BUILDERS IN PRE-HISPANIC PERUVIAN ANDES: ANALYTICAL APPROACHES TO KNOWLEDGE THEIR SEISMIC RESISTANT

Henry Eduardo Torres¹

¹ Civil Engineer of Ministry de Culture of Peru. email: etopec@gmail.com

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Abstract. For a long time in Peru ago and the world has been taking an analytical look at the constructions built with techniques originating in each region of the world, despite the time elapsed still appear the same choices between those who despise knowledge formed in architecture and engineering, which is our area of study, and instead want to learn about it and investigated. The seismic-resistant is an ancient knowledge in Peru since 5000 years until be interrupted by the European conquest in the sixteenth century. In this work will be a compilation of some techniques used that we have contributed to the good earthquake-resistant performance of the monumental structures. The constructive analyzed technologies were: a system for containment of constructive landfills, technologies specialized in the construction of walls of adobe, analysis of the masonry Inca, etc. Earth, vegetable fibers, stone, mud bricks, rammed earth, etc. They are some of the elements used by the ancient engineers and architects, this knowledge resistant earthquake was done without losing your style to constructing with a excellent development the architectural spaces.

1 INTRODUCTION

This work comes as a result of research carried out to pre-Hispanic construction systems, the research in parallel with the field work aimed at conservation. We believe it is necessary to run a successful conservation of archaeological structures in very important to know how they were designed and constructed buildings, the aim is for a period of about 5000 years of buildings made of stone and earth, the mortar used to be always the raw land. The study area is located in the central Andes, in the present territory of Peru and there have been about a dozen archaeological site characteristics of which have drawn these different types of structural masonry.

Figure 1: Location map of Peru and Inca wall in the Sacred Valley, exceptional example of Inca masonry.
2 SHICRAS AND CONTAINMENT SYSTEMS FOR LANDFILLS

The bags are made shicras networks reed, rattan is braided by various techniques to form a network that allows them to form stronger fibers that allow networks and then assemble the bags, sizes are varied, there are very small and very large up to two meters in diameter. The purpose of these exchanges was to contain stones and earth inside when the bag shicra contained stones had the plot of largest network, when land was contained smaller network. It was used in the period archaeologists call archaic late (quote thesis gerbert), it is important to their location within the building fill that formed the "pyramids", or other structures formed from platforms that was the architectural style used very often on the coast central andes, some experts attributed only functions under work assignments by groups of people who have worked in the buildings, the fact is that the records have shown that the location and technical responds to criteria of seismic resistance that has social needs [1], the records made both in literature and in the field allow us to see that the "shicras" functioned as fillers effective lateral thrust avoiding fillings, thrust caused by seismic events that plagued the area frequently. the shicras were part of an effective construction system consists of the construction fill stabilized through "shicras" and walls that bound the shicras by a special technique formed a competent wall and with an appreciable stiffness, landfills is sand stone or gravel, you have angles sharp enough standby around 35 °, so that when the filling was large enough lateral thrusts were detrimental to the stability of the overall structure, the use of shicras was an ingenious step which took into account this feature of granular materials, considerations would thousands of years later by the theories of soil mechanics. The shicras were not infallible, but their deformability and elasticity contributing junco fibers were sufficient to extend the useful life of buildings, engineers objective pursued until today. In archaeological sites are found deformed product of lateral thrust or strategically placed within the building fill next to each other forming layers of fillings. In conclusion, shicras was an ingenious and brilliant solution used in the resources available to address the seismic demand of the coastal environment.

Figure 2: Shicras examples of distribution inside the buildings. (Caral archaeological site)
3 MASONRY DEVELOPMENT AND STRUCTURAL FEATURES

The masonry in the Peruvian Andean had a development special than others cultures around the world, [2] the environmental conditions; the earthquakes and the geography develop the new architectonic concept and engineering concept for the builders. The masonry with earth mortar without any additive for enhance the mortar resistant development constructive technics for optimize the structural conditions. The knowledge about this condition was determine for develop constructive technics, the walls have been built with addition of vegetal fiber inside the mix, for enhance the behavior in front of the seismic events. In second place the architectonic configuration is the more important contribution for your stabilization, in third place were the constructive details in the structure, for example the segmented walls, walls masonry without filled inside, the trapezoidal section of the walls, the bond patterns, etc.

Figure 3: Stone masonry and piece of mortar with fibers inside most used in the buildings. (Las shicas archaeological site)

Therefore, the Andean constructors employed many technics was contribute to build within need chemical additives than lime, there aspects for the architectonics features was done in all west side of south America, In addition the builders considered the maintenance of the surfaces and structures when the unique alternative for a better behavior the masonry in the temp, the maintenance of the surfaces is now visible and is possible identified many layers of mortar application for protect the structure. The pre-Inca structures but also show a wide variety of designs and structural systems, a wide variety of walls constructed of adobe or stone that despite the continuous change of the material using the same wall design recorded a continuity in time, clear is that there are significant changes in the use of the materials according to their geographical location, such as the use is widespread in the central coast of Peru where rainfall is low, with about 5 mm of annual rainfall, while in the high areas Andean use of stone was much better then resisted widespread rains, have in common the use of mud mortar. We think that many types of veneer used by the ancient builders of the Andean area (Diagram No1) have similarities to the Roman architecture, as examples we mention the “Opus africanum” with certain similarities to confined masonry Late Archaic (3500 BC), the “Opus spicatum” the adobes of Lima (200 BC) period or “Opus Incertum” similar to wall construction technique with fillings inside their structure has been used in the Andes for over 4000 years.
3.1 Classification

3.1.1 For Shape of the outer wall

*Confined masonry.* In historic masonry construction, the big stone blocks is used to confine other small blocks linked with mud mortar. Appear in archaic period.

*Masonry of tight blocks (average size).* In this classification, the masonry is wedged and linked to each other around the perimeter of the blocks. It is a wall with very high stiffness.

*Masonry of tight blocks (irregular size).* Same as the previous classification, except that are formed by irregular blocks and yet they fit perfectly.

*Masonry of regular blocks with joint mortar.*

*Masonry of irregular blocks with joint mortar.*

*Masonry of thickset joint mortar.* The use of mortar with a considerable thickness is registered for thousands of years in the study area in the early seasons, the use of the horizontal mortar also considered that no mortar board and yet the wall was used was sufficiently rigid, found adobe walls with a thick mortar seat which has not subtracted stability.

*Small blocks masonry.* Walls with small blocks have been widespread in the Andean region, architectural records show that were used from the Archaic period (3000 BC) to the Inca period so it is and one of the most important construction techniques in the Andean region.

3.1.2 For bond patterns

*Stretcher bond.* When the masonry was entirely composed of stretchers, set in horizontal rows.

*Header and stretcher bond.* The bond is made of alternating layes of stretchers an headers, results a solid wall that is a full masonry in depth.

*Soldier bond.* A brick laid vertically.

*Soldier an stretcher bond.* A brick laid vertically alternating layes with stretcher bond.

3.1.3 For Internal structure

*Masonry fill.* When the masonry has a internal fill between two walls opposite surface.

*No fill in masonry structure (solid).* The masonry has a solid internal structure.

### TABLE N°1

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<th>FOR SHAPE OF THE OUTER WALL</th>
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<td><em>Confined masonry</em></td>
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Builders in pre-Hispanic Peruvian Andes: analytical approaches to knowledge their seismic resistant masonry of tight blocks.

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<th>Masonry of tight blocks (average size)</th>
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<td><img src="image2.jpg" alt="Image of masonry with tight blocks of irregular size" /></td>
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<td>Masonry of regular blocks with joint mortar</td>
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<td><img src="image4.jpg" alt="Image of masonry with regular blocks and joint mortar" /></td>
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Masonry of irregular blocks with joint mortar

Wall in Chankillo archaeological site, the stone blocks has linked with mud mortar.

Caral, wall with heterogeneous blocks, will appreciate an special order of layers.

Las shicras, wall with big blocks combined with small stones.

Wall base with irregular stone blocks at inca settlement, Inca Wasi.

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Incawasi
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### FOR INTERNAL STRUCTURE

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<th>Soldier and stretcher bond</th>
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#### Fill inside masonry

| Wall with fill inside, Vichama, Perú. | Chankillo, Perú. | Pachacamac, Perú |

#### No fill in masonry structure
4 WALLS SEGMENTED AS SEISMIC SOLUTION

Several structures in the central coast of Peru have seen the construction of walls attached vertically, but there are also enlargements in the horizontal direction. The use of vertical joints as possible earthquake-resistant solution was possible by walls vertically built with successive blocks in the construction of large structures [3]. This technique would be able to give it some level of ductility to the structure allowing the movement of the structural masses in case of seismic forces.

Figure 4: Segmented walls in the adobe constructions. (Huaca del Sol and Pachacamac archaeological site)
5 PLATFORMS AND TRAPEZOIDAL WALLS

Most of the structures in the coast consist of platforms and other massive structures; the platform itself is a stable structure for your configuration. Due to the size and volume of these constructions, settlements are not very severe as it’s possible that the soil has consolidated over time. Regarding seismic forces due to the large mass of these structures have a good performance against lateral forces on its high rigidity [4]. The construction of the walls was an important success for buildings could withstand earthquakes, the trapezoidal wall section solved in practical minimum mechanical capabilities of adobes, adopting configurations whose behavior was optimized by using these forms. Another important feature was the height / width ratio of the walls whose values are 2:1 or 3:1, and showing that they are structures that work by gravity, i.e. the weight which allowed to maintain high stability. In other cases when the height / width ratio is much higher were detected severe damage or complete loss of the walls.

Figure 5: Platforms structures and trapezoidal walls in several constructions. (Pachacamac, Huaca del Sol, Parangona, Caral and Chan Chan)
6 CONCLUSIONS AND FINAL NOTES

- The development of structural systems, the proportions of the buildings and other construction techniques such as diverse masonry were developed due to the particular conditions of seismicity of the area, understand that without the use of lime or other binder and without using fire clay to make bricks had to develop ways to improve the stability of the buildings from the use of raw land and plant fibers.

- This investigation of the structural systems used by the prehispanic builders has allowed us to appreciate the level of development obtained from experiments with a limited number of materials and earning achievements, these techniques has also been developed in other civilizations and today some of they are used in modern engineering.

- Our classification of structures is probably not complete, as the amount of archaeological remains in Peru is immense, however despite the small sample (statistically speaking) were able to identify the pre-Columbian masonry has been in continuous evolution and adaptation, the design of its walls and the internal structure of bond also had a similar development to architectural design in other parts of the world with the difference that the Andean area is located in high seismic activity which made it necessary to consider the seismic resistance of the walls.

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REFERENCES


