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EARLY EXPERIENCES FOR THE CONSTRUCTION OF CEB TILE VAULTS. PRELIMINARY STUDY OF THE DOSAGE OF BLOCKS AND MORTAR

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Abstract- The high cost and difficulty in accessing industrialised materials often hinder the development of cooperation projects in the construction of facilities in rural areas of developing countries. In view of this, materials such as compressed earth blocks (CEBs) offer easy alternatives for onsite production by workers with limited specialisation and are used increasingly for this type of building. Based on the research carried out as part of a cooperation project for the construction of a school in Baasneeré (Burkina Faso), this article studies the feasibility of the use of CEBs in the construction of earthen tile vaults. This system makes it possible to build horizontal structural elements with a very limited investment in materials and auxiliary means. The technical feasibility of the solution proposed was studied experimenting with different tests and constructions at Universitat Politècnica de València, using pieces and mortars with different dosages.
Keywords – Tile vault; Compressed Earth Block; Mortar dosage.

1. INTRODUCTION

Compressed earth blocks (CEBs) are small modular elements used in the construction of masonry elements. These are produced by using a press to compact a damp earthen mass which is usually dosed with a small proportion of cement, although other stabilising materials such as lime [1], fly ash or plant waste can also be used [2]. The execution system for CEBs is like that of brick, thanks to this they are easy to handle and use by unskilled workers. Their high resistance to stress, normalised up to 5 MPa by UNE 41410:2008 [3], make them suitable for use in the construction of loadbearing elements. In addition, their high density and thermal inertia mean they are used to produce breathable constructive elements used for insulation.

The power of the machinery used in the production of these pieces determines the degree of compactness and affects their final resistance. However, with small manual block machines which are easy to use and transport it is possible to produce CEBs with a fair resistance to stress. In addition, the production of these blocks allows earth in a wide range of granulometries to be used, making onsite production with local materials easier. This makes CEBs ideal for use in projects with low environmental impact or in areas lowly industrialised or areas difficult to access.

Although CEBs are used mostly in the construction of vertical enclosure and loadbearing elements, their characteristics make them excellent for use in the construction of complete building systems [4]. The natural way of building horizontal structures without reinforcements is through vaults and domes, which work through simple compression. When complete, these are highly resistant elements, although centring is needed while they are being built. The type of centring needed depends mostly on the geometry of the vault and the technique used. Tile vaulting is a traditional building technique from eastern Spain, based on the use of quick-setting gypsum and ceramic brick tiles for the construction of light vaulted systems which do not require centring and are not subject to the metric and formal limitations of Egyptian or Nubian vaults. These elements are made using a gypsum and brick self-supporting sheet which is usually coupled with one or two layers of ceramic tiles with lime or cement mortar to increase thickness and resistance. This article aims to study the feasibility of the technical adaptation of tile vaults using CEB, what would make them an ideal solution to cover horizontal spaces in areas with little industry or wood supply.

2. METHODOLOGY

To successfully adapt the technique of tile vaulting to CEBs, the work methodology developed focuses on the detailed knowledge of the building materials and process. Therefore, the study consisted of three chronological phases:

Material classification of CEBs. The first phases studied the granulometric distribution of the earth in the CEB, while also carrying out compression tests to establish the resistance of the blocks used.

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Study of mortar dosage. Analyses and tests were carried out on the possible proportions for the mortar of the pieces, analysing and testing different earth-sand proportions for the mortar. Different proportions of earth-sand were used in the mortar of the first layer of the vault while proportions of earth-sand-cement were employed in the following layers. Tests were carried out to calculate the ideal proportion, considering the specific constructive characteristics of the tile vault.

Construction of a prototype. The final step in the work methodology consisted in the execution of small- and full-scale prototypes of the vaults for the project of Baasneeré school) [5]. These prototypes, built according to the results of the previous methodological phases, made it possible to verify whether the combined use of CEBs and the mortar proposed provide optimum results for the construction of these vaults.

Yet a final point in the research methodology has not been executed: behaviour tests for these vaults both in terms of structural behaviour (loading test) and of behaviour when faced with the passing of time (aging tests).

3. COMPRESSED EARTH BLOCKS

The blocks used in this case were supplied by a commercial company, meeting the demands of UNE 41410:2008 [3]. The pieces most commonly used for the construction of walls measure approximately 295x140x90mm. However, given that these pieces are too heavy for the construction of tile vaults it was decided to work with special plates measuring 200x95x33mm.

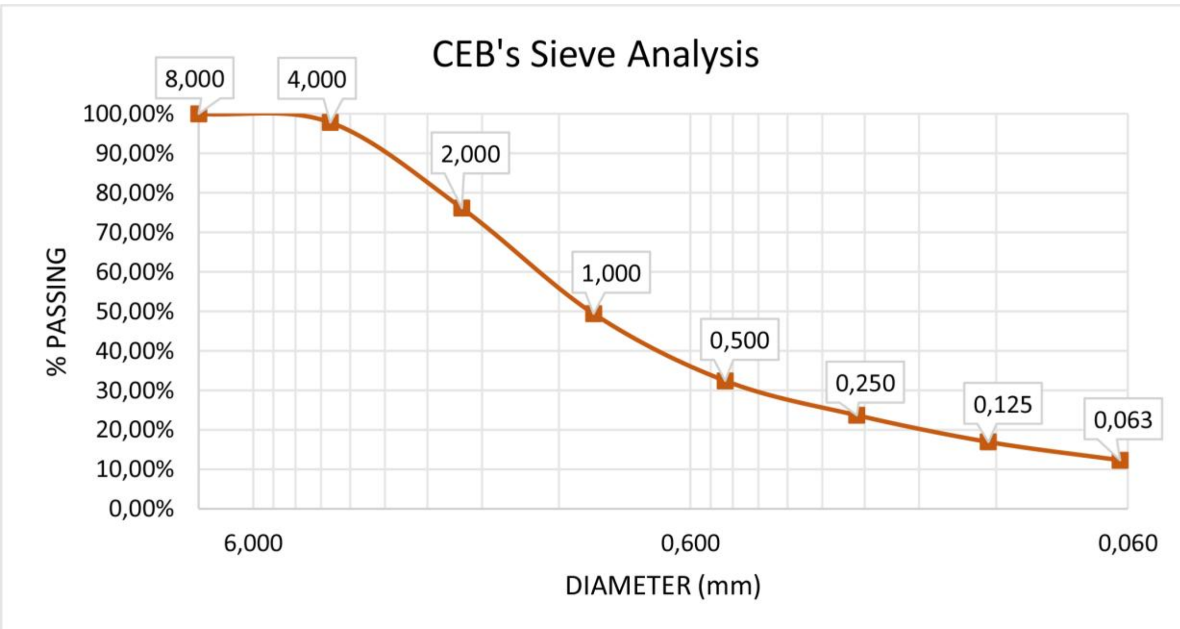

Figure1: Results of the CEB's sieve analysis

The earth used to produce these blocks had a high content in sand (approximately 65% of its weight distributed in particles between 2 and 0,5 mm) and with about 12% silts and clay (Fig. 1). After being stabilised with 5% lime and 2% cement, this soil was compressed to produce pieces with an approximate density of 2,140 kg/m3. To ascertain the compressive resistance of these pieces direct compression tests were carried out following the procedure detailed in UNE-EN 772-1:2002 [6]. In this type of test, the growing compressive stress causes the progressive side deformation of the tests continuing to shear. This deformation is distorted by the friction between the test specimen and test plates so that the apparent resistance of the material increases as the distance between the plates decreases [7]. To counter this effect, Table A.1 of UNE-EN 772-1:2002 establishes a form factor d which reduces the resistance obtained [6]. The four tests, carried out over 3-year-old samples with a speed of 0,3 MPa/s, have shown a corrected resistance of 8,68 kN.

4. STUDY OF MORTARS

To build the first layer of the earthen tile vaults the use of mud mortar with a high clay content was proposed. The aim of this was to ensure a high initial adherence to minimise the need for centring. The second leaf was built using earth-cement mortar to ensure greater resistance for the vault in the medium and long term.

The granulometric tests carried out on soil samples from Baasneere showed a high proportion of silts and clay (approximately 56% in the mix) and a relatively high proportion of coarse sand, with 21% in mass in particles ranging varying from 2 and 0.5mm. This prompted the decision to work with a very clayey material which if necessary could be corrected with sand to obtain a granulometry like the local one. After analysing soil from different sources, earth with a silt and clay content of approximately 67% was chosen from an excavation in the town of Alacuás (Valencia).

A CEM II/B–M (S-L)/42.5R cement was used in the dosage of mixed mortars. Coarse sand with approximately 71% of its mass in particles between 4 and 0.5 mm was used for occasional corrections in the mix (Fig. 2).

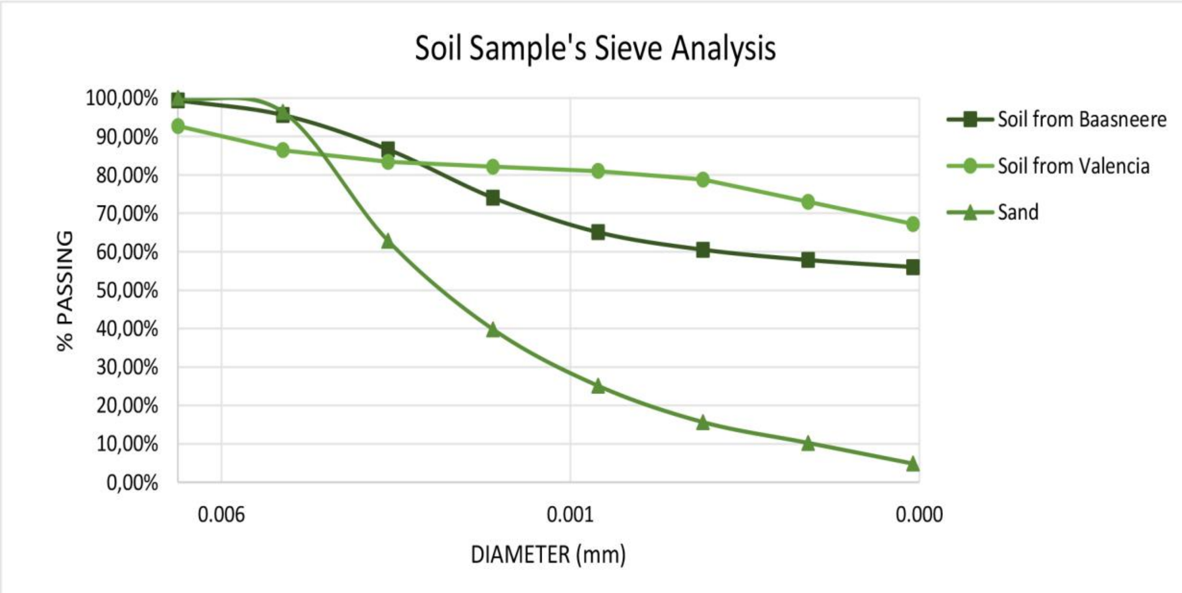

Figure 2. Results of the sieve analysis of the samples of soil and sand

The exact dosage of the earth mortar was established through a fissure control test based on that established in Annex 4 of the Peruvian standard on earthen construction E-80 [8]. Different earth mortars (with increasing quantities of sand) were prepared and used to bind three pairs of CEBs in each case. The three specimens for the individual mixes were separated after 6, 24 and 48 hours to examine the cracks in the mortar.

This test was carried out initially by joining the pieces along the bed, as stipulated in E-80. However, the earth mortar selected had to be used to bind the pieces of the lower leaf of the vault, which are joined in shiner. This led to further testing of the dosages which had provided the best results, this time binding the stretchers. The aim of this test was to increase the proportion of mortar which dried in direct contact with air through the join to identify any potential changes in the result.

In the first observation the best results were obtained when using a mortar with a 3:1 ratio of earth and sand (Table 1a). However, as exposure to air increased in the second test, the mortar dried too fast causing adherence problems so that it was decided to work directly with an uncorrected earth mortar. In this case the high concentration of clay allows the join to remain damp longer and provides it with fair adherence in the time that the upper leaves need to acquire resistance.

To establish the exact proportion of earth mortar and cement the test procedure described in Norm E.80 was followed, working on this occasion with different proportions of earth and cement. The poorest dosage in cement that had no visible cracks after 48 hours would be chosen in this case. The mix selected was tested a second time, adding different proportions of coarse sand. Finally, the decision was made to use a mortar with a 3:1 ratio of earth and cement which was not corrected with coarse sand (Table 1b).

A. EARTHEN MORTAR			B. MIXED MORTAR							
Sample	Soil	Sand	Sample	Soil	Sand	Cement	Sample	Soil	Sand	Cement
A	1	0	E	6	0	1	I	3	0	1
B	6	1	F	3	0	1	J	6	1	2
C	3	1	G	2	0	1	K	3	1	1
D	2	1	H	1	0	1	L	6	3	2

Table 1. Mortar dosages tested

5. CONSTRUCTION OF VAULTS

Once the characteristics of the compressed earth block to be used and mortar proportions of the two leaves of the vault had been selected, the centring elements that the system needed were studied and the first prototypes built.

The lightness of the ceramic tiles and the setting speed of the gypsum allow traditional tile vaults to be built without centring when there is at least one side wall to which the first pieces can be attached. However, when these are built as standalone systems a small guide is used to support the construction of an initial brick arch. Based on this element the subsequent pieces can be added without a need for centring.

Figure 3. Life-sized model of the tile vaults designed for the school of Baasneere

CEBs are heavier than fired bricks and the initial resistance of mud mortar is lower than that of gypsum. Therefore, two guides similar to that used for the execution of standalone tile vaults were employed in the construction of earthen tile vaults. The first of these guides is used in the construction of the first arch of the lower leaf. Once it is complete the second guide is placed to build a second arch beside the first, while eliminating the need to recover the first guide before construction begins on the third arch. This allows the mortar of the first element time to harden enough to be resistant and it is braced at the side by the second arch, still in possession of its centring at this stage.

In this system the first layer of the vault does not behave like a continuous surface but like a succession of arches. This means that the doubling layer breaks up the continuous joins, guaranteeing that the vault behaves as a solid block as its thickness and resistance increase.

This system was first put into practice with the construction of a small vault with a 90 cm span and 70 cm rise, using the local earth selected. Once the model was completed and considered to be feasible a second larger and wider vault was built to the same measurements as the elements to be used in the school in Baasneere. Local earth from the town was used with equally promising results in the construction of this prototype, with 140 cm span and 66 cm rise (Fig. 3).

6. CONCLUSIONS

CEB tile vaulting systems show great potential in the construction of inexpensive sustainable horizontal structures in locations with little industry and scarcity of wood.

In the case examined in this text the compressed 3,3 cm thick earth plaques were used to build vaults using mud mortar and earth-cement mortar, the later in a 3:1 ratio. The use of earth with a high clay content improved the behaviour of the mortar of the lower leaf of the vault as the low adherence of the tests carried out with mixes with a higher content of sand showed. When testing the dosage of these mortars it was observed that the amount of mortar which dries in direct contact with air through the join significantly affects its capacity for adherence. Therefore, the usual study of dosage based on joined pieces [8] alone is not enough and requires complementary adherence tests on pieces joined by their stretcher.

The results obtained to date are promising but are yet to be completed with load and aging tests. Regardless, this experience opens interesting avenues of research for perfecting techniques, including the possibility of using earth mortar with natural fibres or producing lighter slips.

note

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