BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVIII (LXII), Fasc. 1, 2012
Secţia
CONSTRUCŢII. ARHITECTURĂ

THE USE OF CEMENT STABILIZED RAMMED EARTH FOR BUILDING A VERNACULAR MODERN HOUSE

BY

GABRIELA-TEODORA CIURILEANU (CIOCA)* and ILDIKO BUCUR HORVATH

Technical University of Cluj-Napoca

Received: February 15, 2012
Accepted for publication: March 27, 2012

Abstract. Earth and wood are the most common materials in Romania's traditional vernacular buildings. Nowadays, the quality of materials and the building techniques are improved in order to comply with today's standards of comfort and resistance. This paper presents a study concerning the determination of the layer composition of the exterior wall for a modern house that uses local earth as main material for building. The wall is tested for compressive strength and degree of insulation. Four earth recipes are established, combining different percentages of soil, sand and cement. The resulting mixture is compacted in 10 cm^3 metal moulds and extracted the next day. After 28 days, the samples are tested for compressive strength. The results are compared with the existing legal international standards. Then, the layers of the exterior wall are determined in order to provide a proper thermal insulation that fits the Romanian insulation standards. The aim is to obtain a valid proposal for an insulated, resistant, ecological, economical rammed earth exterior wall.

Key words: rammed earth; compressive strength; cement stabilization; thermal insulation.

1. Introduction

Earth is one of the most common materials and it is suitable for building. It can be used in its moist form as rammed earth (poured into

*Corresponding author: *e*-mail: Teodora.Cioca@cif.utcluj.ro

formworks and rammed), poured earth (in formworks or bags), but also in its wet form, as loam, light loam, straw loam. It can be formed into different shapes and forms resulting bricks and blocks that can be used as they are, or they can be sun dried or burned in order to increase compressive strength. All these methods of using earth as a building material can create a fast, economic, natural building, using almost nothing else but the earth at one's disposal.

In Romania, earth was mainly used for building traditional vernacular houses in the South, where wood was difficult to find. Examples of straw loam on wood frame houses exist in our country even from the Neolithic period (4200…3500 b.Chr.).

Today, earth is mainly viewed as a building material for the poor, especially in our country where these techniques are immediately related with the old houses of our great-grandparents. Anyone who wants to build a house now, would rather use building materials commonly available in stores.

In many industrialized countries people want to have an energy – efficient and cost – effective building with a healthy, balanced indoor climate. This choice comes as a result of a process based on cultural, technical and spiritual revolution that is desired for the future. And so, mud, a natural building material, is considered a better choice compared to the well-known industrial building materials (brick, concrete or plastic like materials).

2. Earth's Qualities as a Building Material

Nowadays, earth is an atypical building material, but has a number of qualities that make it stand out from other materials. Here are its main attributes:

1. It balances air humidity: earth walls absorb the humidity inside the house and maintain an almost constant air humidity of 50% for an entire year (Minke, 2005).

2. It has a high thermal mass: compared to other insulating materials, earth can store the heat captured during the day and release it in the house during the night after eight hours (Minke, 2005).

3. It is environmentally friendly: doesn't consume energy when compared to other industrialized building materials. For example, stabilized earth's embodied energy is of 0.7 Mj/kg and cement's embodied energy is of 5.6 Mj/kg.

4. It preserves timber: it is easy to build with, especially when using a timber frame for load-bearing and earth mixture as an infill material.

5. It is natural, economical, available for everyone who has a land and it is ideal for a do-it-yourself construction.

6. It is available almost anywhere in the world .

7. It is very good fire resistant.

There are several ways in which earth can be used as a building material in modern construction. Mainly there are three categories depending on the amount of water contained: a) raw earth; b) moist earth; c) mud.

Usually, when using mud for wall building, cracks may occur when the wall dries. That's why mud walls are plastered after they are finished and dried. Old traditional houses had three layers of earth mixture plaster on the walls.

A rammed earth wall is made using moist earth. The earth used for construction must be picked up at least 50 cm below the vegetation layer. Soil collected this way will not contain roots, insects, or other vegetable traces. The amount of water to be added varies depending on the humidity of the earth. The mixture has to be as dry as possible, but wet enough to be formed into a 4 cm compact diameter ball. When dropped from 1.5 m on a flat surface, the ball should split into several pieces (that means the mixture is not too wet and not too dry) (Minke, 2005).

After the mixture is prepared it is poured into 20 cm high layers in a formwork. Then, the earth is compressed to 50% from its original size with a ram. When the formwork is removed, the wall doesn't necessary need to be plastered.

In comparison with adobe wall, the rammed earth wall has a longer life since is monolithic (Minke, 2005). The rammed earth wall is also not so labor intensive and time consuming as other types of building with earth and it is considered a modern alternative to the traditional ways of building. This type of house building is common in USA, Australia, Africa, New Mexico, New Zeeland, but also in european countries like France, Germany, Spain, Italy, etc.

3. The House Project

A rammed earth wall has a low thermal resistance but a good compressive strength (Minke, 2005). In order to determine the suitable composition that would create an optimum exterior wall for a modern house in Romania, an *in situ* application is proposed for study. Starting from this premise, a construction plan is developed, for a house situated on a specific site – on a hill side village (Feiurdeni) in Transylvania. The project theme requires a house with a small ground surface (4x8 m) and so, it needs very thin walls in order to keep the interior volume of space as efficient as possible. The rammed earth wall has to be minimum 30 cm thick, in order to be a structural wall (Minke, 2005). The goal is to make the walls as thin as possible, but they should also provide adequate thermal comfort.

The rammed earth wall proposed should be load bearing and should also be insulated. First, the structural quality is analysed, then the proper layers are suggested in order to provide thermal comfort.

3.1. Compressive Strength

The first step is to analyse the qualities of the earth provided. According to the geotechnical study, the ground is clayey and contains 33% clay, 42% dust and 25% sand. Clayey soils absorb more water (Reddy & Kumar, 2011) and can generate cracks when drying.

In order to test the soil for compressive strength, four recipes are proposed. An earth sample from the site is transported to the Technical University Laboratory of Cluj-Napoca (in quantity of 50 kg) and is sifted with a Ø = 4 mm sieve, removing larger pieces (Fig. 1). For carrying out different recipes, a 25 kg bag of Portland cement 42.5N and a 20 kg bag of sand are used. The type of filler materials purchased followed the most common choice of the buyer and user of an earth building.

Fig. 1 – The earth is sifted and rammed into metal moulds.

To the sand and cement mixtures is added 10% water. The right amount of water is sprayed, according to the “breaking of the earth ball” sample, as mentioned above.

Table 1
Earth Recipes

No.	Name of recipe	Earth kg	Sand kg	Portland Cement kg	Water, [L]
1	Natural earth	9	–	–	As presented above (2)
2	Earth and 25% sand	9	25% from the amount of earth 2.25 kg	–	As presented above (2)
3	Earth, 50% sand and 5% Portland Cement 42.5N	9	50% from the amount of earth 4.50 kg	5% from the amount of earth 0.45 kg	10% from the amount of earth 0.9l
4	Earth, 70% sand and 8% Portland Cement 42.5N	9	70% from the amount of earth 6.30 kg	8% from the amount of earth 0.72 kg	10% from the amount of earth 0.9 L

Using the recipes proposed in Table 1, a 10 cm^3 cube and a 9 cm diameter cylinder are made using each mixture. The earth is poured into metal moulds in 5 cm high layers, then rammed using a wooden ram and manual force, until they are 50% compressed. After 24 h the samples are extruded from the moulds and kept 28 days for curing.

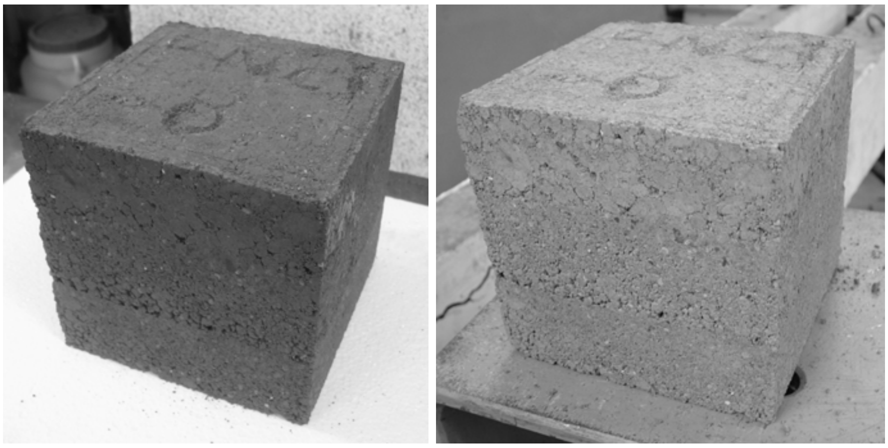

Fig. 2 – Sample rammed earth cubes: after extrusion from the metal mould and after 28 days of curing.

Table 2
Earth Density

No.	Name of the sample	Dimensions mm	Wet weight kg	Dry weight kg	Volume m^3	Density ρ_1 kg/m^3	Density ρ_2 kg/m^3
1	Natural earth cube	0.1×0.1×0.1	1.8106	1.5303	0.001	1,810.6	1,530.3
2	Earth and 25% sand cube	0.1×0.1×0.1	1.9374	1.7006	0.001	1,937.4	1,700.6
3	Earth, 50% sand and 5% Portland Cement cube	0.1×0.1×0.1	1.9826	1.7412	0.001	1,982.6	1,741.2
4	4.Earth, 70% sand and 8% Portland Cement cube	0.1×0.1×0.1	1.8688	1.6251	0.001	1,868.8	1,625.1

The samples are then weighed and the wet and dry weight is established. The density is found to be highest for the sample containing 5%

cement and the lowest for the cube containing only natural earth, as shown in Table 2. This proves that the contact forces are stronger for samples containing cement and the mixture is more homogeneous and more easily compressed.

Then, the samples are tested for compressive strength in the laboratory and the results are presented in Table 3. As demonstrated in other studies, compressive strength increases with increasing density of the mixture (Reddy & Kumar, 2011).

Table 3
Earth Recipes

No.	Name of the sample	Dimensions mm	Force applied kN	Compressive strength, [N/mm²]
1	Natural earth cube	0.1×0.1×0.1	45.5	2.122
2	Earth and 25% sand cube	0.1×0.1×0.1	30.0	1.370
3	Earth, 50% sand and 5% Portland Cement cube	0.1×0.1×0.1	55.1	2.449
4	Earth, 70% sand and 8% Portland Cement cube	0.1×0.1×0.1	42.2	1.870

3.2. Results

The results should be compared to existing standards. In Romania aren't any standards concerning earth house building. There are, however, standards regarding the Classification and Identification of Soils STAS 1243-83 and STAS 8942/1-89, concerning rammed earth used for roads and dam building.

The most accurate earth building standards and the first ones in the world to be exposed so clear and comprehensive are

NZS 4297:1998 Engineering Design of Earth Buildings;
NZS 4298:1998 Materials & Workmanship for Earth Buildings;
NZS 4299:1998 Earth Buildings not Requiring specific Designs (North, 2008).

According to the New Mexico Building Code, the minimum compressive strength of a rammed earth wall is of 2.07 N/mm² and according to the Code Enforcement of Rammed Earth Structures of Zimbabwe (2001), the minimum values of compressive strength is of 1.5 N/mm² for one story buildings and thick wall of minimum 400 mm and compressive strength of 2.0 N/mm² for two level buildings. In Table 4 there are presented several international standards regarding the compressive strength for rammed earth.

Table 4
Foreign Standards for Rammed Earth

Compressive strength, [N/mm²]			
	ACI Materials, Journal Commitee (1990)	Standards Australia (2002)	ASTM International E2392 / E2392M - 10e1 (2010)
Sandy soils with pebbels	2.76…6.89	–	–
Silty soils	2.07…6.21	–	–
Clayey soils	1.72…4.14	–	–
Stabilized rammed earth	–	1…15	2.068

Comparing the values stated in Table 4 with the ones in Table 2, it shows that the value of compressive strength for a rammed earth sample made of only natural soil should be minimum 1.72 N/mm² (ACI) < 2.122 N/mm² (obtained in the Technical University of Cluj-Napoca Laboratory) and for stabilized rammed earth containing 5% Portland Cement the value obtained in the Laboratory is 2.449 > 1 N/mm² (Standards Australia) or 2.449 > 2.068 N/mm² (ASTM International).

According to the tests conducted on samples it can be observed that the highest density belongs to the earth mixture with sand and 5% cement. Mass and density decrease for the 8% cement cube in both dry and wet sample. After compressive strength testing, the best results are obtained for the sample with 5% cement added to the mixture of soil, water and sand.

The compressive strength tests performed show that cement-stabilized soil on site can be used to achieve a load-bearing exterior wall for a single level house.

3.3. Thermal Resistance

The outer wall is load bearing, but it must also be insulated in order to provide thermal comfort inside. That is why thermal resistance of the wall must be determined.

The earth has a high thermal conductivity and a high thermal mass (Minke, 2005). The thermal conductivity of a rammed earth wall is $\lambda = 1.51$ W/m.K (Minke, 2005). This means that the earth wall traps solar heat during the day and releases it inside the house at night. Also, the heat produced by heating sources inside the house is maintained by the earth wall long after the heating device is turned off.

Rammed earth has always needed a formwork. This formwork can be made of wood, iron, or other resistant materials. A wooden formwork is cheaper and can be kept in position, as lost formwork, even after the wall is finished. In this way the amount of work is minimized and the wood can increase the thermal insulation of the wall and will serve as structure for constructing further layers. The wall still needs to have insulation because 30 cm of rammed earth are not enough. A detail of the exterior wall is presented in Fig. 3.

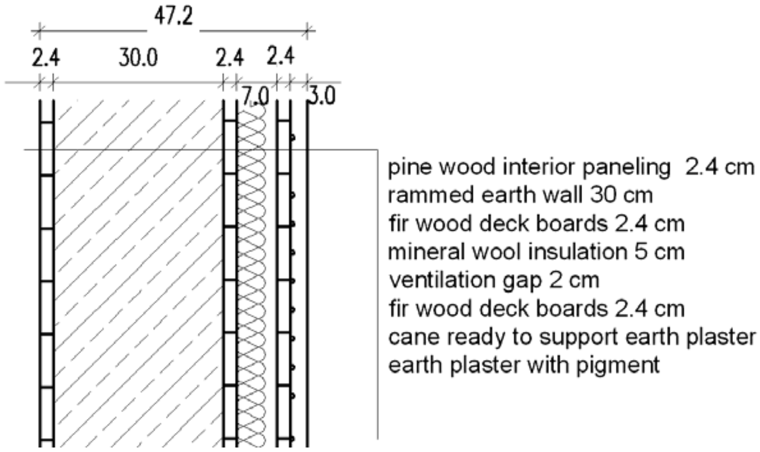

Fig. 3 – Detail of the insulated rammed earth wall.

In the Table 5 there are presented all the layers of the wall and their thermal resistances, in order to calculate the thermal transfer coefficient for the entire wall. The dimensions for density and thermal conductivity of the materials shown in Table 5 are accordingly to the Romanian standard C 107-2005.

Table 5
Thermal Resistance

No.	Name of the layer	Apparent density ρ,[kg/m³]	Thickness d, [m]	Thermal conductivity λ, [W/m.K]	Thermal resistance R_{sj}, [m².K/W]
1	Resinous wood paneling	550	0.024	0.17	0.14
2	Rammed earth	1,800	0.30	1.50	0.20
3	Resinous wood deck	550	0.024	0.17	0.14
4	Mineral wool	130	0.05	0.04	1.25
5	Ventilated air gap	0.02		0.15	0.02
6	Resinous wood deck	550	0.024	0.17	0.14
7	Plaster lightweight straw loam	1,000	0.030	0.9	0.02
R total					1.91

Specific unidirectional thermal resistance of the outer wall is

$$R = R_{si} + \Sigma R_{sj} + R_{se} = 0.125 + 1.91 + 0.042 = 2.077 \text{ m}^2\text{.K/W}. \qquad (1)$$

Minimum thermal resistance according to Romanian standard C 107 – 2005 (Annex 3) for new residential building, is R_{min} = 1.50 m².K/W. Consequently

$$R > R_{min} . \tag{2}$$

Heat transfer coefficient, U, for the exterior wall is

$$U = 1/R = 1/2.077 = 0.48 \text{ W/m}^2\text{.K} . \tag{3}$$

The maximum heat transfer coefficient, U_{max}, for exterior walls for type *b* buildings (which includes residential buildings) is 0.53 W/ m².K according to Annex no.10.17 (Maniatidis & Walker, 2003). It results that

$$U < U_{max} . \tag{4}$$

According to the eqs. (2) and (4), the exterior wall is insulated enough to fit the Romanian standards. For a higher thermal comfort, the thickness of the insulation can be increased.

In order to achieve passive house requirements for an exterior wall insulation, the heat transfer coefficient for the wall must be lower than 0.15 W/m².K. That wall should contain a 60 cm rammed earth layer and a minimum 22 cm mineral wool insulation.

6. Conclusions

In this paper, a rammed earth exterior wall is proposed for study. The earth used for ramming is from the land provided by the building's beneficiary. The wall must meet two important requirements: a) it must be a structural load bearing wall; b) it must be insulated.

The major conclusions emerging from the experiment and laboratory work are the followings:

1. In order to achieve a compressive strength according to international standards, several test need to be performed on different samples containing natural soil and a mixture of soil and 5% cement (for the clayey soil presented in the study, the highest compressive strength was obtained by adding 5% cement on the mixture).

2. A minimum 5 cm mineral wool insulation has to be added to the rammed earth wall in order to achieve the heat transfer coefficient of an exterior wall within the standards stipulated by the regulations in force in Romania.

3. A 60 cm rammed earth with a 22 cm mineral wool insulation wall has the heat transfer coefficient of a passive house exterior wall.

4. The resulting wall is economic because, by using local materials, the cost of the wall is given only by its thermal insulation that has to be minimum of 5 cm.

5. The wall is ecologic because it uses natural local materials, provides resistance and insulation offering a contemporary level of comfort.

This study provides a modern alternative of building with earth, using modern construction means in combination with traditional ones, while keeping the investment value to a minimum.

Acknowledgements. This paper was supported by the project "Doctoral Studies in Engineering Sciences for Developing the Knowledge Based Society-SIDOC" contract no. POSDRU/88/1.5/S/60078, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

REFERENCES

Andreica H.A., Munteanu C., Mureşanu I., Moga L.M., Tamaş-Gavrea R., *Civil Buildings* (in Romanian). Techn. Univ. Press, Cluj-Napoca, 2009.

Maniatidis V., Walker P., *A Review of Rammed Earth Construction*. Natural Building Technol. Group, Univ. of Bath, Dept. of Archit. & Civil Engng., 2003.

Minke G., *Building with Earth. Design and Technology of a Sustainable Architecture*. Kessel, Germania, 2005.

North G., *Waitakere City Council's Sustainable Home Guidelines, Earth Building*. Waitakere, New Zeeland, 2008.

Venkatarama Reddy B.V., Prasanna Kumar P., *Cement Stabilised Rammed Earth.* Part B: *Compressive Strength and Stress–Strain Characteristics*. Sci. Direct, Mater. a. Struct., **44**, 695-707 (2011).

* * * *Normativ privind calculul termotehnic al elementelor de construcţie ale clădirilor*. C 107-2005.

* * * *Studii de arhitectură tradiţională în vederea conservării şi valorificării prin tipizare – locuinţa sătească din România.* Institutul de Proiectare Prahova, Ediţie revizuită şi completată, 1989.

UTILIZAREA PĂMÂNTULUI COMPRIMAT STABILIZAT CU CIMENT PENTRU CONSTRUIREA UNEI LOCUINŢE VERNACULARE CONTEMPORANE

(Rezumat)

Pământul şi lemnul sunt materialele cele mai folosite în costrucţiile vernaculare tradiţionale româneşti. În ziua de azi tehnica de construire şi calităţile materialelor folosite s-au îmbunătăţit pentru a se putea înscrie în standardele contemporane de confort şi rezistenţă.

Se prezintă un studiu realizat cu scopul de a determina compoziţia straturilor pentru un perete exterior al unei case moderne care foloseşte pământul local ca material principal de construcţie. Peretele este testat din punct de vedere al rezistenţei la compresiune şi al gradului de izolare termică. Sunt stabilite patru reţete ce combină procente diferite de pământ, nisip şi ciment. Amestecul rezultat este compactat în cofraje metalice de 10 cm³ şi extras în ziua următoare. După 28 de zile, mostrele sunt testate pentru a se determina rezistența la compresiune. Rezultatele obținute sunt comparate cu standardele internaționale existente. Apoi este stabilită compoziția straturilor peretelui pentru ca acesta să confere izolația termica necesară pentru a se putea încadra în standardele româneşti în vigoare. Scopul este de a obține un perete exterior din pământ comprimat care să fie portant, izolant, ecologic şi economic.