UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS

DYNA
http://dyna.medellin.unal.edu.co/

Some recommendations for the construction of walls using adobe bricks

Algunas recomendaciones para la construcción de muros de adobe

Miguel Ángel Rodríguez-Díaz [a], Belkis Saroza-Horta [b], Pedro Nolasco Ruiz-Sánchez [c], Ileana Julia Barroso-Valdés [d], Fernando Ariznavarreta-Fernández [e] & Felipe González-Coto [f]

[a] *University of Oviedo, Spain, mangelrd@uniovi.es*
[b] *Central University of Las Villas, Cuba, belkiss@fc.uclv.edu.cu*
[c] *Central University of Las Villas, Cuba*
[d] *University of Oviedo, Spain, ilema00@yahoo.es*
[e] *University of Oviedo, Spain, ariznaf@uniovi.es*
[f] *University of Oviedo, Spain, felipegc@hunosa.es*

Received: March 22th, 2013. Received in revised form: January 23th, 2014. Accepted: January 30th, 2014

Abstract
This paper shows some results of the analysis of wall construction with adobe bricks, carried out in a pilot building in Villa Clara, Cuba. Our main objective was to obtain some construction recommendations to avoid the humidity due to capillarity. The recommendations deal with uprising speed of construction, adequate wall longitude, binding mortar between adobe bricks, adobe protection from weathering, etc.

Keywords: Adobe; building materials; collar beams; lintels; opening of the wall.

Resumen
En el presente artículo se estudian las condiciones en las que deben ser levantados los muros de adobe en construcciones de tierra. Para ello, se construye una edificación piloto en Villa Clara, Cuba, que ha servido de base para probar distintas soluciones constructivas. Como resultado de esta investigación se dan recomendaciones para evitar el ascenso de la humedad por capilaridad, sobre la velocidad de levantamiento, la longitud de muro adecuada, el mortero de unión tanto de adobes entre sí como de adobe con otro material, el cerramento, los dinteles, la protección de vanos así como para el revestimiento adecuado para la protección del muro de adobe del intemperismo.

Palabras clave: Adobe; construcción de materiales; cerramento; dinteles; vanos en muros.

1. Introduction

Mud, as a construction material, is one of the oldest materials ever used by man for construction purposes. Its use has been maintained for centuries, and even today it is of great importance, mainly in developing countries.

In the case of Cuba, the use of adobe was a solution in the crisis of the 1990's, but due to the lack of systematic knowledge about its correct use, many adobe brick buildings show today a variety of pathologies. In Table 1 the evaluated pathologies are shown and the percentage of buildings affected by each one.

Even if a wall is well-designed, an appropriate building work and a relatively big thickness is necessary to guarantee the right behavior during its lifespan. In the case of adobe walls, in order to get the highest quality, the construction stage is, probably, the most important one.

Table 1. Common pathologies observed in adobe buildings

Observed pathology	Percent of damaged buildings
Humidity in walls due to capillarity.	80%
Wall inner coatings detached, with damages covering 40-60% of total area, and mainly at the lower half of the wall.	70%
Wall inner coatings detached, with damages covering 5-10% of total area, and mainly above the baseboards of the wall.	60%
Humidity in walls due to rains or splash.	40%
Oblique cracks, almost 45° opening, below windows spaces.	30%
Horizontal cracks in walls.	30%
General damages in lintels.	20%
Vertical crack above door lintels.	10%
Diagonal cracks near the lintel corner.	10%
Diagonal cracks between adjacent lintels.	10%
Vertical crack close to the door frame.	10%
Wall inner coatings detached, with damages covering 10-20% of total area, and mainly in the lower half of the wall.	10%

© The authors; licensee Universidad Nacional de Colombia.

Based on laboratory scale studies carried out by Rodríguez Díaz and Saroza Horta [1], a pilot building was constructed at the village Crescencio Valdés (Villa Clara, Cuba), Fig. 1. These studies allowed us to define the optimal composition which should characterize the adobe found in this zone and which was used in the construction process. According to Casagrande´s classification the employed soil was classified as SC which is ideal for the adobe presenting a 60% of sand, a 15% of lime and a 25% of clay.

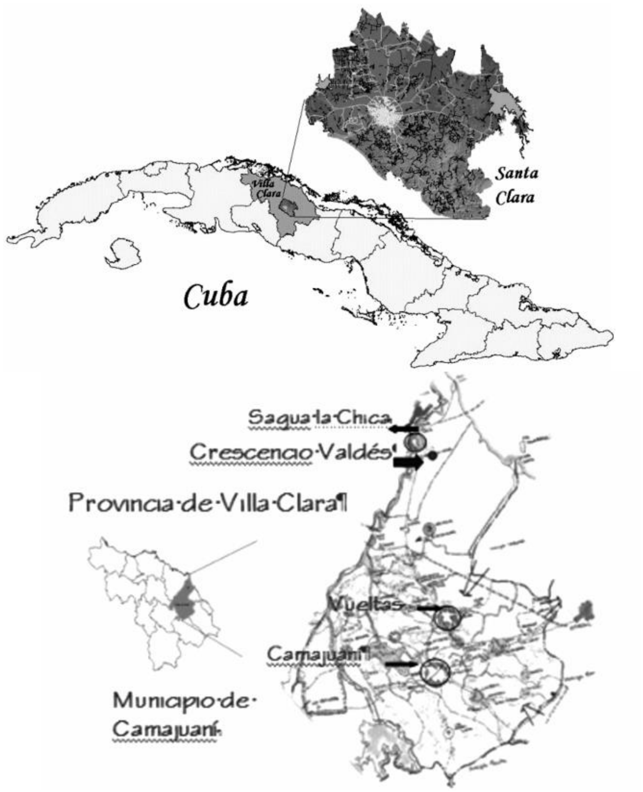

Figure 1. Map

The combination considered appropriate to be used in processing the adobe that is going to be employed in the building was the following: SOIL + 25% of organic matter + 2% of AVE asphalt, which offers a compression strength of 1.90 MPa and a capillary absorption of 0.81 g/cm^2.

Taking these results as the starting point a further step was achieved by working at a real scale, focusing the research on improving the knowledge about the parameters that rule adobe wall construction. In this experimental building different tests to the more problematic and relevant aspects in the adobe wall construction have been done. The specific objective was the study of some variables that influence the adobe wall behavior, such as its type; wall construction speed; wall length; kind of mortar; collar beams, lintels and final wall coating.

2 Methodology

To satisfy the objectives of our paper, we have used the following methodology. After our experience, we strongly recommended it for similar purposes.

2.1. Kind of top-foundation

The adobe walls are usually affected by humidity due to capillarity. To avoid this, the lower part of the wall can be built with other materials. This lower part is called top-foundation. To carry out this study, we have considered the following variants:

- A wall completely built in adobe.
- An adobe wall with 40 cm of clay bricks as top-foundation.
- An adobe wall with 40 cm of concrete blocks as top-foundation.

2.2. Wall construction speed

Members of Habiterra Network [2] recommend a construction speed lower than 1.5 m high per day. This is due to the slow drying process of the material and the high own-weight of the wall. In the other hand, González Limón [3] y Rodríguez et al. [4] proposes a construction speed lower than 1 m high per day, to avoid the settlement of the fresh joints. To study the influence of this parameter, 5 m length experimental wall was built using different speeds: 0.5 m high; 0.7 m high; 0.9 m high; 1.1 m high; 1.3 m high and 1.5 m high per day.

2.3. Wall length

It is known that too long walls, without intermediate pillars, can suffer vertical cracks due to bending. To quantify this limit, some high walls were built with lengths of 2.5 m, 5 m, 7.5 m and 10 m.

2.4. Kind of mortar

Adobe joints are critical. Wall cracks could appear easily in these zones because of the lower mortar strength compared to adobe, and due to the fact that the adherence between mortar and adobe brick is low. Thus, horizontal joints are the weak ones in the wall. In the Peruvian Standard (NTE E.080) [5], mortars are classified in type I (mixture of cement and sand) and type II (adobe mixture).

2.4.1. Mortar between adobe materials

This study was carried out with various mixtures of mortar type II. The authors consider that this is the adequate type of mortar to be used in this case, because it has similar strength properties to the adobe bricks, it gets better adherence in the interface brick/mortar, and finally its lower cost. Habiterra Network [2] proposes the addition of organic fiber in the mixture, while others, like González Limón [3], refuse it.

The authors of this study, decided to avoid the use of any addition because this is not traditional in the zone and it makes the workability of the mixture more difficult. In this case, the role of the organic fiber will be supplied by the sand.

The soil used as a raw material to obtain the mortar has the following composition: 0 % of gravel, 62 % of sand, 14%

of lime and 24 % of clay. Other characteristics are: liquid limit (38.7); plastic limit (19.41); plasticity index (19.29) and specific weight (26.3 kN/m^3). Table 2 shows proportions by volume of the soil and sand used to prepare the samples for a simple strength test, samples for adherence test following, Minke [6], and samples for crack tests following (Habiterra Network, 1995) recommendations.

Table 2 shows the composition and simple compression resistance for each dosage. Samples number 6, 7 and 8 had no results because they were too soft to be tested. For these three samples, the amount of sand in the mixture was too much and the cohesive force of clay particles was affected.

Table 2: Compression test

Nº	Soil	Sand	Rc (Mpa)
1	1	0.25	1.22
2	1	0.50	1.45
3	1	0.75	1.54
4	1	1	1.38
5	1	1.25	1.12
6	1	1.50	-
7	1	1.75	-
8	1	2	-

2.4.2. Binding mortar between adobe and other materials

In this case, the authors decided to study the behavior in the joints adobe/clay bricks and in the joints adobe/concrete blocks. Three types of mortar were tested:

- Soil-sand: mortar with the best tested dosage from Table 2.
- Cement-sand: mortar obtained mixing cement and sand following the Peruvian norm, with a volumetric ratio of 1:5.
- Lime-sand: mortar with volumetric proportion of 1:3.

The tests performed were the same as in the case of adobe/adobe joints, additional crack tests are recommended.

2.5. Collar-beam, lintel and span protection

The collar beam is the upper binding beam in a building. It is a key structural element in the stability and safety for adobe constructions. The best solution is to use a continuous reinforced concrete beam at the upper part of the wall. Its rigidity in the horizontal plane improves the structural behavior of the whole building. This kind of solution increases cost, due to the use of more expensive materials and the need of wood framing systems, in a country like Cuba where wood is scarce.

The specific objectives in this part of the study were the optimization of collar beam support conditions, and also to decide the adequate kind of lintel. To carry out the collar beam support study, next three options were tested:

- Collar beam supported together by the adobe wall and clay bricks or reinforced concrete pillars.
- Collar beam supported only by pillars.
- Collar beam supported only by adobe walls.

In the case of the lintels, three options were tested: wood lintels, pre-cast reinforced concrete, and in place reinforced concrete lintels.

To develop our research, we have used two kinds of solutions for the adobe bricks under windows:

- Type one: with a linear disposition of vertical joints, called “junta corrida” in Spanish.
- Type two: with a discontinuous disposition of vertical joints. It is called “matajunta” in Spanish.

Guillaud et al. [7], Álvarez et al. [8] and Bernabeu [9] say that, if the part of the wall under window is Type two, some 45 degrees cracks could appear. Its path starts at both ends of the span. This cracking occurs, due to vertical load at this zone not being able to equilibrate the vertical pressure of the soil.

In order to study this phenomenon, and to obtain confident results, we built the lintel under the windows using the same dimension for the upper one and the collar beam.

For the protection of span we decided to apply two solutions as follows:

- To surround the span using fired bricks.
- To put a cement-sand coat.

2.6. Coatings

To avoid the problems arising from wind or rain erosion, it is necessary to use the correct kind of coating, able to protect the wall from these agents. In order to select the right one it is necessary to take into account that soil walls need to transpire, due to the material permeability to water, steam and some other gases, which must be able to flow through the wall thickness. To achieve this, it is necessary to apply an incomplete impermeabilization; otherwise water released during the wall wetting and hardening will try to get outside and if it does not find its way out, it would push the coating mortar detaching it from the wall and making it fall.

This is the reason to refuse cement coatings and to promote the use of clay, sand, hydrated lime and just a small proportion of cement.

Observing the opinion from Houben and Guillaud [10], there is a big difference between the behavior of a material in laboratory conditions and actual ones. Many different aspects (change of scale, climatic influences, effect of the building use etc) can affect or modify durability. One of the most efficient methods to get closer to the actual behavior of an adobe wall is the construction of small prototypes, exposed to natural environment at the same place where the future building is intended to be built or in a similar one. It leads to confident composition of coating.

The authors, decided to investigate the group of mixtures shown in Table 3, applying each of them to prototypical adobe walls, and measuring their behavior against cracking, erosion, and impact resistance. These aspects provide a clear definition about durability. They were analyzed during two months which is a very short period to provide final conclusions but it is certainly the first approach to the future behavior of these mixtures.

Table 3: Dosage for the Coating study (in volume)

Dosage	Coat	*Soil*	*Sand*	*Hydrated Lime*	*Cement* (m^3/m^3 on mixing)
1	Thick	1	3	1	-
2	Thin	1	3	1	-
3	Thick	1	3	2	-
4	Thin	1	3	2	-
5	Thick	1/2	3	2	-
6	Thin	-	3	2	-
7	Thick	1	3	2	0.043
8	Thin	1	3	2	0.043
9	Thick	1	4	1	0.043
10	Thin	1	4	2	0.043
11	Thick	1	1	-	-
12	Thin	-	3	1	-
13	Thick	-	3	1	-
14	Thin	-	3	1	0.043
15	Thick	1	1/2	-	-
16	Thin	-	3	2	-

It is very important to mention that, in order to obtain a good adherence, both wall surfaces were thoroughly moistened during four hours, before applying the coating. The process has to be repeated until absorption becomes visible. Coating application has two steps: a plaster and a render.

3. Results

3.1. Top foundations analysis

When the wall is completely built using adobe, its behavior is bad due to humidity.

The top-foundation, consist on a linear cord of fired brick, and it is concerned with the protection of the lower part of the wall against rain splash and environmental aggression but, as you can see in Fig. 2, it is not efficient enough to avoid the capillary humidity.

Foot beams made of hollow cement blocks is a more efficient protection against all kind of humidity, even against capillary effects as Fig. 3 shows.

Figure 2: Fired bricks foot cord

Figure 3: Hollow blocks foot cords

3.2. Analysis of the wall construction speed

After experimenting with different walls, it can be asserted that an important settlement occurs when the wall construction speed is more than 50 cm per day, due to the effect of the bricks own weight and the low resistance of fresh mortar.

Horizontal and vertical bending is also present. This additional pathology is caused by mortar drying contraction being too fast, due to the Cuban climate's high temperatures.

3.3. Wall length analysis

In walls longer than 5 m, with no intermediate pillars, a serious horizontal bending could happen and a vertical crack near the middle of the length may appear. It is caused by a drying stress higher than that allowable for this material (see Fig. 4).

Figure 4: Cracks into wall without pillar

Figure 5: Wall with an intermediate pillar

To avoid this pathology, we could obey the recommendation of Habiterra Network [2], of keeping the length of the wall less than 2.5 times its total height, for walls without pillars. Our experience during this case study, following this recommendation, has provided the best results, as shown in Fig. 5.

3.4. Mortar analysis

Tested mortar for Walls built with adobe only. From Table 2 we can say that sample number 3 has the higher compression strength. Then, sample number 3 is the most efficient. Fig. 6 shows a very good wall, built using mortar number 3 of Table 2.

Tested mortar for Walls built mixing adobe with other material. We have also used combination number 3 of Table 2 for this purpose. Fig. 7 shows an adobe wall with some components of fired bricks, and mortar number 3.

Figure 6: Binding mortar for adobe walls plural o singular

Figure 7: Adobe wall, mortar number three and fired bricks

3.5. Collar beams, lintels and span protection

3.5.1. Collar beams

When the collar beam is supported by the adobe wall and brick (or cement block) pillars, 45 degrees cracks may appear at the point of contact between the pillar and the wall.

Fig. 8 shows a clear example of this pathology. The crushing of the soft material shortens the length of adobe parts and sliding between interface of adobe and bricks occurs.

When the collar beam is supported only by pillars, the wall is free to small movements, because its behavior is near a cantilever wall. No vertical load is on the wall and it is very sensitive to any pulling or pushing action which could cause the collapse of the wall. Fig. 9 shows this case.

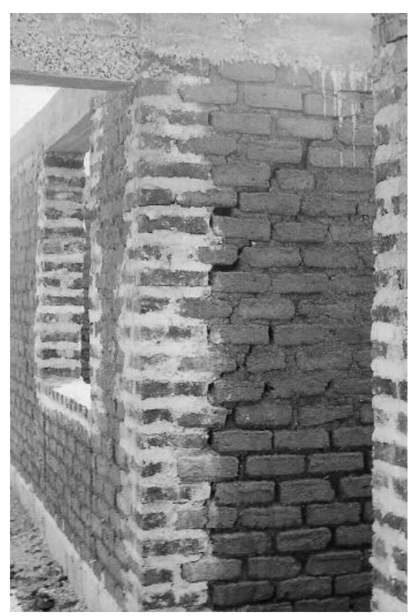

Figure 8: Wall and pillar supporting together the collar beam

Figure 9: Only pillars supporting the collar beam

In the last case, when the collar beam is supported only by the wall, crack appearing is not probable because the settlement of the wall is uniform. To reach this kind of solution, the pillars must be almost 6 to 10 cm shorter than the wall. Fig. 10 and 11 show this situation.

After settlement has finished, the free space between wall and pillar must be filled using the same mortar.

As long as the wall is receiving an important amount of load, its resistance against pulling or pushing is good enough for common situations.

Figure 10: Only wall plural o singular supporting the collar beam

3.5.2. Lintels

When there are no lintels at the lower part of the windows, it is very important to distribute the bricks to reach an independent small piece of wall under the window. In this case, the cracks will appear following the vertical joints as Fig. 12 shows. This solution leads to serious aesthetical and maintenance problems.

Figure 11: Pillar plural o singular 10 cm shorter than the wall

In the second case, when a lower lintel is used, cracks do not appear, due to the stronger behavior of this part of the wall. Obviously, this is the best solution. See Fig. 13.

These upper and lower lintels must be built "in place", because for a pre-cast one, adherence between concrete and adobe wall is too poor.

Figure 12: Fissure opening at the lower part of the wall, under the window

Figure 13: Solution for the lower lintel

A pre-cast lintel will never reach a correct structural behavior because it is like a pinned support, while an "in place" lintel works as a fixed element due to adherence and length of the support.

In pre-cast samples, the reaction against external forces is concentrated on a point, generating very high compression stresses, impossible to be managed by the adobe wall. And the deflection of the pinned piece is 4 or 5 times bigger than the ones in a fixed one.

3.5.3. Protection of door or window opening

- Variant 1: Results are good due to the use of fired bricks which are stronger than adobe. Coating must be done using a mortar of cement and sand, in order to obtain a better protection of this weak area. Bricks must be placed using a linear disposition of vertical joints (called "junta corrida" in Spanish). Interface between adobe and fired bricks must be filled with a cement-sand-clay mortar ("tercio" in Spanish) to get better adherence between both materials.
- Variant 2: It does not work well because adobe refuses the cement coating which will fall down. This effect is especially strong near the door or window opening because of the dynamic component of loads there.

3.5.4. Wall coating analysis

Dosage number 11 of Table 3 (1:1 ratio of soil and sand) gives the best behavior for thick (internal) coating.

For thin (external) coating, dosage number 12 of the same Table 3 (1:3 of lime and sand) is the best one.

These combinations of dosage, 11 and 12, allow obtaining a good adherence after three months of a rainy season, and it maintains a good condition against erosion. Only a few fissure openings were observed at the end of the testing period.

Fig. 14 shows three prototypes of wall, coated by dosage number 11 for the thick (internal) coating, and different kinds of thin (external) coating.

Dosage number 2 of Table 3 was used for left sample, number 14 for central element and number 12 for the right sample. Fig. 15 shows the big difference between an uncoated wall and a wall coated using dosage number 11 for the internal coat, a 1:3 coating for the external one.

It is easily visible, the difference between coated and uncoated walls.

4. Conclusions

The article shows the results of a practical process where some adobe wall samples were built in search of an optimal structural response, with a minimal presence of pathology. Not only are the results delivered, but also a process methodology is presented.

Regarding the aspects we were trying to characterize, our conclusions are the following:

- Adobe walls must be built over two lines of hollow cement blocks, as an interface with the foundation. It gives an efficient protection against capillarity, splashing or rain moisture.
- As the wall building is faster, the risk of pathology appearance (bending and cracking) rises. For Cuban (or tropical) environment, the wall lifting must be inferior to 50 cm per day.
- The use of pillars is absolutely necessary when the length of the wall is more than 2.5 times its vertical dimension.
- The binding mortar for the joint between adobe bricks, should be a 1:0.75 ratio of soil and sand, that delivers the best results. To take into account that the soil could vary from place to place, a simple testing like the one shown in this paper, should be done. For the interface between adobe and fired bricks or cement blocks, a mixture of soil, sand and lime must be used.
- The whole building or each one of its parts must be surrounded by a collar beam, and no combination of adobe walls and bricks should be done.
- The best building protection against openings is to use fired bricks surrounding span ring. Interface between adobe and fired bricks must be filled using a soil-sand-lime mortar.
- The coating had to be done with an internal thick coat and an external thin coat. Our best results were obtained using a 1:1 mixture of soil and sand for the internal coating and a mixture of sand and hydrated lime in a proportion of 3:1 for the external one.

Figure 14: Different kinds of coating

Figure 15: Difference between coated and uncoated walls

Acknowledgements

We would like to thank the support of the Spanish Agency of Cooperation for Development and the aid of the International Relationships Bureau of the University of Oviedo, for supporting authors travelling expenses.

References

[1] Rodríguez Díaz, M. A., y Saroza Horta, B. Identificación de la composición óptima del adobe como material de construcción de una escuela en Cuba. Materiales de Construcción, 56 (282), 2006.

[2] Habiterra Network, CYTED. Recommendation for standarizing of adobe, tapial and soil-cement buildings. La Paz, Bolivia: Habiterra CYTED network. 1995.

[3] Gonzáles Limón, Teresa "Estudio de patologías y caracterización física y mecánica de los materiales de tierra", Revista Ingeniería Civil no. 132. España. 2003.

[4] M. A. Rodríguez, I Monteagudo, B. Saroza, P. Nolasco, Y. Castro. Aproximación a la patología presentada en las construcciones de tierra. Algunas recomendaciones de intervención. Informes de la Construcción. Vol. 63, 523, pp. 97-106, 2011.

[5] NTE E.080. Adobe. ININVI: Adobe construction. Technical Standard for adobe building. Special disposition for seismic-resistant adobe building. Lima, Perú.

[6] Minke, G., Guidelines for building with earth. Soil as a buildings material and its application in modern architecture. Motevideo, Uruguay: Nordan-Comunidad, 2001.

[7] Guillaud, Hubert y Trappeniers, Marina "Building cultures and sustainable development", Basin News. December 2001. no. 22, 2001.

[8] Álvarez, B., Menéndez, J. M., Dzioba, B., Coello, A. C., Evaluación de materias primas en una planta de beneficio de arena de sílice para aumentar la eficiencia energética del proceso de molienda. Revista Dyna, edición 177 - febrero de 2013.

[9] Payá, J. J., La "transmutación" sostenible de los residuos para nuevas materias primas en el ámbito del concreto. Revista Dyna, edición 175E – octubre de 2012.

[10] Houben, H. and Guillaud, H., Earth construction. A comprehensive guide. Intermediate technology publications. Paris, France: CRATerre-EAG, 1994.

M. A. Rodríguez Díaz, has a PhD in Mining Engineer from the University of Oviedo. He is a professor of the School of Mining Engineering, University of Oviedo, which is part of the Department of Mines Exploitation and Exploration, since 1994. In this organization, he teaches on topics related to Soil Mechanics, Rock Mechanics, Soil Behavior, Geotechnical Civil and Mining, etc.
He has directed and collaborated on several research projects with organizations from different Latin American countries such as Cuba, Perú, México, etc. Also he has directed several PhD Thesis and projects with satisfactory results, and published several articles on different subjects. He is currently the Director of a Master of Mining Geomechanics, taught in Peru to mining professionals.

F. Arriznavarreta Fernández, has a PhD in Mining Engineering from the University of Oviedo. He is also a professor of the School of Mining Engineering, University of Oviedo, which is part of the Department of Mines Exploitation and Exploration, since 1995. His specialist topics are related to Soil Mechanics and Geotechnical Engineering in general and modeling structures.

I. J. Barroso Valdes, A Hydraulics Engineer graduated at the Higher Polytechnic Institute Jose Antonio Echeverría in Havana, Cuba, where she taught in the Department of Civil Engineering and was part of the University Group Integrated Project Engineer and she also has a technical Works (Hydrology specialization) from the University of Ávila. She has participated as a lecturer in various university extension and summer courses taught at the University of Oviedo such as the Slope Course, Earth Dams Course, Risk Course, etc. She has also participated in several projects with Spanish and international entities.

B. Saroza Horta, He holds a PhD in Technical Sciences from the Architect Central University of Las Villas, Santa Clara, Cuba. He is a professor at the Department of Civil Engineering of the University. He has participated in several joint projects between the University and the University of Oviedo, publishing several scientific papers together.

P. N. Ruiz Sánchez, has a PhD in Technical Sciences and Civil Engineering from the Central University of Las Villas, Santa Clara, Cuba. He is a professor at the Department of Civil Engineering at the same University and researcher at the Center for Research and Development of Materials.

F. González Coto, holds a PhD in Mining Engineering from the University of Oviedo. He is mining manager at several coal mines of the company Hunosa Group, with more than 10 years of experience in underground mining. He has participated as a lecturer in various university extension and summer courses taught at the University of Oviedo such as the Slope Course, Earth Dams Course, the Course of underground mine Risks, Ventilation, Safety and Security for underground mining, etc., and published several articles on different mining, environmental and civil subjects.