Characterization of materials used for earth architecture in Eastern Croatia

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Abstract. Even though earthen architecture is recognized as cultural heritage in Croatia, most of existing buildings are in deteriorated and heavily damaged state. Until today, there has been no conducted research on earthen architecture in Croatia, nor was any preservation act proclaimed. Therefore, the purpose of this research is to learn more about behaviour of traditional earthen architecture to highlight the importance of sustainable building. For that purpose, earthen houses in Eastern Croatia, mainly Slavonia and Baranja area, were studied and in-situ samples were collected. In order to learn about characteristics and composition of mixtures, five samples were tested. Results gathered within this research will be the first step towards creation of national standard for designing rammed earth structures. In scope of future research, authors are planning to use verified recipe in making of walls that will be tested for seismic resistance.

1. Introduction

Earth architecture was very popular in 19^{h} and 20th century in Eastern Croatia [1]–[3] as well as in most parts of Europe[4]–[7] and even world [8]–[11]. However, with implementing baked bricks and later concrete into civil engineering practice, earth construction faded away. Existing earth constructions in Croatia are recognized as cultural heritage but most of them are in heavily damaged state. To this day, no research has been conducted on earthen architecture in Croatia, nor was any preservation act nor building standard proclaimed.

Earth buildings can be built using different techniques, such as adobe, rammed earth, cob and more. Authors conducted field research and found numerous rammed earth constructions and their high occurrence in Eastern Croatia was also confirmed by Lončar-Vicković and Stober [1] and Živković [2]. For that reason, scope of this research are constructions built using rammed earth technique. Traditionally, rammed earth wall is built by pouring earth mixture between formwork and ramming it using wooden rammer [1]. However, today wooden rammers are usually replaced by pneumatic rammers [12]. After ramming, thickness of a layer usually decreases from about 15 cm to about 10 cm [12]. Process is repeated until desired height of the wall is reached. Layers are distinguished on face of the finished wall, as shown in Figure 1.

Figure 1. Visible layers on face of the RE wall (author's archive).

The aim of this research is to learn more about the behaviour of earthen material in construction. For that purpose, authors conducted field research and visited still existing rammed earth houses and outbuildings in Eastern Croatia (Figure 2). Several buildings have been measured in detail, examined, and photographed, and material samples were collected from walls of houses for characterization.

Figure 2. Rammed earth houses in Eastern Croatia (author's archive).

Collected material was tested in laboratory at Faculty of Civil Engineering and Architecture Osijek. Presented results were gathered from preliminary tests and simplest experiments conducted on five different samples taken from observed houses. Along results from Eastern Croatia, in following paragraph, a digest of results from Europe is presented as well.

2. Material used in earth architecture in Europe

Majority of studies dealing with behaviour of rammed earth structures in Europe to date originate from France and Portugal. Difference in results of material properties are inevitable due to differences in local soil. For that reason, material properties presented in other studies from Europe are good for understanding referent values but should not be the goal.

Earth mixtures used for rammed earth structures usually comprise fine and coarse aggregates [13] in different ratios, depending on location. Optimum moisture content is usually obtained using Proctor compaction test [14], [15]. Moisture content in time of building the wall is crucial and it should be kept at about 10 %, according to Bui, Morel et al [12]. However, during and after curing, moisture decreases. Curing time usually lasts for 28 days, following norms for concrete structures [13], [14], [16], and during that time, moisture content decreases on average to 2 %. However, according to Schroeder [17], rammed earth needs more time to dry completely, so the author recommends 90 days of curing.

Based on 40 reviewed studies published over the last 25 years [10], [13], [23]–[32], [14], [33]–[42], [16], [43]–[51], [17]–[22], dry density varies from 1.53 g/cm^3 to 2,19 g/cm^3, and compressive strength varies even more, that is from 0.21 MPa to 5.89 MPa. Compressive strength is usually determined using uniaxial compression test, using norms for concrete.

3. Material characteristics of samples from Eastern Croatia

Material presented in this study was collected from five rammed earth walls in houses located in Eastern Croatia. During field observation, the authors have found several earthen houses, usually heavily deteriorated and abandoned. With owner's permission, large chunks of material were collected and stored in closed plastic bags in laboratory until testing.

3.1. Moisture content

Immediately after collecting material, moisture content of in-situ material was tested according to BS 1377: Part 2 : 1990 (Figure 3). Moisture (Table 1) ranged from 2.43 to 6,65 %, with average value of 4.38 %. Differences in moisture content between the five specimens can be explained by taking material from different locations in Eastern Croatia area. Furthermore, the specimens were taken from different heights on the wall, varying from 0.3 m to about 1.5 m from the ground. It should also be noted that some walls were exposed to direct sunlight, while others were shaded by vegetation.

Since compressive strength testing was performed approximately one month after collection of samples, moisture content decreased for about 20 %, as seen in Table 1. In time of compressive strength testing, moisture content ranged from 1.95 to 5.59 %, with average value 3.48 %. In Table XY, w_0 refers to moisture determined on the same day when the samples were collected from the field, while w_f refers to moisture determined on the day when the compressive strength was determined.

Figure 3. Samples for determining moisture content.

Table 1. Moisture content of earthen material.

Specimen	w_0 (%)	w_f (%)	Difference (w_f/ w_0) (%)
A2	2.43	1.95	80
B4	6.65	5.59	84
B5	6.48	4.80	74
A7	2.77	2.26	82
A8	3.57	2.82	79

3.2. Dry density

Small blocks of earth material were used to determine the dry density of earth material, according to BS 1377: Part 2: 1990. Dry density (Table 2) was determined one month after collecting samples. Values ranged from 1.56 to 2.09 g/cm^3, with average value of 1.75 g/cm^3.

Table 2. Dry density of earthen material tested.

Specimen	ρ (g/cm^3)
A2	1,.56
B4	1.82
B5	2.09
A7	1.60
A8	1.67

3.3. Compressive strength

Big chunks of earthen material were cut into cubes with side length of approximately 4 cm, using circular saw (Figure 4). From every sample, between two and six cubes were cut, depending on size and shape of the chunk. Compressive test (Figure 5) was conducted using Shimatzu AG-X plus 50 kN testing machine, with stress control 0.01 MPa/s. Values ranged from 1.22 to 3.32 MPa, with average value of 2 MPa.

Figure 4. Cutting earth chunks into cubes for testing compressive strength.

Figure 5. Testing compressive strength.

Table 3. Compressive strength.

Specimen	Number of specimens tested	f_c (MPa)
A2	2	1.37
B4	2	2.22
B5	3	1.22
A7	6	3.32
A8	5	1.88

4. Conclusion

Earthen construction in Eastern Croatia have been forgotten and left to decay since no preservation act nor normative have yet been proclaimed. Aim of this research is to learn more about the behaviour of earth architecture from Eastern Croatia and raise awareness of their importance and benefits over conventional construction methods. For that purpose, rammed earth constructions in Eastern Croatia have been observed and material from rammed earthen walls were collected. Preliminary tests were conducted to gather information on material.

From five different samples collected, moisture content was determined of in-situ and material stored in laboratory conditions for one month. Moisture content decreased after a month for 20 % on average. After a month, dry density and compressive strength was determined. Average dry density was 1.75 g/cm^3 and compression strength 2 MPa.

Besides results from preliminary tests, a short review of material properties presented in studies from Europe has been written. It should be noted that the rammed earth properties are highly dependent on granulometry of earth material used for construction. Therefore, it is not recommended to directly compare physical and mechanical properties presented in studies from different parts of Europe but to use that data merely for reference.

Further investigation on material characteristics from Eastern Croatia is planned to determine more characteristics of earth mixtures.

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Acknowledgment
This research was supported by Croatian Science Foundation under the project UIP-2020-02-7363 Rammed earth for modelling and standardization in seismically active areas - RE-forMS.