Reception: **August 9, 2018** | Acceptance: **March 11, 2019**

GEOMETRIC AND MECHANICAL PROPERTIES OF HOLLOW CONCRETE BLOCKS MANUFACTURED IN THE AREA OF TUXTLA GUTIÉRREZ (CHIAPAS, MEX)

—

J. Alejandro Ruiz Sibaja[1]
asibaja@unach.mx

Francisco Vidal Sánchez[2]
fvidal@iag.ugr.es

Arcadio Zebadúa Sánchez[1]
zebaduaunach@gmail.com

1 Faculty of Engineering, Universidad Autónoma de Chiapas, Mexico

2 Andalusian Institute of Geophysics, University of Granada, Spain

To quote this article:

Ruiz-Sibaja, J., Vidal, F., Zebadúa, A. (2019). Propiedades geométricas y mecánicas del bloque hueco de concreto fabricado en el área de Tuxtla Gutiérrez (Chiapas, Mex.). *Espacio I+D, Innovación más Desarrollo. VIII*(21), 8-31. doi: http://dx.doi.org/10.31644/IMASD.21.2019.a01

— Abstract—

This paper presents the results of a series of tests for geometric and mechanical characterization of concrete block (from 8 local factories) and cement mortar used in masonry in the region of Tuxtla Gutierrez. The laboratory tests were performed according to standards and protocols of Mexican organisms. The results of the analyzed samples show that the height of the blocks is very variable and differs from the standard values while the other dimensions and wall thicknesses comply with the regulations. The compressive strength of the mortar specimens is good (4 times higher than required). The total water absorption of the blocks is greater than the maximum allowed (12%) in half of cases tested, but the volumetric weight does not reach, in any case, the minimum one required (1700 kg/m³). The compression strength of individual pieces and block piles (manmade with type I mortar) is much lower than that required in the regulations (60 kg/cm² and 50 kg/cm² respectively). The quality and poor strength shown by the tests carried out warn of the need for regulation and local control of the block manufacturing process.

Keywords

Concrete block, mechanical testing, compression resistance, masonry, regulation.

The concrete block (CB) is a basic housing construction material in Mexico, being the most used in the construction of masonry walls. In Tuxtla Gutierrez, as in many other regions of developing countries, geometric and mechanical characteristics are used without evaluating in the laboratory, the pieces of CB manufactured in their environment, which are mostly used. It is often forgotten that these real characteristics are those that must be taken into account, both in the project and in the execution phase to ensure a building with adequate structural response to different types of solicitations, including seismic in active regions.

A large part of social interest houses that are built in Mexico, are buildings of one and two levels, based on masonry and concrete walls, which must withstand vertical and horizontal loads. In large cities, such as Mexico City, the construction of apartment buildings of 4 or more levels is common, for this type of housing.

In Mexico, most homes are built based on masonry walls and reinforced concrete slabs. According to the National Institute of Statistics and Geography (INEGI), most of the houses are structures made of masonry brick, CB, brick thick partition, and stone, that in 1990 were 69.5%, increasing to 75.6, 78.9 and 79.5% in 1995, 2000 and 2004, respectively (Castro Hernández et al 2009), and in 2010 they represented 92.0% of urban housing and 65.4% of rural housing (DOF, 2014). In Tuxtla Gutierrez, 47% of social interest homes are built of masonry walls of CB (Argüello Méndez et al, 2012).

Concrete block is a modular element, manufactured by molding concrete, which is used in both structural and non-structural masonry. It is a compact, rectangular, three-dimensional, gray-natural and rough surface product that began to be used in Latin America in the first decade of the 20th century. Little by little it has been imposed in the construction industry, especially for the ease of its manufacture and the speed in the progress of work.

The use of concrete blocks implies certain advantages, compared to traditional materials such as brick or adobe. It is a versatile material and its uniformity allows the walls to be raised to be completely vertical. The vertical cells of the concrete blocks in the walls are very useful because inside them you can place the vertical reinforcing steel, electrical and hydro-sanitary installations, among others. This avoids perforations in the walls and accelerates the placement of the mentioned systems, which saves a lot of time and labor.

The virtues of this material do not end here, because if they are manufactured or cut in a "U" shape they can be used to build the upper reinforcements of door frames and window openings, also known as lintels. Using this procedure saves time, and a good amount of material. It should be noted that the concrete blocks have a great adhesion to the coatings due to their texture; they are of low absorption, which avoids a bad adhesion by contraction, and have a high compatibility with cement-based elements. In addition, it is possible, for example, to increase its thermal and acoustic insulation capacity by filling the vertical perforations with specific materials for that purpose.

Due to the widespread use of concrete blocks in buildings, both in wall-based constructions and in other types of structures, the construction industry has to produce large quantities of this material to meet this high demand. It has been found that the compressive strength of the brick or block is one of the most important structural characteristics, in particular the strength of concrete parts depends mainly on the quality control of the manufacturing process and the level of industrialization of the plant (Alcocer, 1997). Therefore, these quality controls must be established to ensure the safety of end users of wall constructions with this material.

As an example we will cite some research carried out to identify the geometric and mechanical characteristics of CB's masonry. The vast majority of experimental studies developed in masonry in the world have been devoted to the study of the mechanical properties of materials. In Mexico, the research carried out in the 70's by Professor Meli (1975), which included the study of the variability of the component materials, the determination of basic properties of the masonry in trials of small specimens, the study of behavior before lateral loads in one direction and before alternating loads. This work allowed to improve the design recommendations for masonry structures in Mexico.

Tena et al (2007) researched the response to cyclic loading of mixed masonry walls (based on brick pieces and concrete blocks) and confined. They performed tests of the compressive strength of 12×18×38 cm^3 block pieces and of the adhesive mortar according to the protocol for the Technical Standards for Design and Construction of Masonry Structures (NTCM-17) and the standards of the National Standardization Body and Certification of Construction and Building (ONNCCE). Their results indicate that the properties of the blocks are bad (poor) in general, and do not meet the requirements of Mexican standards, except for the rupture module, which was relatively high ($f_r = 8.14$ kg/cm^2 $\cong$ $0.17\,\overline{f_p}$, were $\overline{f_p}$ is the average of the compressive strength of the pieces, referred to the gross area), greater than the minimum value of 5 kg/cm^2 required in NMX-C-404-2012-ONNCCE. The mortar compression test gave a design index strength $f_j^* = 136.6$ kg/cm^2, greater than the 125 kg/cm^2 established in the NTCM-17 for a type I mortar.

Morales Padilla (2008) worked on the compressive strength of concrete blocks in the Perote region, following the ONNCCE standards. Specimens of 12×20×40 cm^3 were evaluated from three suppliers in this region. The results indicated that none of the suppliers complies with the minimum resistance of 60 kg/cm² required by the regulations, the maximum calculated being the average compressive strength of 36 kg/cm² -only 60% of what the regulations require-.

We will mention some of the work done in other Latin American countries, for example, in Peru Quiun et al (2007) tested 60 masonry piles with axial compression, built with brick and CB pieces, to experimentally determine the correction coefficients applicable to the characteristic resistance f_m' (f_m^* in Mexican regulations) in columns that have slenderness other than the nominal value indicated by Peruvian regulations -5 for the National Training Service for the Construction Industry (SENCICO, 2004) and 2 for the National Institute for the Defense of Competition and Intellectual Property (INDECOPI, 2003) -. The results indicated that the correction coefficients were slightly lower than the values of SENCICO, and lower than those of INDECOPI, 2003 - which are the same as those of the American Society for Testing and Materials (ASTM, 2003) -

Also in Peru, San Bartolomé et al (2007) researched how to improve block-mortar adhesion by using additives (in liquid and powder). Axial and diagonal compression tests were performed on masonry piles, and significant improvements in adhesion were achieved when powder additive was used in the mortar, without altering the compressive strength of the masonry.

In El Salvador, Arias Guevara et al (2013) conducted a comprehensive study on the quality of CB through volumetric weight, absorption and compression resistance tests using parts from six local suppliers. The tests were performed according to the ASTM C 90-99a protocol, which indicates the requirements on the physical properties that the concrete parts must meet. For the determination of the quality control of the blocks, samples were taken from several semi-industrialized factories, for the corresponding sampling. The results showed that the average compressive strength of individual pieces is between 77.93 and 56.74 kg/cm², none of the resistance obtained from the blocks made by the factories under study reached the minimum resistance required by the standard of 133 kg/cm². On the other hand, ASTM C-90 establishes a maximum absorption of 240 kg/m³, which met most of the parts tested, except for a supplier that presented an average absorption of 291.16 kg/m³. As regards density, ASTM C-90 indicates that parts with density between 1682 and 2000 kg/m³ are considered medium weight, thus, five of the lots presented medium weight parts (with densities between 1694.13 and 1948.00 kg/m³) and one of them was of normal weight (with a density of 2079.46 kg/m³).

Navas Carro and Fonseca Mojica (2016) analyzed the results obtained in previous studies on CB masonry in Costa Rica. For pieces of 12×20×40 cm, they found that the values of the individual density of the blocks tested are

2067 kg/m³ (dry condition) and 2243 kg/m³ (saturated condition), values considered as normal weight according to the ASTM C-90.

In Chiapas, despite the wide and attractive use of this material, there is a lack of sufficient studies on the geometric and mechanical characterization of the locally manufactured CB, which allow for a realistic calculation of this type of construction and thus achieve convenient levels of structural safety. On the other hand, there is also no regional construction regulation for the design of structures with this manufacture system. The current construction regulation for Tuxtla Gutierrez does not include a section that addresses the design of masonry buildings or recommends the quality of the masonry elements used.

The ignorance of the geometric characteristics and mechanical properties of this material can lead to hypotheses of incorrect calculation of wall buildings, which can lead, for example, to the presence of cracks in the face of extraordinary phenomena, and even jeopardize their structural functionality. The study of masonry pieces does not only include its compression capacity, other characteristics such as geometry, volumetric weight and moisture absorption must also be evaluated. In addition, the capacity of the mortar that is used to glue the concrete blocks must be known.

Due to the absence of specific regulations in Chiapas, in Tuxtla Gutierrez there is no regulation of the quality of the CB produced by the different manufacturers in the region. As a consequence, there is no uniformity in the manufacture of this material, and in general the blocks are of doubtful and deficient quality, which, in the case of an extraordinary seismic solicitation, can put the structures built with this system and its occupants at risk.

This paper presents the results of controlled tests in the laboratory in concrete blocks, from 8 different suppliers in Tuxtla Gutierrez, and of the adhesive mortar, to be able to estimate the behavior of wall structures. The tests were carried out, from September 2016 to May 2017, in the Laboratory of Soil Mechanics and Materials Resistance, of the Faculty of Engineering of the Universidad Autonoma de Chiapas, in accordance with the protocol indicated in the NTCM-17 standards and ONNCCE. The following tests were considered: geometry measurement, total water absorption, cement-sand adhesive mortar capacity, compressive strength in individual parts and block piles. This is a first approximation to the geometric characteristics and mechanical properties of this material, therefore, only simple compression tests were considered during the tests performed. At a later stage, shear or diagonal tension, adhesion and flexural tests will be carried out to achieve a better approximation to the physical reality of the hollow concrete block. The tests carried out are described below and their results are discussed.

PERFORMED TESTS

The necessary material was prepared in accordance with the recommendations of the aforementioned regulations (NTCM-04, ONNCCE). Thus, for each of the 8 lots tested (with BC from each of the suppliers) the following number of pieces were used for each test:

- Geometry characterization: 10 pieces
- Initial water absorption: 10 pieces
- Simple compressive strength: 10 pieces
- Compressive strength of piles: 3 pieces per battery (3 batteries tested).

Therefore a minimum of 29 pieces were needed for each supplier, but foreseeing some kind of alteration of the material by transport, handling or other unforeseen events, several more pieces were acquired for each lot.

Adhesive mortar

To perform the necessary tests of adhesive mortar, cement was used for masonry, with the characteristics recommended by NMX-C-021-ONNCCE-2015 and NMX-C-414-ONNCCE-2017. The tests with pieces of CB, mortar and batteries of CB were carried out in the Laboratory of Soil Mechanics and Resistance of Materials, of the Faculty of Engineering of the Universidad Autónoma de Chiapas.

Mortar tests were carried out in accordance with NMX-C-464-ONNCCE-2010. Steel molds with dimensions of 5×5×5 cm^3 were used to prepare the mortar specimens. In the tests carried out, the ratio most commonly used for adhesive mortar was used in local professional practice of 1:3 (sand-cement, mortar classified as type I according to NTCM-17).

Mortar paste was prepared considering NMX-C-021-ONNCCE-2015 and NMX-C-061-ONNCCE-2015. With this paste the molds were filled in half, the contents were flatten, they were filled again and each mold was flush. In total, 24 specimens were made, which were stored for 3, 7, 14 and 28 days, respectively. At the end of each period, 6 specimens **were tested under compression** (see Image 1), until the 24 prepared samples were definitively tested. The results for the 28-day specimens are shown in Table 1.

Image 1. Mortar cube test in universal press

Table 1
Compression test results of the 28-day mortar specimens

Test tube number	Final load (kg)	Compression strength (kg/cm²)
1	6321.00	245.43
2	6295.00	246.86
3	6348.00	253.92
4	6290.00	246.67
5	6268.00	250.72
6	6353.00	249.14

The average value of the final load applied (Table 1) was 6312.50 kg, with a standard deviation (σ) of 33.96 kg and that of the compressive strength was 248.79 kg/cm², with a σ of 3.12 kg/cm².

According to NTCM-17 the design resistance f_j^* of the mortar specimens is calculated with the following expression:

$$f_j^* = \frac{f_j}{1 + 2.5C_j} \tag{1}$$

Where f_j is the average compressive strength of mortar cubes and C_j is the coefficient of variation of the mortar's compressive strength, which in no case will be taken less than 0.20. Table 2 presents the results of f_j^* after applying in the expression (1) the values of the compressive strengths of Table 1.

Table 2

Compressive design strength of the 28-day mortar specimens

Test tube number	f_j^* (kg/cm^2)
1	163.62
2	164.57
3	169.28
4	164.45
5	167.15
6	166.09

For the data in Table 2, the mean value of the compressive design resistance and its standard deviation are 165.86 kg/cm^2 and 2.10 kg/cm^2, respectively.

Geometric characterization of blocks

For the geometric characterization of the blocks, 10 blocks were chosen for each supplier, as indicated by NMX-C-038-ONNCCE-2013, and their geometric dimensions were measured with a “king's foot” gauge and a support ruler. They were registered: length, height, width, and thickness of walls and interior of holes. Neither the striatum nor the relief were measured, since the pieces did not have these characteristics. The average and standard deviation of the dimensions recorded for each lot were obtained, as well as for the whole set of pieces (see Table 3).

The wall thicknesses of the pieces of each batch were also measured, calling e1 to the thickness of the walls in the longitudinal direction, and e2 to the thickness of the walls in the transverse direction. The average values obtained from these thicknesses and their standard deviations are shown in Table 4.

Table 3

Average value and standard deviation of the CB’s geometric dimensions

Supplier	Length (cm)	σ Length (cm)	Width (cm)	σ Width (cm)	High (cm)	σ High (cm)
1	39.98	0.10	11.98	0.03	19.21	0.44
2	39.90	0.15	11.93	0.08	19.90	0.13
3	39.86	0.11	11.91	0.07	18.76	0.26
4	39.91	0.08	11.95	0.10	19.84	0.16
5	39.82	0.16	12.02	0.08	20.09	0.35
6	40.14	0.07	12.07	0.11	19.35	0.17
7	39.97	0.04	11.99	0.04	19.83	0.13
8	39.97	0.06	12.00	0.04	19.89	0.15
All	39.94	0.14	12.00	0.04	19.61	0.49

Table 4

Average value and standard deviation of wall thicknesses

Supplier	e1 (mm)	σ e1 (mm)	e2 (mm)	σ e2 (mm)
1	26.83	0.60	25.80	0.64
2	26.67	0.52	24.80	0.58
3	26.91	0.52	25.00	0.52
4	27.59	1.12	25.38	0.68
5	31.96	0.83	29.26	0.68
6	41.25	1.88	28.98	0.78
7	27.02	0.34	27.60	0.28
8	30.28	1.20	31.17	0.44
All	29.81	4.81	27.25	2.30

Water absorption

The volumetric water absorption test (see Image 2) was carried out according to NMX-C-404-ONNCCE-2005. The samples, previously identified by their origin and piece number, were carefully dried and weighed. This weight is called *Ms* (dry mass of specimen). Subsequently the specimens were immersed in water at the temperature indicated by the standard, between 17° and 23°, for a period of 24 hours. After 24 hours they were removed from the container in which they were deposited, and water was removed on all surfaces of the block (faces, gaps and walls). They were then weighed again, and this weight is called *Msss* (saturated and superficially dry mass).

With the data obtained from *Ms* and *Msss*, the volumetric absorption (A) was calculated in percentage in 24 hours with the following expression:

$$\boldsymbol{A} = \frac{Msss - Ms}{Ms} \times 100 \qquad (2)$$

Image 2. Photography showing different stages of the water absorption test

Table 5

Average value and standard deviation of water absorption

Supplier	Average dry weight (kg)	σ Dry (kg)	Average saturated weight (kg)	σ Saturated (kg)	Average % of humidity	σ Humidity (%)
1	11.90	0.21	12.94	0.19	8.81	2.31
2	11.97	0.20	12.84	0.28	7.27	1.15
3	12.34	0.32	13.53	0.38	9.61	1.69
4	11.68	0.32	12.67	0.23	8.55	1.64
5	12.28	0.23	14.39	0.28	17.15	1.10
6	11.96	0.17	13.49	0.38	12.74	2.27
7	11.71	0.21	12.84	0.24	9.65	3.29
8	12.82	0.13	14.04	0.12	9.56	2.76
All	12.08	0.42	13.34	0.65	10.42	3.29

Volumetric weight

The volumetric weight of each block was obtained by dividing its weight by the volume of the piece. The NTCM-17 indicates the minimum specific weights for each type of masonry piece, which in the case of the CB must be 1700 kg/m³. The average specific weights - and their typical deviations - of each lot and of the total population sampled, are indicated in Table 6.

Table 6

Average value and standard deviation of volumetric weight

Supplier	Volumetric weight (kg/m³)	σ Volumetric weight (kg/m³)
1	1239.06	22.16
2	1246.36	21.13
3	1285.42	33.20
4	1216.15	32.87
5	1279.17	24.21
6	1245.83	18.18
7	1219.79	21.80
8	1334.90	13.68
All	1258.33	43.86

Compression of individual parts

Compression tests of both individual parts and piles (NMX-C-404-ONNCCE-2005, NMX-C-464-ONNCCE-2010, NMX-C-036-ONNCCE-2013), require the preparation of a pitching. This is a process of modification of the contact surface, which is necessary for the applied load to be distributed evenly throughout the contact area between the block and the press. The pitch must be done on both sides of the piece (see Image 3). Table 7 shows the average values of rupture load and compression stress along with their standard deviations of compression tests performed on individual parts.

Table 7

Average value and standard deviation of rupture load and compressive strength in individual parts

Supplier	Rupture load (kg)	σ Load (kg)	Compressive strength (kg/cm²)	σ Strength (kg/cm²)
1	6524.60	1738.38	13.62	3.61
2	14307.90	2839.70	30.06	5.98
3	8574.80	2013.00	18.06	4.20
4	9253.20	3016.09	19.39	6.27
5	6091.60	296.44	12.73	0.61
6	25089.70	413.06	51.80	1.08
7	31415.20	717.12	65.56	1.64
8	24896.30	530.66	51.91	1.19
All	15769.16	9501.53	32.89	19.73

Image 3. Individual pieces with sulfur pitch

The NTCM-04 indicates that the design resistance of individual parts should be calculated according to the expression:

$$f_p^* = \frac{f_p}{1 + 2.5C_p} \tag{3}$$

Where f_p is the average of the compressive strength of the pieces, referred to the gross area and C_p is the coefficient of variation of the compressive strength of the pieces; the value of C_p will not be taken less than 0.35 for artisanal production pieces. Design resistances were calculated using expression 3. Table 8 shows the average values and their typical deviations.

Table 8

Average value and standard deviation of the compressive design resistance of individual parts

Supplier	f_p^*(kg/cm²)	σf_p^* (kg/cm²)
1	7.26	1.93
2	16.03	3.19
3	9.63	2.24
4	10.34	3.34
5	6.79	0.33
6	27.63	0.58
7	34.97	0.87
8	27.69	0.63
All	17.54	10.52

Pile compression

Three-piece piles were constructed as indicated by NMX-C-464-ONNCCE-2010. A nod was applied to the pieces of the ends, the blocks were bonded with mortar with a 1:0:3 ratio, common in local practice. Figure 4 shows as an example one of the compressed piles.

Image 4. Compression test in block piles

The specimens were subjected to **compression loading** until rupture and the corresponding effort was calculated for each pile. From this effort the corrected compressive strength of the pile f_m was obtained according to:

$$f_m = \frac{P}{t \times b} \times \text{slenderness corrective factor} \tag{4}$$

In the previous expression f_m is the corrected compressive strength of the pile (in MPa or in kg/cm²), P is the maximum applied load (in N or in kg), t is the thickness of the pile (in mm or cm), b is the width of the pile (in mm or cm). The factor depends on the slenderness ratio of the pile, which is calculated as the ratio between its height and the smaller cross-sectional dimension, in this work a corrective factor of 1.05 was used, which corresponds to a slenderness ratio of 5- according to the NTCM-17.

The NTCM-17 also indicates that the value of the compressive design resistance is calculated from the following expression:

$$f_m^* = \frac{f_m}{1 + 2.5C_m} \tag{5}$$

In which f_m^* is the compressive design resistance and C_m is a coefficient of variation of the compressive strength of masonry piles, which in no case shall be taken below 0.15. Table 9 presents the average values and their typical deviations of breaking load, corrected resistance and compressive design resistance in piles.

Table 9

Average value and standard deviation of breaking load, corrected resistance and compressive design resistance in piles

Supplier	Breaking load (kg)	σ oad (kg)	f_m (kg/cm²)	σ f_m (kg/cm²)	σf^*_m (kg/cm²)	σ f^*_m (kg/cm²)
1	5043.67	488.46	11.08	1.06	8.06	0.77
2	3789.33	386.16	8.42	0.98	6.12	0.71
3	5176.67	412.92	11.35	0.77	8.25	0.56
4	4565.00	430.69	10.08	0.91	7.33	0.66
5	3583.00	32.19	7.79	0.05	5.67	0.04
6	11266.00	380.25	24.27	0.57	17.65	0.41
7	25975.67	567.18	56.23	0.59	40.89	0.43
8	16898.67	189.22	36.75	1.04	26.73	0.76
All	9537.25	7751.62	20.75	16.73	15.09	12.17

DISCUSSION OF RESULTS

Adhesive mortar quality

It should be remembered that the main function of the adhesive mortar is to provide a good adhesion of the masonry pieces, which is achieved with a good dosage, such that it provides adequate consistency, sufficient resistance (to compression and bending) and an appropriate capacity to retain water. In turn, the compressive strength of the mortar depends on the water-cement ratio and especially on the granulometry of the sand, which is established by the fineness modulus.

The tests performed show an acceptable behavior of the mortar tested. In the NTCM-17 and NMX-C-464-ONNCCE-2010, it is indicated that the minimum compressive strength required of the adhesive mortar must be 40 kg/cm². The results found (see Table 2) show that the mortar considered complies satisfactorily with what is required by current regulations. It is noted that this material is of good quality (type I mortar according to NTCM-17), and that the 1:3 ratio that is used in local practice is adequate.

Geometric characteristics of the blocks

The regularity of the geometric dimensions of concrete blocks is a feature that depends largely on the manufacturing process. This uniformity facilitates the determination of representative properties such as: net area, density and moment of inertia; in addition to facilitating calculations of shear and flexural capacity, as well as the determination of stiffness. Therefore, these properties are indispensable for the design of masonry structures.

Lots

The average dimensions of the pieces tested for each of the lots did not show significant deviations in length and width (see Table 3) with respect to the manufacturing dimensions 12×19×40 cm³ considered by NMX-C-404-ONNCCE-2005. However, it should be noted that the height of the CBs had significant deviations, it is also different in each supplier (lack of regularity), and its value differs by more than 5 mm from the standard manufacturing height of said standard, its value closest to the one indicated for the modular dimensions of the blocks (12×20×40 cm3 which includes the 10 mm masonry joint).

This same rule indicates that for pieces with these dimensions the minimum thickness of the walls of the CB must be 20 mm, property that is met in all the pieces evaluated (all thicknesses exceed that minimum value) and also the dispersion with respect to the average is small in each lot (see Table 4). However, it should be remembered that NMX-C-038-ONNCCE-2013 indicates that in the case of block walls exposed to the weather without coating, the minimum thickness should be 30 mm in 90% of the area of said face, therefore, if the tested blocks were used to build walls without an exterior coat, this regulation would not be complied with.

It should be noted that the pieces tested have an average $A_{net} \geq 0.56\ A_{gross}$, which complies with what NMX-C-441-ONNCCE-2013 indicates for non-structural parts ($A_{net} \geq 0.4\ A_{gross}$), and strictly complies with the NMX -C-404-ONNCCE-2012 which, for structural use parts requires that $A_{net} \geq 0.50\ A_{gross}$.

These results indicate that the blocks tested show appreciable variations in height (before current regulations), and therefore in their geometry, and have a lack of regularity between manufacturers since in the manufacturing process molds of non-standard dimensions are used.

Water absorption level

Water absorption from concrete blocks is an important property because it is related to shrinkage and, to some extent, to the durability of the piece. Its importance also lies in the fact that it directly influences the adhesion between block and mortar, since if it is high, the kneading water of the second disappears before sufficient cement hydration occurs, resulting in a partial or total loss of said adhesion and resistance of the mortar itself.

NMX-C-404-ONNCCE-2005 recommends that for concrete blocks, the maximum absorption should be 12%. This degree of permeability, depending on the manufacturing process of the pieces (vibrated, compacted, forced curing, controlled), benefits the durability of the piece and the adhesion between block and mortar.

The results of the tests (Table 5) indicate that the parts of only half of the suppliers comply with what the standard indicates. In the case of suppliers 5 and 6, the blocks absorb amounts of water that are well above what said standard states, 17.15% and 12.74%, with **σ humidity** of 1.10% and 2.27%, respectively, and in the case of Suppliers 7 and 8, although the average absorption value is somewhat less than 10%, its **σ humidity** of 3.29% and 2.76%, respectively, indicates that some of the pieces have a porosity slightly higher than recommended.

Volumetric weight

The volumetric weight is a quality index that indicates how much space the aggregate occupies in the concrete mix; and this feature can be used to separate good material from bad. A block of good quality is manufactured with an adequate proportion of cement and a sufficient time of vibration and compaction, which causes the level of structural resistance to be raised even more, giving it a higher density, lower moisture absorption and better superficial quality texture. It also influences the water-cement ratio of concrete, because the larger it is, the more porous the paste with which the block is manufactured will be.

The calculated average volumetric weights of concrete blocks are less than 1340 kg/m³ in all lots (Table 6), which warns that none of the suppliers meets the minimum value of 1700 kg/m³ required by NTCM-04. This deficit indicates that the pieces studied are too porous and that this deficiency in compactness influences the compressive strength of the material tested.

Compressive strength of individual parts

The compressive strength of concrete blocks is an important feature since the basic function of masonry is to withstand compression loads. This property depends mainly on the density and composition of the CB and its importance can be considered from two points of view: first, the greater the resistance, the greater the durability of the material under extreme weather conditions, and second, the resistance of the pieces affects that of the walls to a greater extent than that of the mortar.

The calculated values of compressive strength of design for individual parts are scarce (Table 8). These values reveal that none of the pieces tested reach the minimum resistance of 60 kg/cm² established by NMX-C-404-ONNCCE-2012. This poor compressive strength, which is only 11.32% (supplier 5) up to 58.28% (supplier 7) of the minimum required strength, implies that the parts tested do not guarantee in any case a good quality masonry, since the concrete blocks must have sufficient mechanical strength to ensure the correct transmission of loads, ensure their durability, and thereby ensure resistant walls.

In addition, NMX-C-441-ONNCCE-2013 points out that for **non-structural** parts the average resistance must be 35 kg/cm², and its minimum resistance is 28 kg/cm², so these pieces are not admissible for non-structural use, except for pieces of supplier 7 that do meet this requirement, those of suppliers 6 and 8 being close to this resistance value.

Compressive strength of piles

The compression test of masonry piles is intended to reproduce in the best possible way the working conditions of the masonry; as a consequence, information is generated that can be used for an adequate structural design of the walls of a building, as well as for a good quality control of the masonry. The test specimens presented a fragile failure, with the development of a vertical crack that cuts the pieces and the mortar; this crack, which began in the pieces and extended to the mortar, is due to lateral expansion caused by the compression applied.

The results achieved show that the compressive design resistance of the piles (see Table 9) ranges from 5.67 kg/cm² (supplier 1) to 40.89 kg/cm² (supplier 7), values that are all below 50 kg/cm² recommended by the NTCM-17 for CB piles made with type I mortar. Despite the good quality of the mortar used for its manufacture, this behavior is dominated by the insufficient compressive strength shown by the individual parts tested.

CONCLUSIONS

In general, the results obtained in controlled tests of concrete blocks manufactured in Tuxtla Gutierrez during 2016 show a poor quality of the pieces tested. The tests reveal that the pieces do not comply with current regulations, with notable deficiencies in their volumetric weight and in their resistance to compression - both individual parts and piles. In addition, a great variability of the parameters measured between batches from different manufacturers has been observed. In other investigations (Tena *et al*, 2007; Morales Padilla, 2008; Arias Guevara et al 2013) it was also determined that the quality of the blocks and the masonry tested does not comply with the reference regulations.

It should be noted that the compressive strength of the adhesive mortar satisfactorily complied, in all cases, with what is required in the NTCM-17 and NMX-C-464-ONNCCE-2010, since the specimens presented capacities for above 40 kg/cm², which indicates that the mortar follows the usual local practice is of good quality.

The pieces tested did not show acceptable geometric uniformity in the block height, which exceeded the standard manufacturing height of the standard by more than 5 mm; each manufacturer supplied pieces of different height and in addition, the pieces of one of them showed a great variation in their height. However, it should be noted that the thickness of the block walls did exceed the minimum specified in the regulations in all lots.

The estimated value of volumetric water absorption is very variable among lots tested, and only in half of them is less than 12% required. In the other cases, the excessive permeability of the CB (greater than 17% in a manufacturer) indicates an appreciable loss in the block-mortar adhesion and a lower durability of those pieces.

The volumetric weight values are low and do not reach, in any case, 78% of the minimum required in the NTCM-17 (1700 kg/m³). This together with the above, shows the convenience of improving the manufacturing process, especially the compaction and vibrating system, to reduce the current porosity. In addition, to reduce or eliminate these deficiencies, manufacturers should make a proper gradation to the sands they use in block manufacturing (in accordance with NMX-C-077-1997-ONNCCE), in order to meet the density that demands the regulation. Arias Guevara *et al* (2013) recommend using a 1:1.5:1 ratio of cement-sand-gravel to achieve parts with optimum absorption, convenient volumetric weight and adequate compressive strength.

The compression tests of the individual parts also showed a very poor and different resistance of the blocks between manufacturers. The compressive design strength values are between 6.79 and 34.97 kg/cm², well below the minimum resistance of 60 kg/cm² required by NMX-C-404-ONNCCE-2012.

The compression test of piles also showed the poor quality of the blocks to build wall structures. The calculated values of compressive design strength of the batteries are clearly insufficient, between 5.67 kg/cm² and 40.89 kg/cm², and are well below the minimum value of 50 kg/cm² established in the NTCM-04. The good quality of the mortar used did not translate into a better compression performance of the tested batteries, so the compressive strength characteristics of the blocks must be improved.

The results obtained show the need for local regulation and control of the manufacturing process of the concrete block to improve its quality and ensure the resistance of the walls that are manufactured with this material, a necessary condition in the local construction sector in which many of the activities are still handmade.

REFERENCES

Alcocer, S. M. (1997). *Comportamiento sísmico de estructuras de mampostería: una revisión.* XI Congreso Nacional de Ingeniería Sísmica, Veracruz, México, pp. 164-191.

Argüello Méndez, T.; Argüelles León, B. y Badillo González, R. M. (2012). Características físicas de la vivienda popular en la periferia urbana de Tuxtla Gutiérrez, Chiapas, México. *Quehacer Científico en Chiapas (4)*, ISSN 1405-6542, pp 4-13.

Arias Guevara, Al. U., Fuentes Aguilera, J. I., Granados Mendoza, V. J. (2013). *Control de calidad de las propiedades de resistencia a la compresión, absorción y peso volumétrico para las unidades de carga de mampostería, fabricados mediante procesos manuales y semi-industriales utilizando agregados de las canteras de Aramuaca y Ereguayquín de la Zona Oriental de El Salvador* (Tesis de licenciatura). Facultad Multidisciplinaria Oriental, Universidad de El Salvador, San Miguel, El Salvador, Centroamérica.

ASTM C 1314, 2003. *Standard Test Method for Compressive Strength of Masonry Prisms*. United States of America.

ASTM C90-99a, 1999. *Standard Specification for Loadbearing Concrete Masonry Units*. United States of America.

Castro Hernández, P. A., Gaspar Vázquez, J. L., Palma Ordaz, N. (2009). *Manual de fabricación de tabicón sólido de concreto* (tesis de licenciatura). Unidad Profesional Interdisciplinaria de Ingeniería y Ciencias Sociales y Administrativas, Instituto Politécnico Nacional, México, Distrito Federal.

DOF (Diario Oficial de la Federación) (2014). *Programa Nacional de Vivienda 2014-2018*. Recuperado de http://dof.gob.mx/nota_detalle.php?codigo=5342865&fecha=30/04/2014.

Fernández Baqueiro, L.; Marín Gómez, F.; Varela Rivera, J.; Vargas Marín, G. (2009). Determinación de la resistencia a compresión diagonal y el módulo de cortante de la mampostería de bloques huecos de concreto. Ingeniería, *Revista Académica de la FI-UADY*, 13-2, pp. 41-50.

INDECOPI, 2003. NTP 399.605. *Método de ensayo para la determinación de la resistencia a compresión de prismas de albañilería*. Perú.

Meli R. (1975). *Comportamiento sísmico de muros de mampostería*. Instituto de Ingeniería, UNAM, Serie Azul No. 352. México, DF, abril, 114 pp.

Morales Padilla, M. A. (2008). *Evaluación de la resistencia a la compresión de blocks fabricados en la región de Perote Ver., de acuerdo a la norma NMX-C-ONNCCE-2004* (Tesis de licenciatura). Facultad de Ingeniería Civil, Región Xalapa, Universidad Veracruzana, Xalapa de Enríquez, Veracruz.

Navas Carro, A.; Fonseca Mojica, C. (2016). Densidad de la mampostería de concreto en Costa Rica. *Ingeniería 26* (2): 93-116, ISSN: 1409-2441; 2016. San José, Costa Rica.

Normas Técnicas Complementarias para Diseño y Construcción de Estructuras de Mampostería. (2017). Gaceta Oficial del Distrito Federal. México.

ONNCCE. (2015). NMX-C-021-ONNCCE-2015. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2013). NMX-C-036-ONNCCE-2013. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2013). NMX-C-038-ONNCCE-2013. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2015). NMX-C-061-ONNCCE-2015. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (1997). NMX-C-077- ONNCCE-1997. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2012). NMX-C-404-ONNCCE-2012. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2017). NMX-C-414-ONNCCE-2017. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2013). NMX-C-441-ONNCCE-2013. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

ONNCCE. (2010). NMX-C-464-ONNCCE-2010. Organismo Nacional para la Normalización y Certificación para la Construcción y Edificación. México.

Quiun Wong, D., San Bartolomé, A.; Mendoza, G. (2007). *Corrección por esbeltez en pilas de albañilería ensayadas a compresión axial*. Proyecto SENCICO-PUCP. Pontificia Universidad Católica del Perú. Recuperado de http://blog.pucp.edu.pe/blog/wp-content/uploads/sites/82/2007/04/Esbeltez-en-Pilas.pdf

San Bartolomé, A.; Romero C.; Torres, J. C. (2007). *Mejora de la adherencia bloque mortero*. Pontificia Universidad Católica del Perú. Recuperado de http://blog.pucp.edu.pe/blog/wp-content/uploads/sites/82/2007/04/Adherencia-bloque-mortero.pdf

SENCICO, 2004. *Proyecto de Norma Técnica de Edificación E.070 "Albañilería"*. Comité Técnico de la Norma E.070. Perú.

Tena Colunga, A.; Artemio Juárez, A.; Salinas Vallejo, V. H. (2007). Resistencia y deformación de muros de mampostería combinada y confinada sujetos a cargas laterales. *Revista de Ingeniería Sísmica No. 76*, pp 29-60

Varela Rivera, J. L.; González Torres, V.; Fernández Baqueiro, L. E.; Vargas Marín, G. (2008). *Determinación de la resistencia a compresión axial y el módulo de elasticidad de la mampostería de bloques huecos de concreto*. XVI Congreso Nacional de Ingeniería Estructural. Sociedad Mexicana de Ingeniería Estructural, Veracruz, Veracruz (México).