Characteristics of Masonry in Romania in Correlation with the European Codes

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SUMMARY:
Most of the loss in the past and recent earthquakes has accured due to the collapse of the buildings, constructed in traditional materials like bricks, which were not particularly engineering to be earthquake resistant. Romania is a very strong earthquake area in a south-east part of the Europe, that is very important to know the characteristics of the masonry, to design the buildings in correct way. The paper refers to the characteristics of the bricks and mortars used in brick masonry, which was commonly used in masonry construction in Romania. The basic components of bricks and mortars used in masonry are determinated with both Romanian standards and European codes.

Keywords: masonry, brick, mortar, characteristics, standards

1. INTRODUCTION

For masonry design in each of the categories accepted in Romania and presented in masonry structures design code CR6 – Eurocode 6 National Annex for Romania:

- Simple / unreinforced masonry (**URM**)
- Confined masonry (**CM**);
- Confined masonry with horizontal reinforcing bars (**CHRM**);
- Reinforced masonry (**RM**).

is necessary knowing the characteristic strength values for structural design of new or existing buildings.

Strength and deformation characteristics of structural masonry need to be determined for each type of masonry according to its specific composition (masonry block – mortar type). It should be noted that for each type of masonry block, specific values are essential for the designer to ensure structural design in accordance with specific national regulations from CR 6 and P 100-1 – Eurocode 8 National Annex.

The following characteristics of strength and deformation are necessary:

a) Strength characteristics to centric compressive loading:
- masonry compressive strength - $\mathbf{f_b}$;
- specific strain at compression failure - $\boldsymbol{\varepsilon_u}$;
- longitudinal elastic modulus - $\mathbf{E_o}$;
- normalized compressive strength perpendicular to bed face - $\mathbf{f_b}$;
- normalized compressive strength perpendicular to bed face in wall's plane- $\mathbf{f_{bh}}$;

b) Strength characteristics to diagonal compression loading:
- in-plane stress on inclined sections- $\mathbf{f_{pr}}$
- shear strain - $\boldsymbol{\gamma}$;
- shear modulus - **G**.

c) Initial shear strength - $\mathbf{f_{vko}}$;

d) Out-of-plane bending strength characteristics:

- out-of-plane bending strength parallel to masonry horizontal joints - $\mathbf{f_{xk1}}$;
- out-of-plane bending strength perpendicular to horizontal joints - $\mathbf{f_{xk2}}$;

2. COMPARATIVE ANALYSIS OF METHODS USED FOR DETERMINING THE DESIGN VALUES FOR STABILITY AND DEFORMABILITY CHARACTERISTICS OF MASONRY

For current use of masonry blocks specific values (design, normalized, average values) of the deformation strength properties obtained in the laboratory, determined on masonry samples made of materials to be used effectively in masonry work must be known. Determination is based on harmonized standards.

Design values used in practice are determined based on normalized values, following a probabilistic analysis. Thus, determination of normalized values for strength is done by taking into account the probability of a number of results obtained from testing masonry specimens and involves the following:

- The use of judicious methods to obtain statistical data, significant both in terms of the phenomenon they describe, and in terms of quantity (numerically, following the establishment of the necessary number of results to be obtained for correct description of the characteristics);
- Probabilistic definition of normalized values: evaluation of statistical indicators of location (mean) and spread (standard deviation, variance, etc.), defining normalized values using fractiles and calculating these fractiles.

By implementing the standards from EN 771-1… 5 series (SR **EN 772-1; SR EN 771-4**), a major change occurred in Romania in terms of the shape and especially the size of masonry blocks. The introduction of thermal insulation requirements and reducing energy consumption (energy efficiency) guided the production process towards hollow blocks with larger volume of holes, the products passing from low density to high density category. Filled pressed ceramic blocks with usual dimensions (240x115x63 mm) called FN "normal format" have been put aside and they become more rare on building materials market in Romania, by improving production processes and introducing new technologies.

In terms of geometrical characteristics the following parameters are specific:

- The pore volume (% of gross volume);
- The volume of each cavity (% of gross volume);
- The minimum thickness of internal and external walls (mm);
- The combined thickness of internal and external wall in each direction (% of the dimension of the element in the direction in question).

From this point of view in Romania in accordance with the requirements of CR 6 code, only unbaked or baked clay or brick blocks or autoclaved aerated concrete (AAC) from groups 1 and 2 having the following characteristics will be used:

Table 1. The characteristics of masonry blocks used in Romania

<table>
<tr><td rowspan="2">Characteristics</td><td rowspan="2">Group 1
baked clay
and AAC</td><td colspan="4">Group 2 Baked clay vertical hollow masonry blocks</td></tr>
<tr><td colspan="2">$a_g \leq 0.12g$</td><td colspan="2">$a_g \geq 0.16g$</td></tr>
<tr><td>Total volume of cavities
(% of gross volume)</td><td>≤ 25</td><td colspan="2">>25; ≤ 55</td><td colspan="2">>25; ≤45</td></tr>
<tr><td>The volume of each cavity
(% of gross volume)</td><td>≤ 12,5</td><td colspan="4">Each of multiple cavities ≤ 2
total handling cavities up to 12.5</td></tr>
<tr><td rowspan="3">Interior and exterior walls thickness
specified value (mm)</td><td rowspan="3">No
requirements</td><td colspan="2">Interior wall</td><td colspan="2">Exterior wall</td></tr>
<tr><td>$a_g \leq 0.12g$</td><td>$a_g \geq 0.16g$</td><td>$a_g \leq 0.12g$</td><td>$a_g \geq 0.16g$</td></tr>
<tr><td>≥ 5</td><td>≥10</td><td>≥8</td><td>≥ 12</td></tr>
</table>

a_g – site's design acceleration determined according P 100 -1 code and EN 998-1 National Annex (for a return period of 225 years).

For some sites it is accept the use of products classified in Group 2S "special" for which the features supported are:

a) block's geometry meets the following requirements:
   - the volume of cavities ≤ 50% of gross volume of the block;
   - the thickness of exterior walls 11 mm ≤ t_e < 15 mm;
   - the thickness of interior walls 6 mm≤ t_i <10 mm;
   - vertical interior walls are continuous throughout the element's length.

b) σ-ε masonry constitutive law a is linear or elasto-plastic with limited ductility.

Masonry manufacturer of the blocks to be used for masonry construction is obliged to declare standardized strength (fb) in documents accompanying products. Determination of strength shall conform to standard operating procedures described in EN 772-1 - Testing methods for masonry.

The methods for determining the strength characteristics to compression (important value for characterizing the masonry) are different depending on the type of masonry block, so for baked normal ceramic blocks, determination is made by processing surfaces with mortar, while the ceramic blocks with "large" dimensions with rows height greater than 150 mm, surface treatment is made by grinding. In the first case cooling specimens is not required and therefore conditioning coefficient for standardized strength is unitary. For autoclaved aerated concrete products the strength is obtained on cubes with sides of 10 cm cut from masonry blocks.

Figure 1. Specimens to determine the compressive strength of pressed full bricks

For vertical hollow masonry blocks in Group 2 and 2S is important to determine the strength values, parallel to the horizontal joint in the wall f_{bh}, in order to characterize the behavior of masonry.

Compressive strength values of ceramic blocks are analyzed by the designer in close contact with the characteristics of mortars used. In Romania the mortars accepted and used for masonry are general purpose (G) or thin joint mortars (T). The masonry building technology using "glue" type mortars is being tested for masonry used in seismic areas.

Compressive strength values of ceramic blocks have experienced continued growth due to improving manufacturing technologies with computer-aided process control parameters so that the production flow is controlled: fineness of grinding, mixing clay, extruding, drying, and baking after controlled curve. In addition to increasing values of compressive strength characteristics of ceramic blocks a significant reduction in their coefficients of variation has been found.

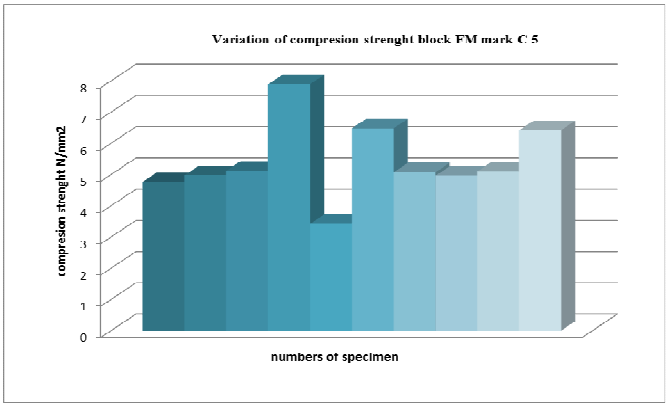

Figure 2. Variation of individual values of compressive strength for ceramic pressed full bricks, normal-technology format until 1995

The values of coefficients of variation comply with the limits presented in Table 2.

Table 2. Values of coefficients of variation for masonry blocks

Masonry block type	Coefficient of variation %
Ceramic full brick normal format 240x115x63 mm	22
Vertical hollow ceramic blocks 240x115x88 mm	10
Vertical hollow ceramic blocks group 2	6
Autoclaved aerated concrete (AAC)	8

It can be observed that for products made using modern technologies coefficients of variation fell very far below the limits of 10%, masonry made with such blocks having greater uniformity. Uniformity may be a consequence of building masonry using good performance mortars.

The analysis of coefficients of variation of masonry compressive strength values obtained in series of 20 specimens, made in different combinations of masonry blocks brands is presented below. The number of specimens results from the calculation of a probability p = 0.05 by applying the relationship:

$$\text{Number of tests} = 1/0.05 = 20 \text{ specimens} \quad (1)$$

The values of the coefficients of variation V%, obtained for general purpose mortars, used in testing the specimens are given in Table 3

Table 3. Values of the coefficients of variation for general purpose mortars used during the experimental program

Mortar use with blocks	Coefficients of variation					
	C5 (blocks)			C10 (blocks)		
	M2.5	M5	M10	M2.5	M5	M10
Ceramic full bricks normal format 240x115x63 mm	9	10	12	12	7	12
Vertical hollow ceramic blocks 240x115x88 mm	10	5	5	9	11	4
Vertical hollow ceramic blocks group 2	-	-	6	-	8	6
Autoclaved aerated concrete (AAC)	6	5	3	-	-	-
Heavy concrete blocks	13	7	-	-	-	-

The values for the coefficients of variation V %, obtained for different combinations of masonry are presented in table 4.

Table 4. Values of coefficients of variation for masonry compressive strength

	Coefficients of variation					
	C5			C10		
	M2.5	M5	M10	M2.5	M5	M10
Ceramic full bricks normal format 240x115x63 mm			12	13	7	12
Vertical hollow ceramic blocks 240x115x88 mm	6	12	15	16	16	13
Vertical hollow ceramic blocks group 2	-	-	6	-	8	6
Autoclaved aerated concrete (AAC)	12	11	12	-	-	-
Heavy concrete hollow blocks	4	5	-	-	-	-

It should be noted that for certain values of variance of the component materials, same levels of values of coefficients of variation for the composite material walls are not found, coefficients of variation being comparable with the coefficients of variation for mortars. Significant differences are visible for masonry built with autoclaved aerated concrete blocks.

3. COMPARATIVE ANALYSIS OF COMPRESSIVE STRENGTH VALUES OF MASONRY USED IN BUILDING DESIGN IN ROMANIA

3.1 Strength values for ceramic blocks masonry

For the analysis of compressive strength values of masonry expressed in N/mm^2, made of baked clay elements of class 1 with rows height less than 150 mm were considered values of compressive strength, determined according to Soviet standards (values used in Romania until the emergence of CR6) that are presented in table 5 and the values determined in accordance with the requirements of Eurocode 6.

Table 5. Design strength values for masonry built with full ceramic blocks and vertical hollow block

Block grade	Mortar grade			
	10	5	2.5	1
	Design strength fb (N/mm2)			
200	2.75	2.25	1.75	1.5
150	2.25	1.75	1.5	1.25
125	2	1.65	1.4	1.15
100	1.7	1.5	1.25	1
75	1.5	1.25	1.1	0.9
50		1	0.9	0.7

The values of compressive design strength of masonry are given for a row height of 150 mm including the mortar joint thickness of 12 mm. The ceramic block grade, was determined and defined according to STAS 457 standard by correcting the surfaces using a layer of mortar.

The values from the table are the design strength values used in design practice according to P 2-85 normative and they were defined in STAS 10109/1-82 standard.

For row heights greater than 150 mm strength values is recommended to be define based on laboratory tests, using the same principles of method.

The variation law obtained by computing the values of design strength provided by STAS 10109/1 standard is given in Figure 3.

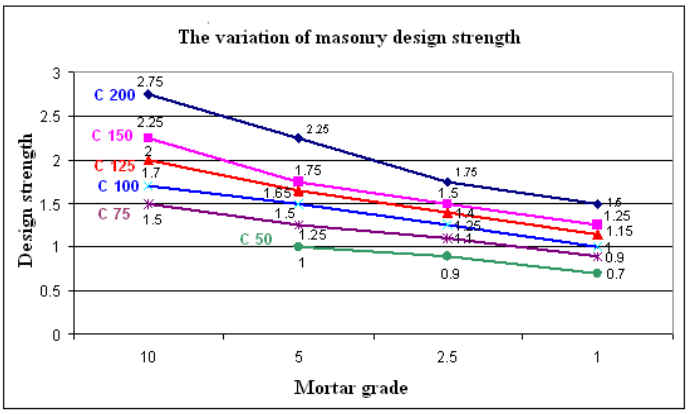

Figure 3. Variation law of design strength used until 2006

The values from table 5 do not consider the existence of median joint nor the imposed restrictions to masonry elements. In accordance with CR 6 code requirements characteristic compressive strength, f_k, of masonry built, using baked clay elements and general purpose mortar (G), for perpendicular loads to the plane of horizontal joints, calculated according to characteristic compressive strength of masonry elements and mortar, is obtained by applying the following equation:

$$f_k = K f_b^{0.70} f_m^{0.30} \tag{2}$$

where:

- K - coefficient depending on masonry element type. K = 0,5 for masonry made of baked clay elements;
- f_b – normalized unit compressive strength of masonry element, on perpendicular direction to horizontal joints, expressed in N/mm^2 , defined according to SR EN 771-1 for baked clay elements. For the values from the table average values of compressive strength of masonry blocks determined according to the previous standard STAS 457 have been considered.
- f_m – average compressive strength of mortar, expressed in N/mm^2 .

The characteristic compressive strength f_k of baked clay masonry specified values is presented in table 6.

Table 6. Values of characteristic compressive strength f_k for ceramic elements masonry

Block grade	Mortar grade			
	10	5	2.5	1
	Design strength, *fk* (N/mm^2)			
200	8.1	6.6	5.4	4.1
150	6.6	5.4	4.4	3.3
125	5.8	4.7	3.9	2.9
100	5.0	4.1	3.3	2.5
75	4.1	3.3	2.7	2.0
50	-	2.5	2.0	1.5

The masonry characteristic compressive strength values for design are determined using the following equations:

$$f_d = \frac{f_k}{\gamma_M} \tag{3}$$

where:

- f_k – characteristic masonry compressive strength perpendicular to bed joints presented in table 6;
- γ_M - material safety factor. In design for obtaining similar results γ_M =3.

The values calculated using material safety factor γ_M =3 are given in table 7.

Table 7. Unit design compressive strengths for baked clay masonry

Block grade	Mortar grade			
	10	5	2.5	1
	Design strength *fk* (N/mm2)			
200	2.7	2.2	1.8	1.4
150	2.2	1.8	1.5	1.1
125	1.9	1.6	1.3	1.0
100	1.7	1.4	1.1	0.8
75	1.4	1.1	0.9	0.7
50	-	0.8	0.7	0.5

The variation law based on design strength values obtained using the equations from CR 6 code is given in figure 4.

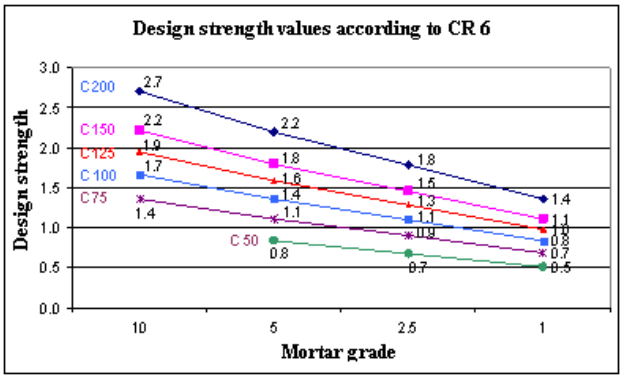

Figure 4. Variation law of design strength used according to CR 6 design code

3.2 Strength values for AAC blocks masonry (BCA in Romania)

For the analysis of compressive strength values expressed in N/mm^2, of masonry made of brick elements the following compressive strength values from STAS 10109/1-82 standard presented in Table 8 were considered.

Table 8. Design strength values for AAC blocks masonry

Block grade	Mortar grade			
	25	10	50	75
	Design strength *fk* (N/mm2)			
50	0.95	0.85		
40	0.85	0.75		
35	0.75	0.65		

The variation law obtained based on design strength values presented in STAS 10109/1 standard for AAC blocks masonry is presented in figure 5.

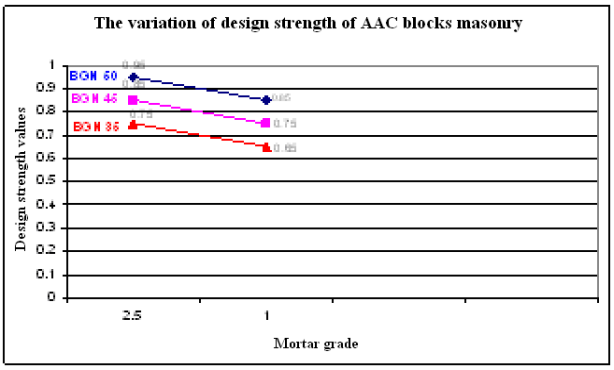

Figure 5. The variation of design strength values for autoclaved aerated concrete masonry used until 2006

The values from table 8 do not consider the existence of median joint nor the restrictions for masonry elements. The characteristic unit compressive strength f_k of AAC elements and general purpose mortar (G) masonry for loads perpendicular to horizontal joints, calculated according to unit compressive strengths of masonry elements and mortar by using the design equation is given in table 9.

Table 9. The values for characteristic compressive unit strength f_k of AAC elements masonry

Block grade	Mortar grade			
	10	7.5	5	2.5
	Design strength fk (N/mm^2)			
75	4.1	3.8	3.3	2.7
62.5	3.6	3.3	2.9	2.4
50	3.1	2.8	2.5	2.0
37.5	2.5	2.3	2.0	1.7
25	1.9	1.7	1.5	1.3

Compressive design unit strengths for masonry made off AAC elements are determined using the equations:

$$f_d = \frac{f_k}{\gamma_M} \tag{4}$$

Calculated values using material safety coefficient γ_M =3 are given in table 10.

Table 10. Compressive design unit strengths for AAC elements masonry

Block grade	Mortar grade			
	10	7.5	5	2.5
	Design strength fd (N/mm2)			
75	1.4	1.3	1.1	0.9
62.5	1.2	1.1	1.0	0.8
50	1.0	0.9	0.8	0.7
37.5	0.8	0.8	0.7	0.6
25	0.6	0.6	0.5	0.4

The variation law determined based on design strength values obtained using the equation provided by CR 6 code is given in figure 6.

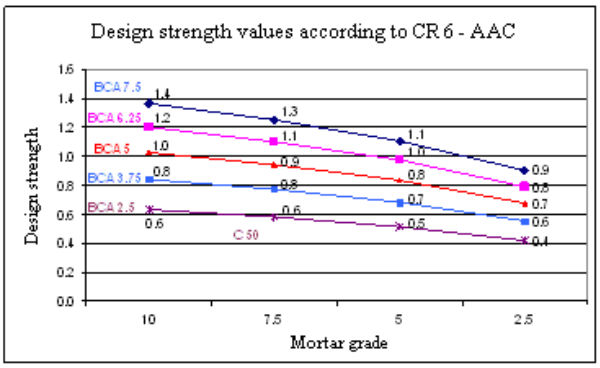

Figure 6. The variation of design strengths for autoclaved aerated concrete masonry used according to CR 6 code

4. CONCLUSIONS

The characteristics of masonry are most important from the point of view of the seismic design. The structural elements such as wall and columns, which were bearing only vertical loads before the earthquake, have now to carry horizontal bending and sharing effects as well. When the bending tension due to earthquake exceed the vertical compression, net tensile stress will acour. To design the structure in achieving seismic safety it must to know the characteristics of masonry specially the compression strength.

From the analysis of compression strength of masonry made with baked clay ceramic blocks and autoclaved aerated concrete (most used in the construction market in Romania) some general conclusions can be drawn.

The analysis was made considering the design values used before the implementation of Eurocodes, values presented in national standards. Values obtained in experimental programs were not taken into account in this analysis.

Following aspects regarding baked clay ceramic blocks are important:

- the values used in design practice are similar to the ones provided by STAS 10109/1-82 standard and the ones calculated based on CR 6 code;
- specified values do not consider the bricklaying techniques used;
- design equations from CR 6 can be used for masonry made of group 1 elements;
- the values are similar for a material safety coefficient γ_M =3.

Following aspects regarding the characteristic design strength of autoclaved aerated concrete blocks masonry, should be noted:

- the values provided by STAS 10109/1-82 have been determined on another sort of mortars used for masonry, e.g. M1, M2.5, while CR 6 code limits the mortar grade above M2.5 grade;
- the specified values do not consider the bricklaying techniques used;
- design equations from CR 6 can be used for masonry made of masonry elements that satisfy the conditions from table 1;
- comparing the results obtained from different combinations of masonry is not possible;
- in CR 6 code contains new superior classes of AAC blocks compared to the ones existing in the market until the emergence of SR EN 771-4 standard.
- The only common combination of the two codes is the one made with M2.5 mortar and autoclaved aerated concrete elements grade 5. For this combination in STAS 10109/1-85 standard the current design strength is f_d = 0.95 N/mm^2, while the value obtained by using

equations from CR 6 code is f_d = 0.7 N/mm^2. A difference of 0.25 N/mm^2 representing a safety reduction of about 26 % can be noted.

A comparison between code design values and the experimental values will be made after completing the experimental programs for determining the strength characteristics of masonry products having modified physical and mechanical characteristics so that they could meet the requirements of CR 6 and P100-1 Romanian codes.

REFERENCES

CR 6 - Eurocode 6 National Annex for Romania
Eurocode 6 Design of masonry structures – European standard (EN 1996-1-1, EN 1996-2, EN 1996-3) .
Eurocode 8 – Design provision for earthquake resistance of structures (EN 1998)
P 100-1/2006 - Seismic design code: Provisions for building design (in Romanian). Eurocode 8 National Annex for Romania
SR **EN 772-1** Testing methods for masonry blocks
SR EN 771-4 Standard for AAC blocks
STAS 457 – Standard for ceramic solid block
STAS 5185 – Standard for perforated ceramic block
STAS 10109/1-85 Standard for masonry characteristics values for design