Science and Technology, 1 (1996) 69-80

Modern Concrete Wall-Units with Improved Thermal Resistance for Housing in Hot Climates

By Dr. Jerzy Pierzchlewicz

Department of Civil Engineering, Sultan Qaboos University, PO Box 33, Al Khod 123, Muscat, Sultanate of Oman

خلاصة : هذه الدراسة تقترح استخدام نوع جديد من القوالب المجوفة (الطابوق) لتشييد الجدران الخارجية للمباني . هذه القوالب المقترحة تمتاز بشكل فريد وترتيب معين للتجاويف في الجدار المبنى منها من أجل زيادة المقاومة الحرارية للجدار وأيضا حماية داخل المبنى من الظروف المناخية الشديدة الحرارة . تم اختيار وتحليل تحمل هذه القوالب ذات الخواص الحرارية الجيدة (وكذلك بعض تطبيقاتها) للقوى الضاغطة ن هذه الاختبارات أثبتت أنه يمكن استعمال هذه القوالب ذات التجاويف المصممة بشكل وترتيب معين في بناء الجدران الخارجية الحاملة للقوى في مختلف المباني . هذه النوعية الجديدة من القوالب صممت خصيصا للمناطق ذات المناخ الشديد الحرارة لغرض الترشيد من استهلاك الطاقة في تبريد المباني وكذلك خفض كمية مواد البناء المستخدمة . وبالتالي المحافظة على البيئة .

ABSTRACT: New wall-units have been designed at the Civil Engineering Department of SQU, with improved and reliable thermal insulation properties for construction of buildings in hot climatic conditions, as in the Sultanate of Oman. The thermal resistance of many types of concrete units has been analysed. Hundreds of various types of the new concrete hollow blocks as well as six-column sections made of these wall-units have been tested in full scale. The relationship of compressive strength of the new concrete hollow blocks, walls made of these units and cube samples has been investigated. The wall columns have been tested under axial load and with various eccentricities. The types of column failure have been studied. The aim of the test was to determine the characteristic compressive strength of the new concrete hollow blocks and the characteristic compressive strength of masonry made of these hollow blocks. The results of the test have shown that the new wall-units could have been used successfully for construction of the walls in buildings.

Many buildings are being built so that the external walls fill the spaces between reinforced concrete frameworks. The external walls should be characterized by high thermal resistance to create good microclimate and wholesome living conditions within the buildings. Those external walls made only of solid blocks are characterized by a very low thermal resistance. The temperature within such buildings without cooling is very high especially in the summer. Where air-conditioning is in use, the energy consumption is very high. The consumption of energy for cooling (in warm climates) is much higher than that for heating in countries in cold climatic conditions (in order to achieve the same total difference of temperature between the outside and inside of the building).

Cavity walls are costly and more labour-consuming than single skin walls. Construction of cavity walls requires the erection of two thin walls braced with metal ties (Fig.1). Ties should preferably be of stainless steel which increases cost. Ties made of plastic materials should not be used due to their short durability in hot climatic conditions. The durability of light chemical thermoinsulating materials e.g. styropor, styrotop, polyurethane, polystyrene, is questionable especially in hot climates, because these materials deteriorate in the

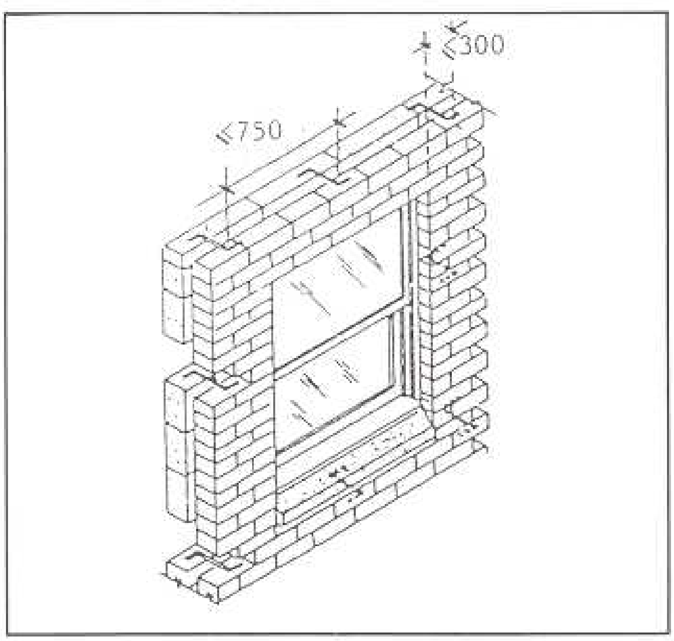

Figure 1. Cavity wall.

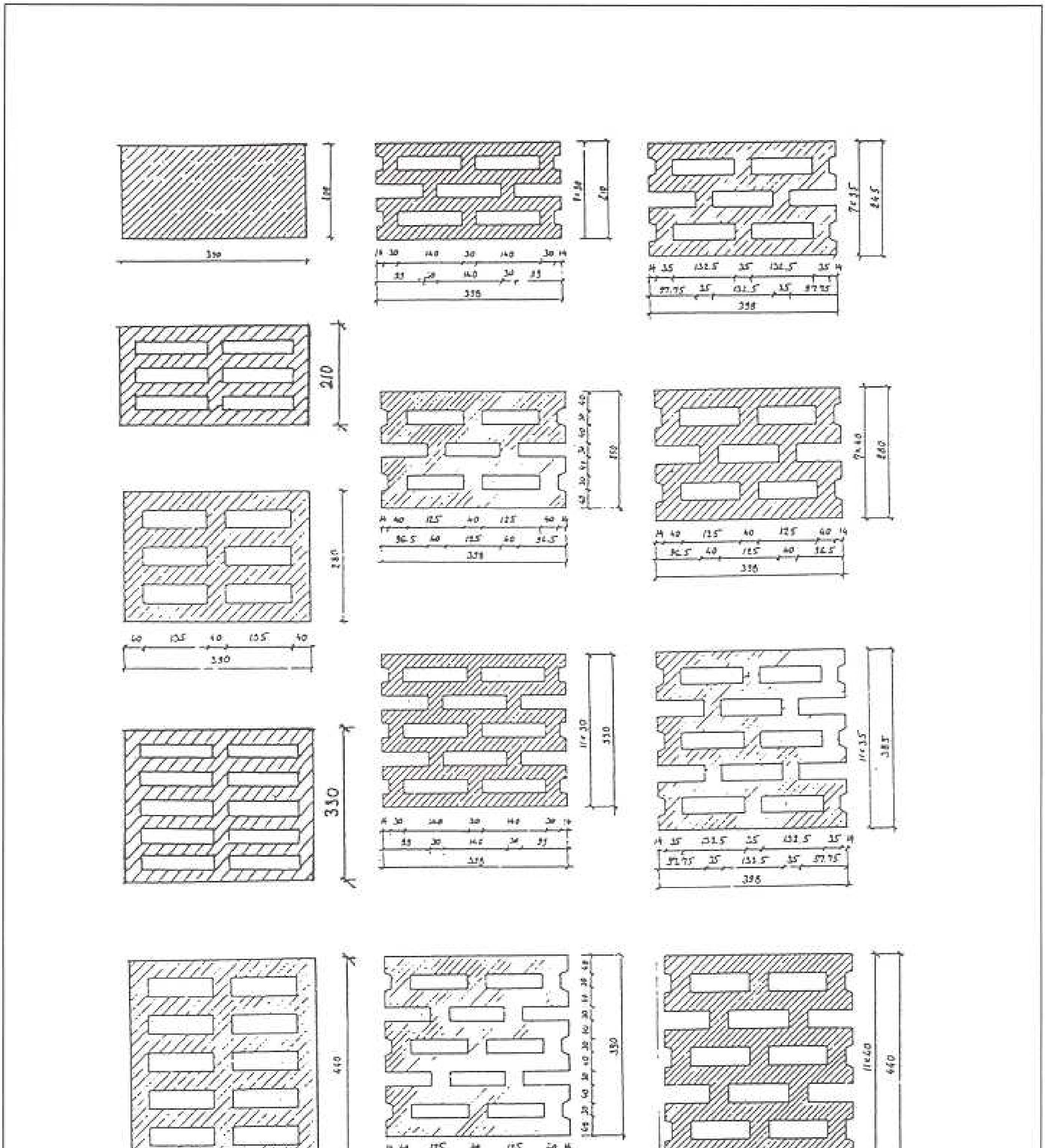

Figure 2. Concrete blocks under investigation.

course of time if exposed to high temperatures. Those external walls erected as cavity walls usually have a lot of thermal bridges. The thermal bridges in external cavity walls render the thermal resistance of the whole enclosure much lower than that assigned for the cavity wall itself, because much more heat flows through thermal bridges than through the cavity wall.

The best way to obtain higher thermal resistance in such walls would be by introducing many air-gaps, cavities, hollows etc. into the wall (Pierzchlewicz, 1994a). The air-gaps do not change the thermoinsulating parameters; they are therefore the most reliable medium for thermal insulation inside the wall.

Wall-units with Improved Thermal Resistance

At present many types of hollow concrete blocks are manufactured but with little attention paid to the thermal resistance of the units. The thermal resistance of the wall is usually only enhanced with an additional layer of thermal insulation material. These units are therefore characterized by low thermal resistance. With the aim of external walls made of concrete units, a particular shape and structure of unit has been elaborated (Pierzchlewicz, 1994b). The following objectives have been assumed for the study of thermal insulation properties:

- to design the concrete wall-unit for an external wall with the highest possible thermal resistance without use of any thermoinsulating material.
- to increase the thermal resistance of the wall-unit by inserting the maximum number of rows of cavities.
- to lenghten the heat flow path through the wall-unit.
- to cancel the direct heat flow through perpend joints.
- to provide wall-units with reliable and stable thermal resistance parameters.
- to decrease the consumption of concrete by increasing the percentage of hollows.
- to decrease the unit weight of external wall.
- to facilitate the construction of external wall.
- to make a wall-unit that can be easily handled.

After a comprehensive investigation the thirteen concrete units shown in Fig. 2 and Fig. 3 have been selected for final analysis.

The minimum thickness of the shell of the hollow block was 30 mm paying attention to the feasibility of units, because the striking off of the moulds must be immediate after concreting and vibrating. The other assumed thicknesses of shells were 35 and 40 mm. The widths of hollows were assumed to be 30, 35 and 40 mm. These thicknesses had been adopted for technological reasons (to make their production possible by companies with lower technology level). Staggering hollows was the basic means used to attain elongation of the heat flow path through the wall. The spacing of transverse shells must be limited in order not to impair the stiffness of the longitudinal shell and to avoid local buckling. There were no particular problems in producing blocks with shells of 25 or 30mm thickness. It is very important to avoid a direct heat flow through perpend joints (vertical transverse joints). Those vertical joints fully filled with mortar are cancelled in the proposed wall structures. Hollows cross the perpend joints. Instead of ordinary vertical joints, pockets filled with mortar have been introduced. That creates a beneficial key-effect in the plane perpendicular to the wall plane (Fig. 4).

Air contained in the hollows does not change its thermal parameters in the course of time and provides the wall with stable and reliable thermal resistance. Moreover air in hollows costs nothing. Reducing the mass of concrete in the unit volume of the wall reduces the

Figure 3. Stack of hollow blocks.

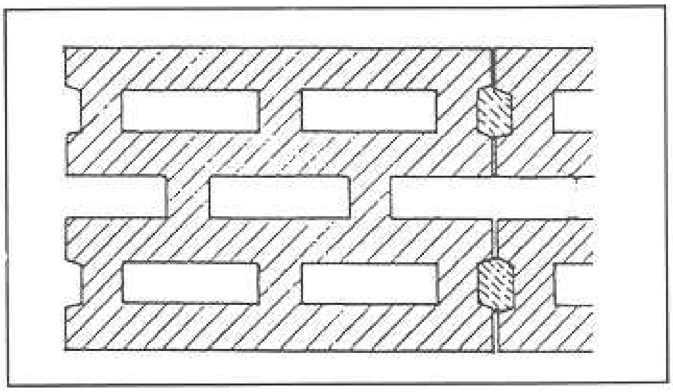

Figure 4. Detail of vertical joint with mortar pockets.

consumption of concrete and cement with beneficial effects on environment and transportation. The construction of walls made of hollow blocks is much easier than the construction of cavity walls where it is necessary to build two leaves of wall and tie them properly. The carrying out of masonry layers made from proposed hollow blocks is very simple especially when the placing of mortar on vertical sides of wall-units in perpend joints is cancelled.
The new wall-units are handy and it is easy to lay them in masonry walls.

Thermal Resistance of Concrete Hollow Blocks

Those walls made of concrete hollow blocks conventionally are regarded as homogeneous enclosures. In this context the thermal conductivity of the hollow blocks may be characterized by only one value of the thermal conductivity called "k_{hb}". The method of determination of the thermal conductivity of the hollow blocks had been proposed by J. Zembrowski (1966) and (1969). The obtained results of numerous tests of hollow blocks have shown a very good agreement with the values given by Zembrowski's formula:

$$k_{hb} = k_c (f_l + f_h/q_h + f_c/W_m) \quad (1)$$

where:

- k_{hb} - thermal conductivity of the hollow block, W/(mK).
- k_c - thermal conductivity of the concrete, W/(mK).
- f_l - the ratio of the hollow block edges' area parallel to the direction of heat flow to the whole area of the hollow block.
- f_h - the ratio of the hollow area to the whole area of the hollow block.
- f_c - the ratio of the concrete area except edges' area (described at f_l) to the whole area of the hollow block.
- q_h - the ratio of thermal resistance of the air in the hollow block to the thermal resistance of the concrete with the same thickness as the hollow's thickness.
- W_m - the average elongation of the heat flow path through concrete in relation to the dimension of the hollow block in the direction of the heat flow.

$$W_m = (W_A + W_B)/2d \quad (2)$$

where:

TABLE 1

Computed Parameters of the Concrete Wall-unit.

WALL-UNIT	Thickness t [mm]	Thermal Resistance R [m²K\W]	Thermal Conductivity K_{hb} [W/(mk)]	Shape factor W_k	Hollow's sizes [mm]	Percent of Hollows [%]	Weight of Wall-unit [kg]
STAGGERED HOLLOWS	210	0.368	0.571	2.119	30/140	34.2	16.9
	245	0.388	0.631	1.918	35/132.5	32.8	20.2
	250	0.367	0.681	1.777	30/125	26.4	22.6
	280	0.411	0.682	1.774	40/125	31.4	23.6
	330	0.643	0.513	2.359	30/140	36.5	25.7
	385	0.671	0.574	2.108	35/132.5	35.1	30.6
	390	0.628	0.621	1.948	30/125	28.4	34.2
	440	0.698	0.630	1.921	40/125	33.6	35.8
ALIGNED HOLLOWS	210	0.242	0.869	1.392	30/150	33.0	16.9
	280	0.304	0.921	1.314	40/135	29.7	23.7
	330	0.389	0.848	1.427	30/150	35.0	25.8
	440	0.487	0.903	1.340	40/135	31.5	36.2
SOLID BLOCK	200	0.165	1.210	1.000	0	0	24.0

W_A - the longest path of heat flow through concrete,

W_B - the shortest path of heat flow through concrete,

d - the dimension of the hollow block in the direction of the heat flow.

There are no straight edges in the proposed concrete hollow blocks. Therefore $f_l = 0$ and hence the formula (1) now becomes as follows:

$$k_{hb} = k_c (f_h/q_h + f_c/W_m) \tag{3}$$

The ratio of the thermal resistance of the hollow block, R_{hb}, to the thermal resistance of the solid concrete block, R_{sb}, with the same overal dimensions is called the "shape factor" and denoted by "W_k" (Zembrowski, 1969). The shape factor expressed by the formula:

$$W_k = (R_{hb}/R_{sb}) = (k_c/k_{hb}) \tag{4}$$

where:

R_{hb} - the thermal resistance of the concrete hollow block, m^2K/W.

R_{sb} - the thermal resistance of the concrete solid block, m^2K/W.

and k_c and k_{hb} have been defined previously.

From formulas (3) and (4), it then follows that:

$$k_c/k_{hb} = (f_h/q_h + f_c/W_m)^{-1} = W_k \tag{5}$$

This formula is the most convenient method of calculation to evaluate the thermal efficiency of the hollow space in the hollow blocks. The thermal resistance of any wall made of wall-units is the resultant of the thermal resistances of hollow blocks and bed joints and perpendicular joints. It has been assumed, for comparison, that all wall-units such as hollow blocks and solid blocks are of the same dimensions. The influence of the bed joints on the analysis could therefore be omitted. Because of the discontinuity in the mortar due to the presence of gaps in the perpendicular joints, the perpendicular joints in the walls made of the proposed hollow blocks have a higher thermal resistance than the walls made of solid blocks or made of hollow blocks with aligned hollow space. The results are shown in Table 1 for wall units presented in Figure 2.

Analysis of Thermal Resistance of Wall-units

Two groups of concrete hollow blocks have been proposed: with three and five rows of hollows (Fig. 2). The hollows are staggered in rows.

The proposed hollow blocks have been compared to the hollow blocks with aligned hollows in groups of three and five rows of hollows respectively and to the solid blocks. The thermal resistance of each group of hollow blocks with staggered and aligned hollows and of solid blocks, depending on the thickness of the wall, is shown in Fig. 5. The acute dips in the curve (for hollow blocks with staggered hollows - Fig. 5) indicate the change in the

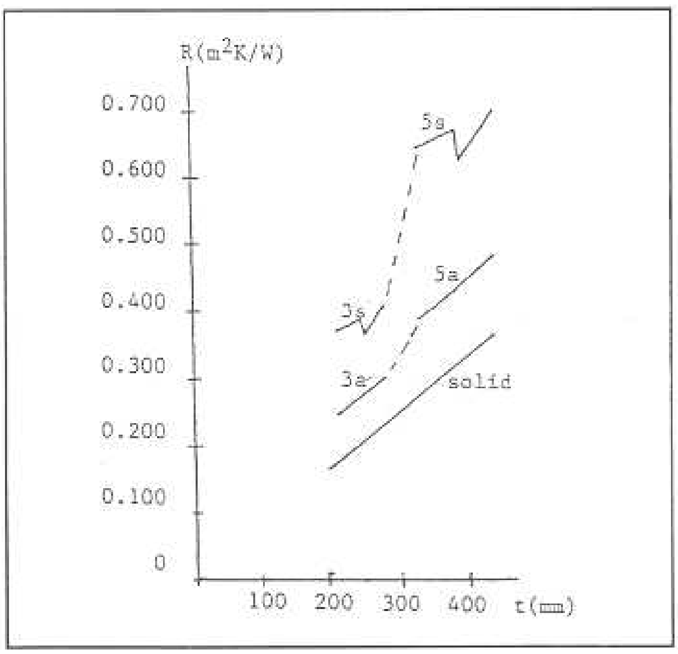

Figure 5. Thermal resistance of concrete wall-units (in relationship to thickness of wall). 3 and 5 - number of rows of hollows; s-staggered hollows; a-aligned hollows.

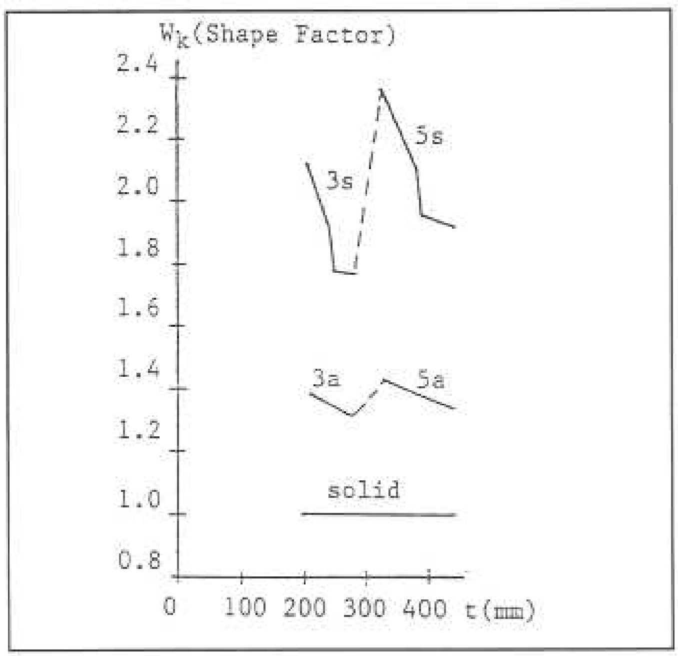

Figure 6. Shape factor W_K of wall-units. 3 and 5-number of rows of hollows; s-staggered hollows; a-aligned hollows.

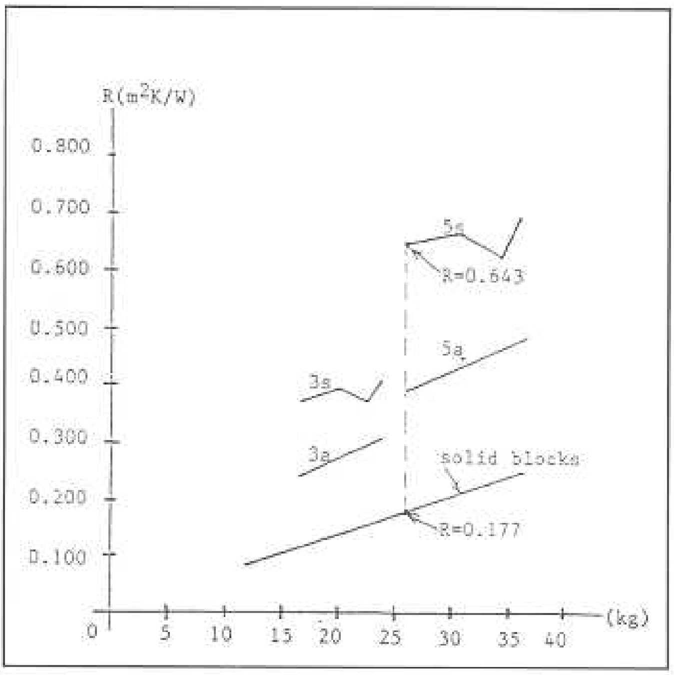

Figure 7. Weight of block or consumption of concrete related to thermal resistance: s-staggered hollows, a-aligned hollows, R-thermal resistance in m²K/W.

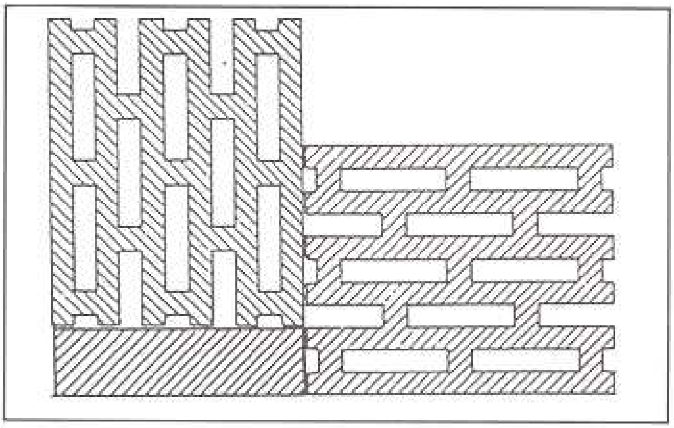

Figure 8. Detail of the corner of wall made of concrete hollow-blocks.

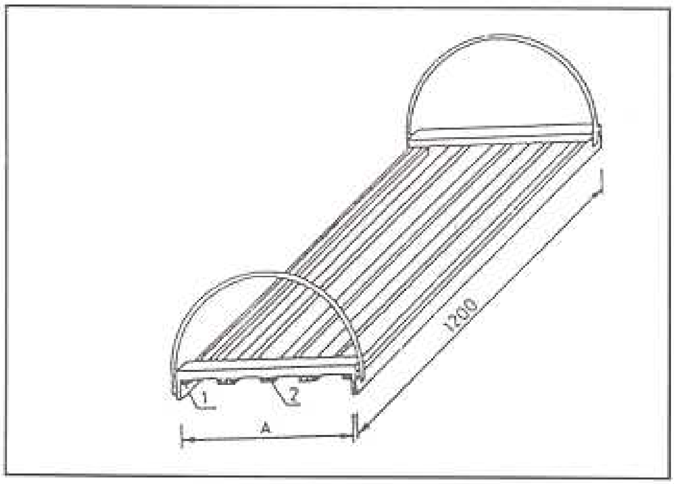

Figure 9. Template for mortar laying in bed joints. 1 and 2-laths over hollows, A-thickness of wall.

hollows' length and shortening of heat flow path. It is clear, analyzing the graph, that hollow blocks with staggered hollows, especially with five rows, are characterized by much higher thermal resistance than other wall-units.

The shape factor W_k indicates the thermal resistance efficiency of the arrangement of the hollows in the hollow block and of the shape of the wall-unit and it is presented in Fig. 6. The higher value of the shape factor W_k shows better design of the hollow block with respect to thermal resistance. Figures 5 and 6 are derived from Table 1.

On average, hollow blocks with staggered hollows in three rows (with respect to their thermal resistance) are 2.13 times better than solid blocks and 1.52 times better than hollow blocks with aligned hollows (assuming the walls are of the same thickness). The gain in thermal resistance with five rows of hollows is greater than with three rows and amounts to 3.37 and 2.65 times respectively. Comparing the units for the same value of thermal resistance the consumption of concrete in the proposed hollow blocks with five rows of hollows is only 28% of that in solid blocks (Fig. 7).

The corner of a wall made of the new hollow blocks is shown in Fig. 8.

The template shown in Fig. 9 is used for the spreading of mortar in bed joints and facilitates the work and does not allow mortar to enter hollows (Pierzchlewicz, 1994a). It is also possible to seal up the hollows at one side (at the top of the hollow block) in the production process but it then reduces the thermal insulation properties of the wall.

Masonry units for compressive test

As a result of the above analysis of the thermal resistance of a number of concrete hollow blocks, four types of new hollow blocks with staggered hollows and two types of hollow blocks with aligned hollows have been selected for analysis of compressive strength of wall units (Fig. 10). The best two types of hollow blocks with staggered hollows (types 3 and 6 with regard to thermal resistance) were selected for analysis of compressive strength of masonry. The hollow blocks types 1 and 2 were tested only for comparison and analysis of the characteristic compressive strength of the wall-units and to define the influence of the staggering of hollows and the influence of the shell's thickness on the compressive strength of the wall-units. All hollow blocks for test of compressive strength of wall-units and (for test of compressive strength of masonry) have been made from the same concrete mix and put to the test in the Laboratory of the Civil Engineering Department, Sultan Qaboos University (Pierzchlewicz, 1995).

The cube strength of concrete was tested with cubes 100x100x100 mm in an Automatic Compression Machine

"ELE". Each part of a cube test consisted of ten samples. The characteristic compressive cube strength of concrete at 28 days was 10.3 N/mm^2. The details of this concrete are given below. The length and height of all blocks were the same. The width of block, i.e. the thickness of the wall, was the only difference. The spacing of bed joints was 150 mm; the height of blocks was 140 mm. The objectives of the research work, regarding the compressive strength were as follows:

- to determine the characteristic compressive strength of proposed new concrete hollow blocks of particular shape and the arrangement of hollows to get better thermal resistance of walls than in those made of the concrete blocks used at present day.
- to determine the characteristic compressive strength of masonry made of two selected types of new concrete hollow blocks with the best thermal resistance.
- to analyse the influence of staggering of hollows and shell thickness on the compressive strength of wall-unit and the masonry.
- to determine the characteristic compressive strength of masonry made of two selected types of new concrete hollow blocks in relation to the given strength of masonry in Table 3 in British Standard BS 5628: Part 1 (British Standard, 1992).
- to investigate the behaviour of the columns made of two types of new concrete hollow blocks under axial load and under eccentric load with eccentricity of 0.2t and 0.3t, where "t" is the thickness of the wall.

Some Aspects of Manufacturing the Hollow Blocks

In the market for manufacturing concrete blocks there are special machines called hollow-block making machines that produce many blocks at the same time and very quickly (Fig. 11). Those moulding machines are usually made of steel and various metals that are durable and stiff enough to sustain the large compressive and vibrating loads. All tested concrete blocks have been manufactured in Civil Engineering Laboratory, SQU, using apparatus designed and constructed in the university. The apparatus and the moulds of the hollow blocks were made of wood with some steel elements.The bottom of the mould was made of two plates. One part of the bottom held together with spigots was movable. The

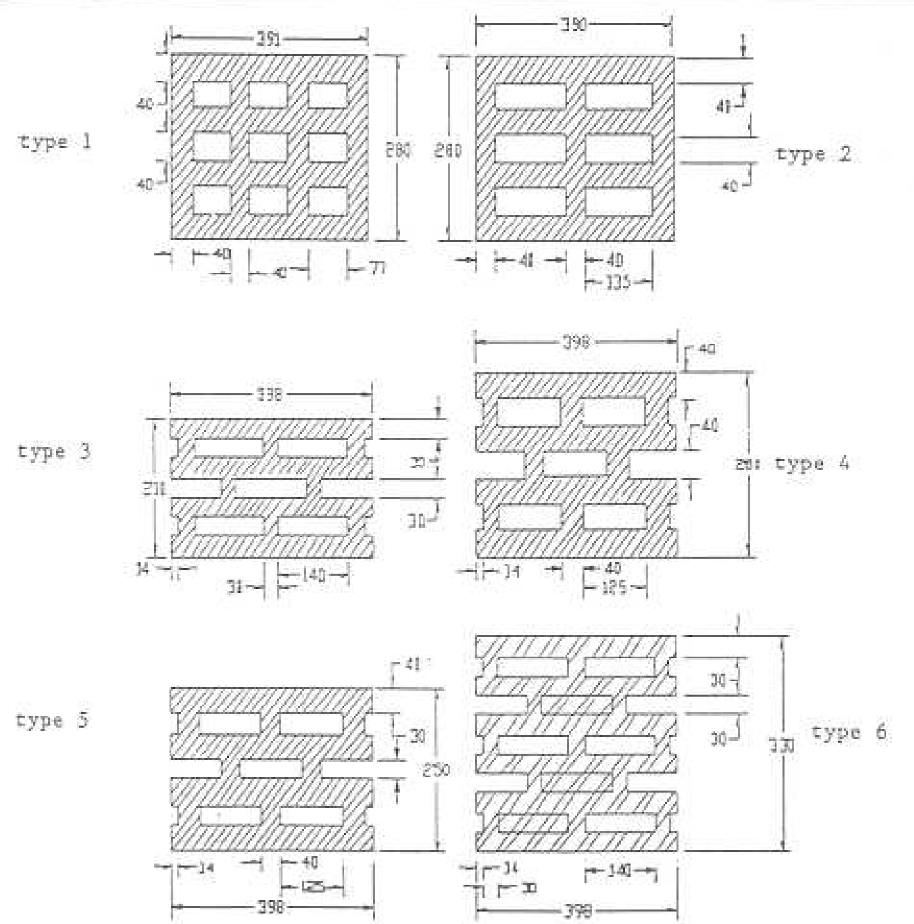

Figure 10. Selected hollow-blocks for compressive strength analysis.

TABLE 2

Some Parameters of Hollow Blocks.

Type of Hollow Block	Characteristic Compressive Strength of unit [N/mm²]	Coefficient of Variation [%]	Percentage of Voids [%]	Thickness of Shell [mm]	Thickness of Wall [mm]
1	15.2	11	25.3	40	280
2	13.8	12.8	29.7	40	280
3	6.2	26.9	34.2	30	210
4	11.5	17.6	31.4	40	280
5	10.4	19.9	26.4	40	250
6	4.9	23.3	36.5	30	330

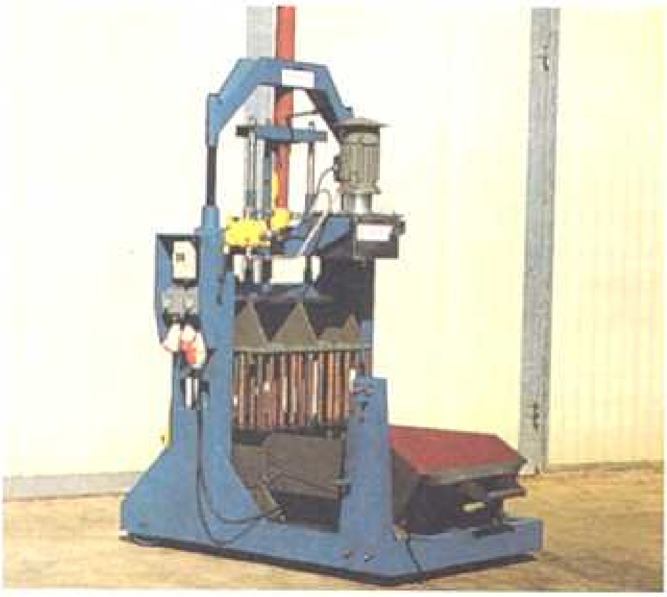

Figure 11. Block-making machine.

Figure 12. Block-moulding apparatus used in the laboratory

sides of the mould were dismountable (Fig.12) (Pierzchlewicz, 1995).

The method employed for the design and manufacture of concrete-mix requires the removal of the mould of a green concrete block right away after concreting.There should be no wait for the setting and hardening of the concrete. Blocks of types 3 and 6 required careful design of concrete mix in order to minimize the slump or the deformation that would have occurred due to the thickness of their shells. After several trials the concrete-mix chosen had the following quantities per 1 m³:

Cement	390 kg
Water	160 kg
Fine aggregate (natural sand)	1129 kg
Course aggregate (max. 6 mm)	730 kg

Test of Hollow Blocks

All hollow blocks have been tested in a universal compression/tension testing machine made by DARTEC Company. The diameter of the piston of the testing machine was 400 mm and therefore it was necessary to use two steel bearing platens 50 mm in thickness in order to avoid projecting corners of the blocks beyond the edge of the piston. Soft boards of 10 mm thickness were placed (one over the lower platen and the second on the top of the hollow block) to distribute the load evenly over the rough surface of the block (Fig. 13). The block was placed symmetrically to the centre of the piston to avoid any eccentricity effect. The test started by compressing the block until complete failure during which the readings were taken and recorded for loads at first crack and at failure. The number of blocks required for individual block test according to Omani Standard OS 1/1977 and British Standard BS 6073:Part 1:1981 is ten blocks per each type of wall unit. The total number of tested hollow blocks was 6x10 = 60 blocks.

Three units of each type of hollow block were sent to the Concrete Block Laboratory at the Directorate General of Specification and Measurements to compare the results. These results were included in test result analysis. The agreement between the test results obtained by the Civil Engineering Laboratory, SQU, and the laboratory of DGSM was very good.

Some parameters of hollow blocks are given in Table 2. Characteristic compressive strength of hollow blocks is shown in Fig.14.

Test of Masonry

Two types of concrete hollow blocks types 3 and 6 were selected to make columns for the test of masonry. Each column to be tested consisted of ten layers of blocks. The height of column was 1.5 m. The mortar used for masonry was the cement : sand mortar of designation (iii) according to BS 5628:Part 1, Table 1. Three columns of each type of hollow block were made. The columns were tested under:

- axial load,
- with eccentricity of 0.2t,
- with eccentricity of 0.3t.

The eccentricity was applied at the top of the column over the upper platen by fixing a solid steel bar of section 70x100 mm at the middle of the upper piston. The column was shifted out of the centre of the piston and of the steel bar to get the required eccentricity distance. A soft board of 10 mm thickness was used under the upper platen to distribute the load over the rough surface of the top hollow block of the column. Two sets of spring gauges were placed at both faces of the column to measure the deflection (Fig.15).

The rate of loading for type 3 was 3 kN/s and for type 6 was 4 kN/s. The load had been applied in increments of 30 kN for type 3 and of 40 kN for type 6. The reading of deflection was taken after each increment. The initial reading of deflection was assumed as zero at the applied load of 10 kN i.e. at approximately 1% of the expected ultimate load to get a uniformly distributed load over the whole area of the column (Fig.16). Load/deflection curve of column made of blocks type 3 with eccentricity e=0.3t is shown in Fig.17.

The characteristic compressive strength of masonry was obtained from test results and was as follows:

- for masonry made of hollow blocks type 3, f_k=4.6 N/mm^2
- for masonry made of hollow blocks type 6, f_k=2.9 N/mm^2

Compressive Strength Analysis

The test of the hollow blocks was done according to the Omani Standard OS 1/1977 and British Standard BS

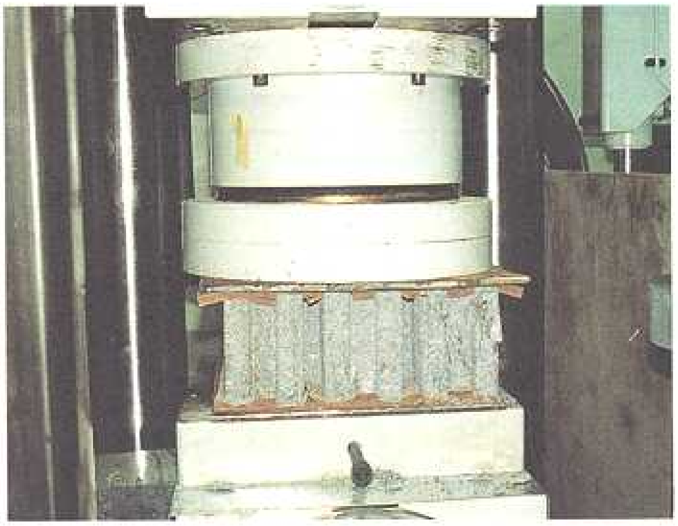

Figure 13. Test of hollow blocks.

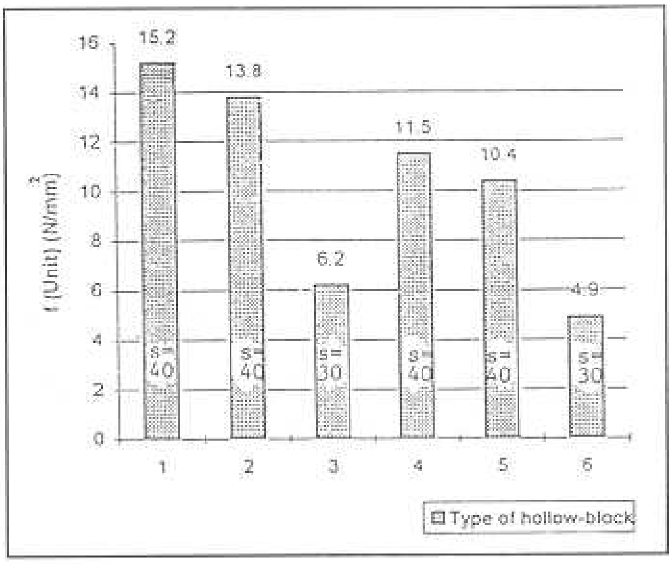

Figure 14. Characteristic compressive strength of hollow-blocks s-thickness of shell.

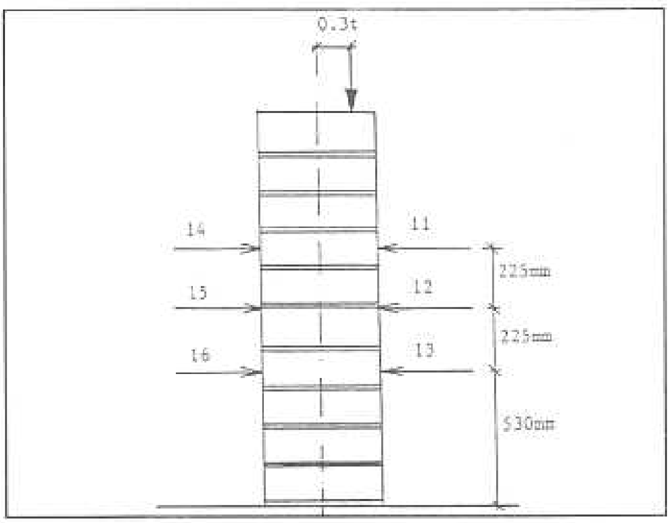

Figure 15. The location of the gauges.

TABLE 3

Some Parameters of Hollow Blocks. [In brackets: percentage of the cube strength]

Type of Unit	Cube Strength $[N/mm^2]$	Hollow Block Strength $[N/mm^2]$	Column Strength $[N/mm^2]$	Masonry Strength after BS 5628 $[N/mm^2]$
3	10.3	6.2 (60%)	4.6 (44.7%)	3.0
6	10.3	4.9 (47.6%)	2.9 (28.2%)	2.45

Figure 16. Test of column.

6073:Part 1:1981 with the sufficient number of samples. All test results were within acceptable limits taking into account the coefficient of variation of obtained results. The hollow blocks with alligned hollows were characterized by the highest compressive strength. All types of hollow blocks with shell thickness of 40 mm were much stronger than ones with the shell thickness of 30 mm (see Fig.14). The percentage of voids in the hollow blocks have less significant influence on the compressive strength of wall-units.

The characteristic compressive strength of masonry made of hollow blocks type 3 was 74% of the characteristic compressive strength of those units. The thickness of the wall was only 210 mm and there were only three rows of hollows within the thickness of the wall (Table 3).

The characteristic compressive strength of masonry made of hollow blocks type 6 was 59% of the characteristic strength of these blocks, whereas the thickness of the wall was 330 mm and there were five rows of hollows within the thickness of the wall. Both characteristic compressive strengths of masonry made of hollow blocks types 3 and 6 are placed well within the strength values given in Table 2(b) in BS 5628. Comparing the compressive strengths obtained from the test with that given in Table 2(b) BS 5628 for the same values of compressive strengths of unit and mortar, the proposed units are characterized by higher values of characteristic compressive strength of masonry than in BS

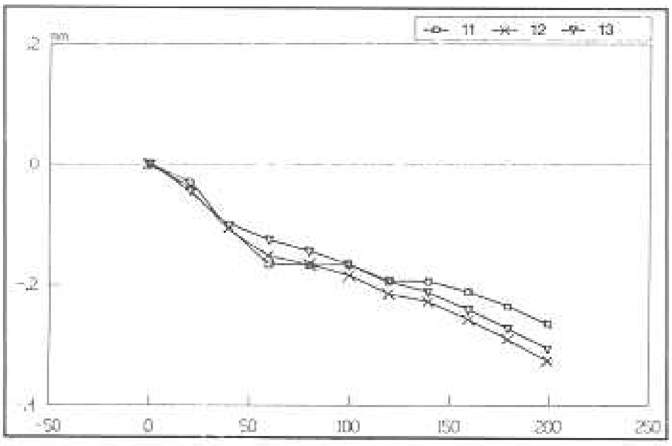

Figure 17a. Load/deflection curve of column test no.6 from linear displacement transducers # 11, 12, 13 (see fig. 15).

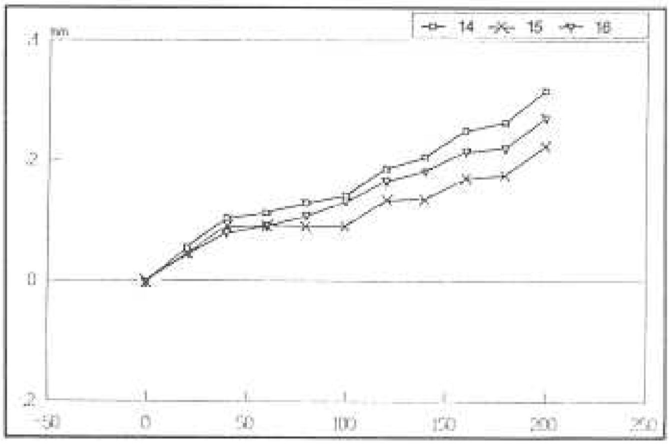

Figure17b. Load/deflection curve of column test no.6 from linear displacement transducers # 14, 15, 16 (see fig. 15).

5628. The characteristic compressive strength of masonry made of hollow blocks type 3 was 53% higher than that given in BS 5628; blocks type 6 were 18% higher than that given in BS 5628. This proves that the proposed hollow blocks types 3 and 6 may be used for construction of buildings. Examples of failures of tested columns are shown in Fig. 18.

Figure 18b. Failure of a tested column.

Summary and Conclusions

The hollow blocks proposed for the construction of external walls are characterized by a particular shape and arrangement of hollows, used in order to increase the thermal resistance of the wall and to protect the interiors of buildings against hot climatic conditions.

External walls, using the proposed hollow blocks with five staggered rows of hollows, are characterized by higher thermal resistance than others and they save energy for cooling the interiors of buildings. The thermal resistance of the proposed external wall-structures is 1.5 to 2.6 times higher than that made of hollow blocks with aligned hollows and 2.1 to 3.4 times higher than that made of solid blocks, assuming the walls are of the same thickness.

The consumption of concrete in the new hollow blocks with five rows of staggered hollows is only 28% of that in the solid blocks assuming the units have the same value of thermal resistance. The proposed hollow blocks of types 3 and 6 may be used for the construction of buildings and the characteristic compressive strength of masonry can be determined from Table 2(b) of BS 5628: Part 1 for appropriate compressive strength of unit and for assumed mortar designation.

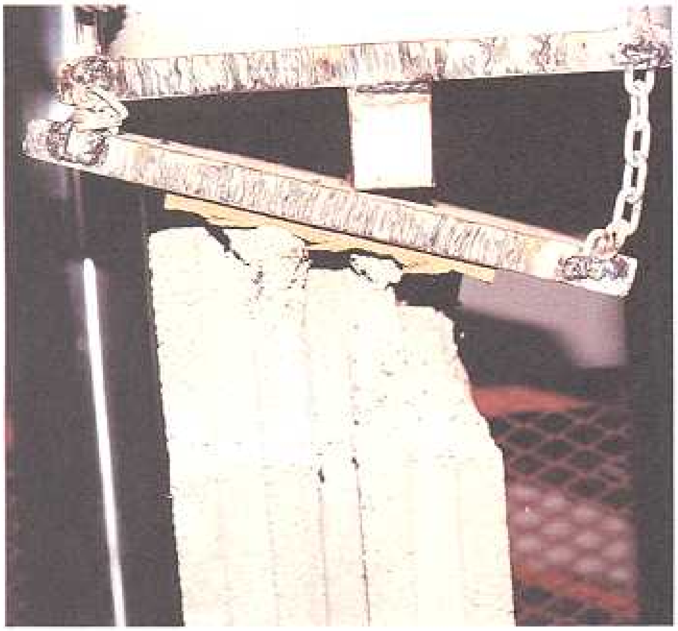

Figure 18a. Failure of a tested column.

Figure 18c. Failure of a tested column.

Walls made of hollow blocks of type 6 may be used as load bearing walls in buildings of up to three-storeys in height, provided that the structural analysis permits that. The use of the proposed hollow blocks for construction of external walls would decrease the consumption of energy for cooling interiors of buildings because such walls are characterized by higher thermal resistance than those erected at present day.

An extension of this work should include a trial design and the construction of a model of a one or two storey building. All necessary field measurements and tests should be done and displayed to clients to indicate the feasibility of this technique.

Walls made of the proposed hollow blocks should be tested in full scale in an environmental chamber to verify the calculated values of thermal resistance presented in this paper.

References

PIERZCHLEWICZ J., and R., JARMONTOWICZ. 1994a. *Masonry Buildings, Materials and Structures.* Arkady, Warsaw.

PIERZCHLEWICZ J. September 18-20, 1994b. New concrete external wall-structures in hot climatic conditions, *Proceedings of ASCE-SAS First Regional Conference*, Manama, Bahrain.

ZEMBROWSKI J. 1966. Thermoinsulation of the Walls Made of Clay Hollow Blocks. *ITB Bulletin No. 22*, Warsaw.

ZEMBROWSKI J. 1969. Influence of the Arrangement and Number of Hollows in Clay Hollow Block on the Value of Thermal Conductivity. *ITB Bulletin No.* **29/30**, Warsaw.

PIERZCHLEWICZ J., and ABDULLAH SAIF AL-HADY. November 16-18, 1995. Compressive strength of masonry made of various types of new concrete wall-units designed for hot climatic conditions and to save the environment, *Proceedings of ASCE-SAS Second Regional Conference "Save The Environment"*, Beirut, Lebanon.

BRITISH STANDARD BS 5628 Part 1 1992. Code of practice for Use of masonry, Part 1 *Structural use of unreinforced masonry.*

OMANI STANDARD for Precast Concrete Block OS 1/1/1977.

BRITISH STANDARD BS 6073 1981, for Precast Concrete Masonry Unit.

Received 23 December 1995
Accepted 14 July 1996