength ranged from 10 MPa to 14 MPa.

Figure 5: Hollow Concrete Blocks used in the housing project

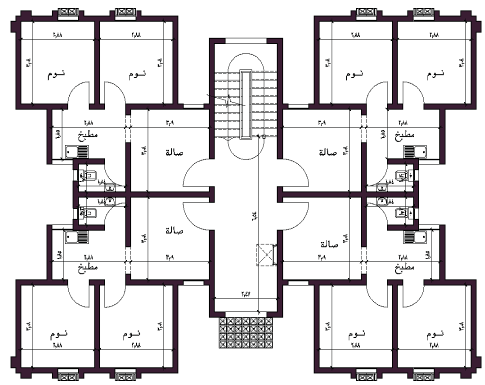
BUILDING DESCRIPTION

The building is six stories high (Figure 6-a). Figure 6-b shows a typical floor plan. Each floor has 4 apartments; each is 43 square meters of usable space.

BUILDING DESIGN

The building was designed using the Egyptian Masonry code which follows MSJC working stress design methodology (MSJC 2008). Seismic loads controlled the design. Walls have to be fully grouted and reinforced at 1.2 m spacing vertically and horizontally. Additional reinforcement was required around openings. Walls are spaced at 3.2- 3.6 m. The floor slab is cast-in-place 12 cm thick reinforced concrete.

(a) Façade of the Building



(b) Typical Floor Plan

Figure 6: Loadbearing Masonry Building at 6th of October City

CONSTRUCTION AND PROBLEMS ENCOUNTERED

The following are problems encountered during construction that resulted in slowing the construction and delays:

1- Excessive cutting of blocks to accommodate horizontal steel, particularly at wall-to-wall intersections resulted in construction delays and increased cost.
2- Mortar Laying: the mortar did not have adequate plasticity and workability probably because of inadequate quality of hydrated lime used. Head joints were not filled properly. Because of the thin face shell, the bedded area was not sufficient and resulted in significant mortar droppings in the cavity. Therefore, cleanouts were placed every cell.
3- Accommodation of electric conduits presented a challenge during construction and affected construction speed.

CASE STUDY OUTCOME

Loadbearing concrete masonry is a viable and a cost-effective building system for housing construction in Egypt. Many challenges are experienced in introducing this new system in the market. The feasibility study conducted shows a cost saving of 10-15 percent. In addition, more durability and less maintenance cost are evident. There is a learning curve and it going to take

time, patience, determination, dedication and hard work to fully utilized this system in building construction in Egypt.
To overcome many of the problems encountered during construction, particularly those related to workmanship, mortarless interlocking masonry is highly recommended. Arab Contractors has already adopted Azar Mortarless System [3] for building construction in Egypt.

USE OF AZAR INTERLOCKING SYSTEM IN EGYPT

The proposed solution to Low Quality, Poor Workmanship and Low Productivity of conventional mortared concrete masonry is to introduce Mortarless dry-stack interlocking concrete masonry construction. In this non-traditional system the blocks are interlocked in the vertical and horizontal directions, see Fig. 7

There are many systems available worldwide. Azar block from Windsor, Canada has been recently introduced in the Egyptian market.

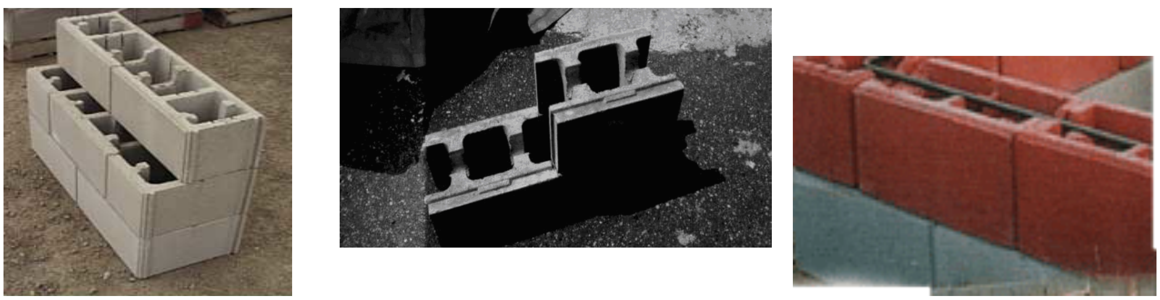


Figure 7: Interlocking Dry-Stack Masonry

Azar Building system [1] is an interlocking dry-stack loadbearing walls with RC floors. No need for reinforced concrete beams and columns. The walls carry the vertical and lateral load from wind or earthquakes. Azar block (Fig. 8) is designed with the following advantages:

1- Aligned Cavities
2- Easy vertical rebar installation
3- Easy concrete grouting
4- Indented web design
5- Easy horizontal rebar installation

The main advantages of Azar System are:

1- Azar system is 5-6 faster than conventional mortared masonry since there is no need for mortar mixing and placement.
2- No need for skilled masons
3- Do-it-yourself
3- Saving on mortar material and labor for placement

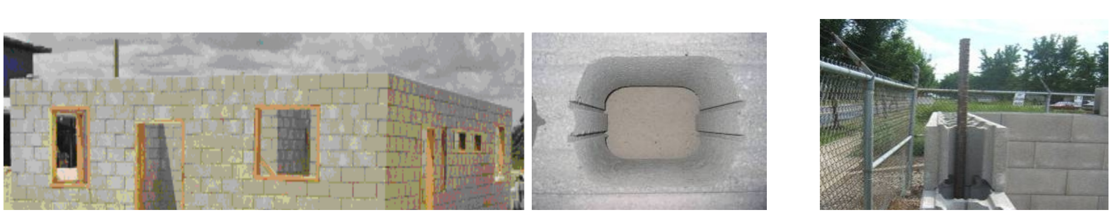


Figure 8: Azar Interlocking Building System

WALL CONSTRUCTION/REINFORCEMENT

There are three ways (Fig. 9) to reinforce/bond the blocks together to form a composite with adequate strength to withstand structural and environmental loads:

1- Gluing the blocks using mortar-bond agent (Fig. 9-a)
2- Surface bonding with wire mesh and plastering (Fig. 9-b)
3- Grouting and reinforcing (Fig. 9-c)

(a) Gluing (b) Surface plastering (c) Reinforcing rods

Figure 9: Constructing Azar Walls

SURFACE TEXTURE AND COLORS

The surface texture can be flat or ribbed (Fig. 10). As shown, different colors can be used depending on the architectural design. Most common stable colors are gray, white and red.

Figure 10: Azar Blocks Texture and Color

QUALIFICATION TESTS

The goal of the test program was to compare Azar units and fully grouted assemblages to similar mortared specimens to be able to draw conclusions regarding the validity and applicability of code's design provisions to Azar system.

UNIT DIMENSIONS AND COMPRESSIVE STRENGTH

Azar Blocks (AB) with nominal dimensions 400 by 200 by 200 mm (Fig. 11) were used in this study. For comparison conventional Blocks (CB) 400 by 200 by 200 mm shown in Figure 13 were adopted. Unit dimensions are presented in Table 1.

Intermediate

Edge

Half

Figure 11: Azar Blocks used for the test Program

Intermediate

Edge

Figure 12: Conventional Arab Contractor Blocks

Table 1: Unit Dimensions

No.	Unit	Overall Dimensions (mm)			Average Face Shells Thicknesses (mm)	Average Webs Thicknesses (mm)
		Length	Width	Height		
1	AB	404	200	200	31	30.5
2	CB	400	200	198	20.5	21

Units were tested under axial compression (Fig. 13) to determine compressive strength according to ASTM C 140. The results are presented in Table 2.

Table 2: Unit Compressive Strength Test Results

No.	Unit	Cross Section Area (mm^2)		Failure Load (kN)	Compressive Strength "f_u'" (MPa)			
					Results		Average	
		Gross	Net		Gross	Net	Gross	Net
1	AB	80000	33328	241	3.01	7.23	3.51	8.44
2				364	4.55	10.92		
3				239	2.99	7.17		
4	CB	80000	26080	318.0	3.97	12.19	3.59	11.03
5				245.0	3.06	9.39		
6				300.0	3.75	11.5		

Azar Block

Conventional Block

Figure 13: Test Setup For Unit Compressive Strength

PRISM COMPRESSIVE STRENGTH

Three 3-course grouted prisms (Fig. 14) with dimensions 400 by 200 by 600 (each consists of 3 stacked blocks) were used to determine masonry compressive strength. The specimens were grouted using coarse grout with 17.2MPa compressive strength. The test was carried out according to ASTM C 1314. The test results for the two types of prisms are presented in Table 3 and typical failure mode is shown in Fig. 15.

Table 3: Prism Compressive Strength Test Results

No.	Unit	Cross Section Area (mm^2)	Max. Load (kN)	Compressive Strength " f'_m " (MPa)	
				Results	Average
1	AB	80000	900	11.25	11.35
2			950	11.87	
3			975	10.93	
4	CB	80000	850	10.62	11.00
5			900	11.25	
6			890	11.12	

AB Prism

CB Prism

Figure 14: Test Setup for Prism Compressive Strength

AB Prism

CB Prism

Figure 15: Failure Modes for Masonry Prisms

DIAGONAL TENSION (SHEAR) TEST

Diagonal tension test was carried out on three grouted specimens constructed with Azar blocks. Square specimens with overall dimensions of 800 by 800 by 200 mm were used. The specimen was tested diagonally under vertical compression load (Fig. 16) following ASTM E 519 provisions. Test results are presented in Table 4 and typical failure mode is shown in Fig. 17.

ANALYSIS OF TEST RESULTS AND CONCLUSION

Azar blocks and conventional blocks have similar physical and mechanical properties. As shown in Table 3, prism compressive strength (f'_m) of Azar prisms is similar to that for conventional mortared prisms. Because f'_m is the basic property for assigning design values, it can be concluded that the code's provision for mortared masonry is equally applicable to Azar mortarless system with fully grouted construction.

For diagonal tension, masonry codes specify diagonal tension (shear) strength in terms of the square root of f'_m with maximum values not to exceed 0.24 MPa for allowable strength design and ???? for strength design. Test value of 1.55 MPa exceeds the code's upper bound value for shear strength. This clearly indicates that grouted masonry built with Azar blocks meets the code's limit of diagonal tension.

Table 4: Diagonal Tension Test Results

No.	Unit	Cross Section Area (mm^2)	Max. Diagonal Load (kN)	Tensile Strength "f_d" (MPa)
1	AB	160000	340	1.50
2	AB		370	1.63
3	AB		350	1.55

Figure 16: Test Setup for Diagonal Tension (Shear) Test

Figure 17: Failure Modes for Diagonal Tension (Shear) Test

AZAR SYSTEM LIMITATIONS

The application of Azar system in structural applications such as multi-story residential construction is limited to fully grouted walls. Test results of fully grouted Azar concrete masonry walls [3] indicated the significant contribution of grouting in providing continuity and adequate compressive, tensile and shear strengths that are comparable with mortared construction. This conclusion is consistent with many other researches [1] that full grouting significantly reduces the contribution of mortar bond strength at the block-mortar interfaces. Thereby, it is safe to conclude that current codes' provisions for mortared fully grouted masonry are applicable to mortarless fully grouted masonry. In addition, full grouting provides adequate resistance to environmental loads and air and thermal flow through the joints.

No data is available on the strength characteristics of partially grouted Azar block masonry walls. Confining the grout in locations of vertical and horizontal steel reinforcement is challenging and poses difficulty in the construction and will significantly impact speed of construction.

PROBLEMS ENCOUNTERED

The main problem encountered is the quality and tolerance of the blocks produced. Many of the recesses of the blocks were broken as shown in Fig. 18. The maximum aggregate size used was larger than allowed to produce thin unbroken recesses for proper interlocking. Also, the tolerance of the block producing machine (Italian-made) was not good enough (produces tolerance greater than 1/16" (1.6 mm). In addition, there is an issue of adequate curing condition that resulted in main hairline cracks, see Fig. 18.

RECOMMENDATIONS FOR IMPROVING BLOCK QUALITY

The following steps have been recommended for improving the quality of Azar block production in Egypt:

1- The geometry of the mold to be modified to increase the thickness of the interlocking projections and recesses.
2- Use a block-making machine with high precision and lower tolerance such as Besser machines.
3- Build an environmental chamber for adequate vapor curing of Azar blocks.

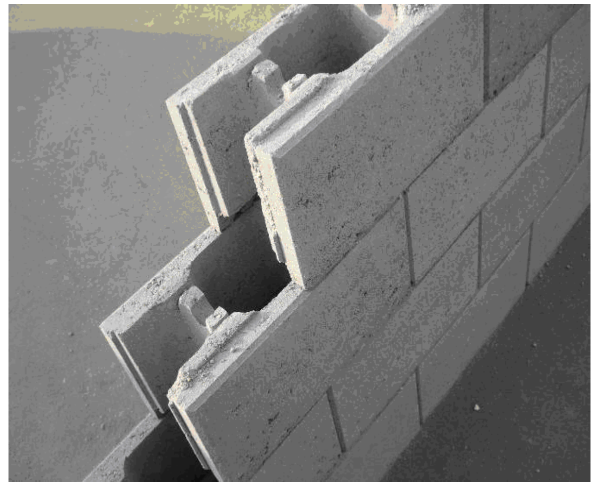


Figure 18: Problems with Azar Block Production in Egypt

CONCLUSIONS

Azar blocks has many advantages such as speed of construction, no need of skilled masons and less cost that make it a viable building system for housing construction in Egypt. Tests reported in this paper demonstrate that compressive and diagonal tensile strength of fully grouted Azar specimens are comparable with conventional mortared fully grouted masonry. Therefore, it is concluded that code's provisions for conventional mortared concrete masonry are equally applicable to fully grouted Azar system.

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