III.23  
Mortars in the Buildings of Pre-Hispanic Peru: Structural Behaviour Studies

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Abstract The Peruvian’s prehispanic constructions are constituted by buildings of religious, military and social character. The remains that have survived to the present day have different levels of deterioration caused by an action of man or environment. Their conservation is undoubtedly a necessary and also interesting task. The structural evaluation of the Monuments that constitute the archaeological patrimony of Peru should be based on a previous research of the masonry components including mortars. This demands a study that allows to classify and identify the masonry materials so that one proceeds adequately in the identification of the stress levels to which they are submitted and likewise in the design of new Compatible Repair Mortars (MRC). It is important that the new repair mortars contribute appropriately to the preservation of the structure, i.e. they are durable and also provide the required functions. The mortars used in the buildings of the civilizations that developed in the Peruvian territory, which still remains in good conditions, are in some cases more than 4000 years and were able to support hard seismic activities. One has to bear in mind that in this geographical zone the earthquakes are very frequent and masonry has to absorb stress and displacements without coming to the collapse.

1  Introduction

According to the studies developed, the first urban settlements of America are located in the Central Coast and Northern Peru. The Peruvian coast is located in the The Pacific Ring of Fire, planet zone with more seismic activity of the world (Fig. 1-a), the land is crossed by the Andes Mountain; in the South of country occur an important volcanic activity.

The coast desert to contributed of many structures do not deteriorate completely today is possible to study the ancient cities and verify the important development in their constructions. The lack of rain due to phenomena such as El Niño, frequent earthquakes, avalanches, wind erosion and especially the human
factor have been the principal agents to contributed the progressive deterioration of these structures, all built with the clay mortar, a very fragile material.

As part of the conservation work of the buildings, it is necessary, in principle, to analyze the most important structural typology and also to analyze the stress type in their parts, where the mortar clay have an important role when the material has been used in adobe or stone masonry from the first settlement of human groups, the large ceremonial centers, to the latest manifestations of Inca architecture. The mortar used was made with water, clay and sand, was built with earth, there are no known archaeological sites with features like pozzolan or binders such as cement, however due to the fragility of clay mortar were devised solutions or building systems that favour building maintenance may be trying to masonry structures that were made with clay mortar, weak in nature, were not working to capacity limit, surviving until today in good conditions at some cases.

The use of clay mortar is classified:

Decorative
- Friezes
- Plaster

Structural
- Mortar in masonry walls Adobe
- Mortar on stone masonry walls
- Plaster plates quincha
- Mud wall

Fill
- Conglomerate of clay mixed with other elements

Fig. 1 a) Seismic Map of Peru (Fuente: Geophysical Institute of Peru). b) Clay figure, 2000 BC.
2 Hypothesis of development of the use of clay mortars

For have an structural analysis of constructions to the early civilizations in the coast and the highlands of Peru, we can see the technical development by clay mortars was becoming more complex as it was understood their mechanical properties to verify that weather conditions were considered, the mechanics of their physical behaviour and definitely the political and religious character. Special mention are the techniques used in the hydraulic, roads, bridges, etc., of which depended on a growing economy and infrastructure of which deserves further analysis. No doubt the ancient Peruvians found in the materials were at hand, earth, stone and water, alternative solutions for demanding construction requirements of your community, it’s remarkable the ability to go was achieved taking advantage of these materials to your domain almost total in their mechanical behaviour, in some cases was combined with vegetal fibers using it a binder mortar in stone masonry walls, which gave substantial improvements in their mechanical abilities, it’s known that the breaking strength of vegetable fibers is similar to ductile steel, so that we can say that these properties were exploited in these constructions [8], further research in this regard are necessary. We identified four stages, as in the technological development of the use of clay mortar in ancient Peru as a building material.

3 Stages use of clay mortar

3.1 First Stage - 2800 B.C.

It identifies a rudimentary use of clay mortar was used as filler in the platforms of the pyramids as bedding mortar on the walls of stone blocks of various sizes, with little use of the physical capabilities of the mortar, it is understood that its use was in its early days and still there was no extensive domain of this material, later shown improvements in the use of mortar for the settled of stone blocks

Uses:

- Seated stone block walls type orthostats.
- In adobe or stone masonry walls in platforms structure
- With bricks forming the filling of the platforms,
- How to fill platforms,
- In high relief and plasters, etc.
At this early stage, \textit{raised platform} is the architectural expression of more recurrent and meaning of all the Pre-Hispanic Peru. The structural system of the platform was in some cases a grillage type construction, this technique was settled the construction of walls with clay mortar, which were folded and locked together, these planes of walls that were left in a place that were filled in many types of filling: with \textit{shicras} (vegetal fibber bags filled with stones), bricks, mortar in large quantities, and bricks in many shapes\cite{1}, this procedure allowed to gain height and volume with low weight, stability is guaranteed against earthquakes and flexibility for settlement of the soil (Fig. 4). These filling of \textit{shicras} or mortar, are stable in themselves, that is, the force was not horizontal (the \textit{shicras} piled on each other) in the case of dry mortar that is shaped like a large block of adobe, the push was in vertical direction of such form that the contour walls was not made a stress in their plane and supported small deformations.
3.2 Second Stage – 200 B.C.

At this stage the mortar mixed with mud bricks used in several ways, tapered, and hexahedral planes, forming filled with platforms, this association adobe-mortar, followed patterns established in the blocks, forming the structures of pyramids and walls of great height (Fig. 5). They are made of plaster surfaces, handling of high relief with colour applications. In some cases, where the mortars is in perimeter walls are used as an additive of vegetal fiber reinforcement [6]. The use of clay mortar at this stage was certainly more developed, the mortar was better spent on the settlements of adobe, grouped into large volumes settled in different ways but using the mortar in adept form [2], the bricks were many different shapes, (hexahedral, conical) [4], in different sizes and shapes of complex armed masonry. Although their fragility, these types of buildings could stand a long time, and its main deterioration factor is the rain and vegetation is close of the constructions.

Uses:
- Adobe wall masonry.
- Adobes shaping the pyramid platform.
3.3 **Third Stage - 1000 A.C.**

At this stage the mortars start to use in mass to form large masses, these casts were forming the large brick adobe or mud wall. The use of mud walls were reported in the construction of the great cities and ceremonial centers, its use was widespread in the last stage before the Spanish conquest and his technique is still in force in the Peruvian Andes. We know that building with adobe blocks involved the manufacture of molds and *brick mold* [3]. To shape in the same building site, compacted clay was carried out with blows of a wooden hammer, getting a good height walls, and straight and sufficiently earthquake resistant stability. The walls apparently had a relationship width: height to 1:3, and generally trapezoidal section which gave it good stability. You can verify that at this stage is a more technical use of clay mortar as a building material.

![Fig. 5](image)

Fig. 5 a) Rigging of conic shape adobe [2], b) Rigging in book shape [2], c) Complex rigging in Pachacámac [2], d) Adobe wall with reinforcement in Chan Chan-Nord Peru [5].

![Fig. 6](image)

Fig. 6 a) Mud wall in Cajamarquilla, Lima. b) Mud wall and adobe construction, Lima.
3.4 Fourth Stage - 1400 A.C.

At this stage the use of clay mortar reaches its maximum development, its manifestations are mostly associated with the use of mud wall and adobe and stone masonry. The use of clay mortar due to their fragility to face agents of deterioration such as moisture or earthquake, is used in conjunction with other construction techniques, such as quarrying, the results are the most notable achievements of the pre-Hispanic building in Peru. In the Inca period in which the masonry reaches its maximum development was dispensed with the use of mortars, this due to the fragility against the rains of the highlands. Despite these limitations are achieved remarkable structures (Fig. 8-b), with very slender walls, and even columns made of mud bricks, these examples in the Coast are impossible for your seismicity.

**Fig. 8** a) Section of Stone wall with clay mortar fill, b) Inca’s adobe wall, Templo de Wiracocha, Cusco.
4 Conclusions

As demonstrated in the paper, the mortars in the Pre-Hispanic Peru were prepared with soil and did not have a satisfactory performance itself, about your mechanical parameters however the mortars seemed to performed much better as a part of the building systems used. It is interesting to note the construction of masonry without mortar in the Inca buildings located in the mountains. The dry stone construction without mortars could be explained by the Inca’s knowledge of poor durability of clay mortars. The preservation of Pre-Hispanic buildings in Peru needs the knowledge of structural and material performance. Important is also the traditional technologies of mortar production and preparation as in some cases the mortar components have been used by local societies over a thousand years.

According to this study we can identify a constant progression in the development of typologies and the use of component materials, stone, mortar and bricks. More studies are necessary to guide correctly Conservation of Archaeological Heritage of Peru.

5 References

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