# Determination of Fundamental Properties of Masonry for different cities of Albania

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## ABSTRACT

This study deals with the properties of unreinforced masonry. Masonry is a two phase material, and the properties of the assemblage depend on that of bricks and mortars. On the other hand, the quality of bricks mostly depends on the type of raw material and the production process. The quality of mortars is more complicated to assess since it depends on its mix design, which is highly variable from batch to batch. The procedure of assessment of properties for bricks and prisms is well established in various standards while the compressive strength of existing mortars has always been a challenge. In Albania there are a considerable number of URM structures and therefore assessing the properties of masonry is an important task. Therefore, samples from Tirana, Vlora, Elbasan, Rreshen and Bulqiza are obtained and tested, mainly in compression to assess the compressive strength of bricks and mortars. Large and highly populated cities are targeted. The expected outcome of this experimental program is the set of mechanical properties of unreinforced masonry for the selected cities, confronted with the design values provided by production factories and theoretical values.

## INTRODUCTION

Masonry is a two phase material, being composed of bricks (or any other type of units) and mortars. Depending on the type of unit it can be classified as stone masonry, adobe masonry, concrete masonry and clay/silicate brick masonry. The units are responsible for the main load carrying capacity of masonry, while mortars are responsible for the cohesion.

Stone and adobe masonry are characteristic of old masonry structures and the structure of the walls is often irregular. In Albania there are a considerable number of masonry buildings with clay or silicate bricks mainly build between 1900 and 1990. The bricks used for construction has been produced by factories with two lines of production M7.5 and M10, i.e. the compressive strength of bricks was 7.5 and 10 MPa [1]. The standard dimension of such bricks is 250×120×65 mm. The mortar is in-situ casted and its properties greatly vary on the mix proportions used for each mix therefore it is difficult to standardise.

It is of importance to gain an insight on the characteristic properties of brick masonry in Albania. There is no existing database for existing masonry properties in Albania. For this purpose, samples of bricks and mortars have been obtained from existing structures. The locations from which brick specimens have been obtained are Tirana, Vlora, Rreshen, Bulqiza, Elbasan. The locations from which mortar samples have been taken are Rreshen, Tirana and Vlora.

Variation in production lines, the raw material used, such as clay from different areas, age and exposure conditions directly affect the properties of bricks and consequently the behaviour of unreinforced masonry buildings. For a reliable assessment of URM buildings, the compressive strength of bricks and mortars should be determined. The aim of this study is to investigate the compressive strength of masonry for existing representative buildings in Albania. The bricks are obtained from highly populated cities, where main brick production factories are located, and the raw material is likely to vary.

These specimens are tested in laboratory, based on ASTM standards and the properties are correlated according to the Eurocode 6 equations, as described in many literatures [2]. For mortars it is not possible to draw location-oriented conclusions, since they are not produced in factory, under certain control. Whereas they are usually mixed in-situ, where the proportions, and as a consequence, the properties vary greatly for each mix. However, existing mortar properties need to be specified for reliable assumptions hence assessment of existing structural performance.

As masonry structures have bearing walls as load carrying elements, masonry is primarily designed to work in compression. Besides, all structures may be subjected to earthquakes, which induce shear forces and deformations to URM buildings. Therefore, when design of URM structures is considered the most important properties are the compressive strength, elastic modulus, shear modulus and shear strength of masonry assemblages. As masonry assemblages or prisms are composed of bricks and mortars, the properties of the prisms directly depend on the properties of its constituents. Eurocode 6 [3] correlates the compressive strength of bricks and mortars with the compressive strength and shear strength of prisms.

ASTM standards provide guidelines for the tests on masonry prisms [4-5] and masonry units [6]. The ASTM test on mortars is not applicable to existing buildings' mortars, since it requires 50 mm-cubes. Different studies have tried to build test procedures on irregular mortar samples. Drdacky [7] has experimented with mortar samples of different heights and aspect ratios, to obtain correlations between the compressive strength and the geometric characteristics of the samples. The heights of mortar specimens range from 6-40 mm, while the areas are 20×20 mm, 40×40mm and 60×60 mm. For different mix-proportions of mortar and for different compressive strengths have been obtained charts relating the strength and the dimensions of the specimens by Lumantarna [2].

## TESTING PROGRAM AND EMPIRICAL EQUATIONS

For purpose of this experimental program, a series of samples are taken from above mentioned cities. Bricks from Vlora, Tirana, Rreshen, Elbasan, Bulqiza (Figure 1) are tested under compression. Mortar pieces were taken from Rreshen, Tirana and Vlora. These pieces were cut to obtain samples, 21, 7 and 3 samples respectively, shown in Figure 2.

The procedure for the compressive strength test on bricks is given by ASTM C67-07 [5]. The bricks are oven dried for at least 24h and then cooled at room temperature and capped (Fig. 1) according to ASTM C1552-07 [10] and tested in compression.

Figure 3 Brick specimens


Figure 4 Mortar samples cut into regular forms

The standard procedure for testing mortar samples consist of having standard cubes of 50 mm as per ASTM C109 [11]. This size of specimen cannot be obtained in existing buildings, where the bed joint ranges from 15 to 30 mm. Therefore the irregular mortar pieces are cut into regular shapes-rectangles. The specimens are measured, and the dimensions are noted down. The samples are tested in compression. Equations 1-4 correlate the compressive strength of standard mortar specimen from non-standard specimen [2]:

$$f_j = \alpha_{t/l}\alpha_{h/t}f_i \quad (1)$$

$$\alpha_{t/l} = 0.48\frac{t}{l} + 0.52 \quad (2)$$

$$\alpha_{h/t} = \frac{1}{M.F.} \quad (3)$$

$$M.F. = 2.4\left(\frac{h}{t}\right)^2 - 5.7\left(\frac{h}{t}\right) + 4.3 \quad (4)$$

When planning the mortar tests, it was aimed to get similar dimensions of specimen as described in the literature [7], but as some of the specimens were very weak, the sizes of the specimen were random. The mortars are cut in regular forms as much as possible (Fig. 3-4).

Figure 5 Mortar specimen being cut


Figure 6 Cut mortar specimen

The mechanical properties of masonry prisms depend on the properties of its constituents, bricks and mortar. Eurocode 6 [3] provides several equations to relate the mechanical properties of bricks and mortars with the properties of the prisms.

The **compressive strength of prisms** is obtained from the compressive strength of bricks and mortars from the following correlation:

$$f_k = K f_b^a f_j^c \quad (5)$$

*Where $f_k$ is compressive strength of masonry, $f_b$ is compressive strength of bricks, $f_j$ is the compressive strength of mortars, while constants K, a, c depend on the type of masonry, and type of mortar.*

For general purpose mortar, which is the case of the materials herein studied, the equation is:

$$f_k = 0.55 f_b^{0.7} f_j^{0.3} \quad (6)$$

The **elastic modulus of masonry prisms** is obtained from the compressive strength of the prisms as:

$$E = K f_k \quad (7)$$

*where K is a constant that varies in the range [200; 2000]. The most typical value if K=1000.*

The **shear modulus** is correlated with the elastic modulus by the following equation:

$$G = 2 \times E \times (1 + \rho) \quad (8)$$

*and typically is taken as:*

$$G = 0.4 \times E \quad (9)$$

*assuming that Poison ratio is taken as $\rho$=0.25* [9]

## RESULTS AND DISCUSSIONS

The experimental work presented in this paper consists of tests performed on bricks and mortars. Tables 1 and 2 present the results of the compressive strength test on bricks and mortars, while Table 3 presents the correlated compressive strength, elastic modulus and shear modulus for masonry.

Table 1 Compressive strength of bricks

| • **Location**<br>• **(nr of samples)** | **Average Compressive Strength (MPa)** | **Variance** |
|---|---|---|
| Tirana (11) | 21.91 MPa | 3.65 |
| Vlora (8) | 19.28 MPa | 3.84 |
| Rreshen (7) | 12.71 MPa | 7.89 |
| Elbasan (6) | 14.07 MPa | 2.87 |
| Bulqize (6) | 20.29 MPa | 4.68 |

Table 2 Compressive strength of mortars

| **Location (nr of samples)** | **Corrected Compressive Strength (MPa)** | **Variance** |
|---|---|---|
| Tirana (7) | 3.56 MPa | 1.19 |
| Vlora (3) | 6.21 MPa | 1.09 |
| Rreshen (21) | 2.42 MPa | 0.97 |

Table 3 Compressive strength elastic modulus and shear modulus of masonry of masonary

| Location | Compressive Strength (MPa) | Elastic Modulus (GPa) | Shear Modulus (GPa) |
|---|---|---|---|
| Tirane | 6.99 | 6.99 | 2.79 |
| Vlore | 7.55 | 7.55 | 3.02 |
| Rreshen | 4.25 | 4.25 | 1.70 |

The compressive strength, elastic modulus and shear modulus for masonry given in Table 3 are calculated with equations (5-9). Variances are observed in the results of the tests on bricks and mortars (Tables 1 and 2), which is common for masonry [12] .The results obtained from this test program (brick test) can be shown visually in Figure 5:

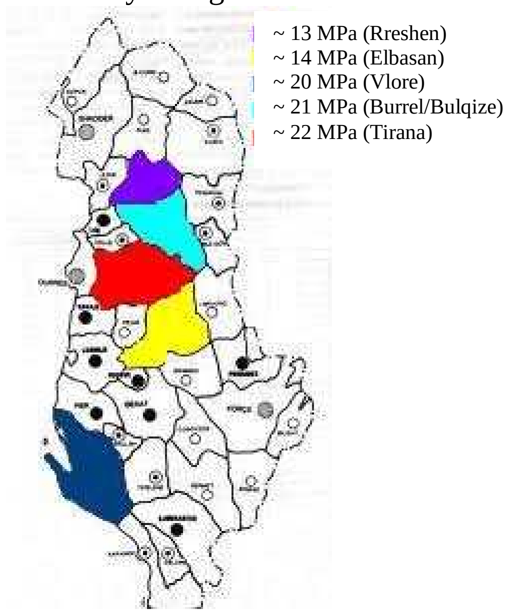


Figure 7 Map of Brick Compressive Strength in Albania

## CONCLUSIONS

This paper presents a study related to the properties of existing masonry in Albania. The difficulties in characterizing the most important material properties that are used in design and analysis are observed. During the experimental program, the compressive strength of mortars and bricks is determined with the compressive strength machine. Thereafter the properties of masonry prisms are correlated from these data. Bricks were taken from 5 cities, while mortars were taken from 3 locations. As expected, variations were encountered for both brick and mortar tests, even within the same sample location.

The test results showed that:

- The compressive strength of bricks is considerably high, when compared to the theoretical values provided by the literature. It ranges from 12.71 to 28.36 MPa. At the same time, the standard deviation of the series is relatively high. When compared to the theoretical compressive strength from the literature, 7.5 to 10 MPa, all the test results are higher, indicating a better quality than assumed in design.

- The compressive strength of mortars is low to medium. It ranges from 2.42 to 6.21 MPa. Variations are encountered in the test results, which is common for mortars.
- The compressive strength, elastic modulus and shear modulus of masonry is calculated from the Eurocode 6 equations. The compressive strength of masonry ranges from low to medium, in the interval 4.25 to 7.55 MPa.
- A map is produced which color-codes the compressive strength of bricks for 5 cities of Albania, with the aim in completing and improving it in the near future.

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