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Critical analysis of interventions in historical rammed-earth walls—military buildings in the ancient Kingdom of Seville

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ABSTRACT: Despite the general acceptance regarding the interest of dealing with heritage interventions using specialized approaches, thanks to the Charter of Krakow, actions on historical rammed earth walls are to often undertaken without support from any preliminary critical assessment. Hence, in recent decades, this has contributed towards the generation of a wide disparity of intervention criteria and technical solutions. This paper addresses a critical analysis of interventions carried out over a specific period of time on military buildings of the ancient Kingdom of Seville. Prior recording and cataloguing of interventions was carried out in order to propose criteria for their value, in terms of their adaptation to formal and technical interventions characteristics.

1 INTRODUCTION

Andalusia possesses a long military heritage as a result of its ancient territorial and political structure, consisting of towers, castles and city walls, which have been restored over the last 7 years under the framework of the Andalusian Plan of Defensive Architecture (PADA), designed and developed by the Dirección de Bienes Culturales de la Junta de Andalucía.

These buildings, whose most common constructive technique is rammed-earth, are especially vulnerable to external agents that, together with inappropriate conservation and maintenance techniques, have frequently increased their state of risk.

Hence, it is appropriate to propose a critical revision of the latest interventions on military rammed-earth walls in order to establish those material factors and technical solutions that must be assessed, and as far as possible to estimate the efficiency and durability of their responses over time. This analysis will lead to the establishment of objective criteria which may allow a classification of interventions according to their responses to these criteria.

The proposed critical analysis has been applied to a group of military buildings of the ancient Kingdom of Seville that have been totally or partially built with military rammed-earth during the North-African (Almoravid and Almohad, XII–XIII centuries) and Mudejar periods (XIII–XIV centuries), and have been restored in recent decades. In spite of the clear predominance of monolithic rammed-earth walls in the cases selected, it was intended to cover the maximum number of constructive techniques and states of conservation, so that conclusions would be stronger and could be extrapolated to include a variety of geographic locations.

Specifically, this study takes the following building as case studies: the Castle of Alcala de Guadaira, Castle of the Guardas, Alcazar of the City Gate to Seville (Carmona), Hacienda de los Quintos (Dos Hermanas), Ecija City Walls, Castle of Lebrija, Castles of Los Molares, Niebla City Walls (Huelva), Tower of Saint Antonio (Olivares), Sanlucar la Mayor City Walls, San Juan de Aznalfarache City Walls, Seville City Walls, Alcazaba of Reina (Badajoz), Castle of Utrera, and the Tower of Alcantarilla (Utrera).

2 INTERVENTION COMPARISON

The analysis presented in this paper of the main intervention criteria used in the case studies has been developed according to the most frequent technical and formal solutions, as well as to their results and responses. Furthermore, repair work due to water erosion, and in the form of consolidations, restitution/restoration of mass, renderings and crack repairs are pointed out for each study case.

2.1 *Repairs due to water*

The vulnerability to water of rammed-earth walls and its weakening effect on the inner structure are normally manifested at the base and top of a wall. Several techniques may be considered in order to prevent the gathering of water through capillary action and through filtration at the base. First, passive techniques limit the access of water but fail to remove it. In comparison to the proposed technique of Macías & Espino (2001) to dry out interior walls of low ventilation, which consists of the placing of a ventilation pipe with the two ends at different heights, or similar solutions based on ventilated chambers (Ashurst 1988, Monjo 2001), other kinds of simple actions may help the proper hydrothermic performance of the wall. For instance, when rammed-earth walls are confined between hard and impermeable surfaces (such as the Seville City Walls in the Macarena sector, which are surrounded by concrete and asphalt), the removal of these materials and the action of leaving 50 mm free from the surface of the wall (Ashurt 1988) or the replacement of those dense materials with softer materials (Walker et al., 2005) constitute a major step towards correct hydrothermic behaviour. Nevertheless, in the restoration of the Seville City walls, as in other case studies (Écija, Niebla, Córdoba, and Cáceres), no action has been carried out to prevent this situation, and the consequent erosion of the base of the wall due to water splashing. In contrast, in the Portuguese Alentejo, certain straightforward and inexpensive solutions have been accomplished through the placement of a small slope along the base of the wall in the form of a narrow pavement, in order to prevent the water from gathering (Guillaud 2004).

Although the usage of drains, prudentially placed away from the wall, is very effective in order to control the amount of water that reaches the base of the wall, is has not been possible to check neither analyze this situation on the study cases.

Other passive systems, such as certain kinds of waterproof barriers (Ashurst 1988; Keefe 2005; Walker et al., 2005; Easton 2007), may be applied in order to control capillary rising damp. Although it is a simple solution in case of new buildings, it becomes seriously complicated when dealing with restoration work. Siloxane injection systems into historical walls (Ashurst 1988, Ortega 1994) show certain difficulties for military rammed-earth walls, due to their great thickness and inner irregular void distribution. This technique is therefore proved less feasible, and hence its responses have not been assessed for this study.

The tops of walls, principally in the lengths of city walls, tend to constitute the most eroded area due to their high exposure to weathering agents. Although the placement of a roof and overhangs might appear to present a straightforward solution, this is not the case when dealing with military walls, since it would be necessary to choose an alternative solution such as the placing of coverings or layers of a sacrifice material at the top of the wall, which would have to be permeable to water vapour exchange in order to prevent water ponding under this protection. To this end, Oliver (2000), considering erosion as an unavoidable process, suggests using adobe as a sacrifice material that should be replaced within a regular maintenance program. A number of technical solutions have been applied in the case studies, commonly in the form of sacrificing layers made of lime or lime-cement mortars. Some examples, such as restoration work at the Castle of Lebrija and the City Walls of Sanlúcar la Mayor, show this solution, in the latter case with the worst esthetical results. As an alternative, at the Castle of Alcalá de Guadaría, special pieces of steel-reinforced limecrete were produced on-site, designed with sufficient slope and overhang for the correct protection, and were simply laid on top of the walls. However, it is remarkable how, for such outstanding restorations as those carried out on the Seville City Walls, no effective technical solution has yet been accomplished.

Although the protection of the base and the top of the wall would suffice, high exposure levels to weathering agents may demand greater attention to be paid to the surface of the wall by means of an adequate rendering. When dealing with retaining walls, opening certain channels through the wall could help the drainage of water from the terrain, so that infiltrations may be prevented for the whole surface. This technique was efficiently put into practice in Alcazaba of Reina, however for other case studies under similar circumstances (Castle of Lebrija and the City Walls of San Juan de Aznalfarache) no technical solutions were planned even where damp and consequent damage is currently evident.

2.2 *Consolidations*

Consolidation is one of the most frequent actions on rammed-earth walls due to their specific characteristics. Through industrial or traditional products, it is intended to stabilize the deterioration process of the inner structure of the mass and likewise to improve cohesion and adherence of its particles. The efficiency of the consolidation usually depends on the infiltration capacity of the product.

Inorganic consolidants fill up the accessible pore system thanks to their chemical precipitation in water, thereby cementing particles of the inner structure of the earth. Limewash or lime water, of 1:5, 1:7 lime/water proportions respectively, applied with brush or spray improve cohesion when the carbonation process occurs inside the wall. To this end, consecutive layers are spread leaving one day between each application in order to let each layer properly harden (Goreti 2005). For instance, surfaces of the Alcazaba of Reina (Rocha 2005) were brushed with limewash containing a small proportion of sand, not only to harden the wall but also to smooth over the contrasts between restored and original surfaces. Nevertheless, the current state of conservation of both covering and wall implies that restoration work was largely ineffective mainly due to the low infiltration of the limewash that would have required a regular maintenance on order to be effective.

Another kind of inorganic compound in the form of ethil silicate has been used in several cases studies of restoration work, although it was not designed specifically for earthen construction. Its usage is widely used for the enhancement of stone cohesion, and is especially appropriate in the case of sandstone and limestone (Zoghlami 2003). Furthermore, this compound is permeable to water vapour, is suitable to siliceous materials, and presents no chromatic change. Ethil silicate was used in the restoration of the Golden Tower in Seville (2004) and in the case of the restoration of the Macarena sector of the City Wall of Seville (2008). The performance in the Tower seems to have yielded positive results so far, mainly since no damage has appeared because its rammed earth is protected by a lime mortar. Regarding the Macarena sector of the City Wall of Seville, there is currently no serious damage where ethil silicate has been sprayed in consecutive layers. However, due to the lack of maintenance, earth is beginning to appear at the base of the wall, as a consequence of erosion and loss of cohesion of its consolidated surface. Some specialists (Aymat 2000) argue that this compound is the direct cause of some losses of surface material in certain earthen walls. Hence, it is always recommended to test the response of rammed earth before any application since this is not a reversible technique.

Organic compounds, such as asphaltic emulsions and acrilic epoxie resins, constitute another line of consolidant products. These have been proved to be non-suitable products however, mainly due to the low permeability of the layers generated on the surface of wall, which drastically changes the hygrometric behaviour of the wall and consequently weakens the structure of the rammed earth due to water ponding.

Therefore, polymeric and resin-based consolidants have proved to be largely unreliable due to their major physical and chemical differences to earthen wall characteristics. The use of inorganic compounds is currently more common in restoration work. Some authors argue that lime in the form of limewash, lime water, or fluid mortar may present the best option in consolidations whether they be rammed earth or any other kind of earthen walls (Goreti 2005). Lime provides extraordinary compatibility, and induces no damage. On the other hand, certain compoundds such as ethil silicate currently display a good response, although further studies are needed in order to prove its efficiency in medium—and long-term responses. Even so, there is no permanent treatment; therefore periodical maintenance is required, whose cycle and intensity depends on the level of exposure of the wall, among other factors.

2.3 *Restitution/restoration of mass*

The restoration of mass occurs when the loss of the original mass, due to erosion, is significant, and may even render the wall unstable, or when integration or reconstruction of certain sections is intended. This technique is much more destructive than consolidation since the carving of original rammed earth is required. In addition, new volumes of rammed earth are placed covering and hiding the wall, and may even lead to the wrong interpretation of constructive characteristics when no criteria is borne in mind. Moreover, since this technique is permanent, International Restoration Charters advise against its indiscriminate use.

Various techniques of the restitution of rammed earth may be carried out according to the specific circumstances of the wall. All of these techniques are based first on the placement and stabilization of a formwork and the later compaction of a certain mixture of earth. Both one-sided and two-sided restitutions have been registered corresponding to surface restitutions and those of whole sections.

However, it remains essential to design the technique in accordance both with the physical and chemical parameters of the old wall and with the constructive characteristics of each component of the rammed-earth wall. If these guidelines are followed, the restoration will certainly be appropriate and coherent.

There are several solutions for fixing the formworks, whether they be wooden or metallic, from ancient techniques based on ropes and nails to modern systems. The first step is always the placement of the needles, which will support the entire formwork structure. To this end, a small aperture is carved in the lower course, allowing the formwork to enclose a few centimetres of the top of this lower course. Before setting the wooden needles in place, it is necessary to completely soak them in water for one day in order to prevent any unexpected increase in their volume. The dimension of wooden needles may widely vary, from those square needles used in the Alcazaba of Reina and the City Walls of Seville, to those of a rectangular cross-section of the Monteagudo Castle in Murcia (López 1999). The typology of the needles should be carefully chosen in accordance with the characteristics of the original needles; a consideration largely ignored in the past.

Regarding the case studies, both formwork systems have been used; in certain restorations in the form of traditional wooden formworks made of 4 or 5 nailed planks (walls of Seville, Alcazaba of Reina, Castle of Paderne, walls of Niebla), on other sites in the form of metallic boards for concrete (Castle of Toral de los Guzmanes). Despite this, it is clear that the key to accomplishing an adequate response is to guarantee the adherence of the material of the new restitution with that of the original. A number of techniques have been proposed and applied, based on protected or unprotected metallic connectors (Castle of Paderne), insertion of ceramic pieces, stones or creosote-protected wooden beams and carving of hollows or cavities in the existing wall (walls of Niebla). However, prior cleaning and soaking of the surface by means of limewash or lime water (Goreti 2005) is essential. Since rammed-earth walls depend largely on vertical compression, it is crucial to assure a maximum of horizontal surfaces to properly hold newly rammed earth. To this end, the original wall will be cut out, in order to generate a stair-shaped cross-section. It is also essential to protect the upper end of the restitution, especially the interface, in order to prevent infiltration of water, internal erosion, and the consequent collapse of the restitution. This is the reason why intervention of the walls of Niebla (1982–83) failed and currently entire sections of restituted one-sided rammed earth are falling apart. An adequate selection of soils and stabilizers and their compaction is also crucial. Restoration in both this last cases and in the City Walls of Seville (1987), failed to properly deal with these factors. The latest experiences carried out in Niebla in 2010, Reina in 2009 and at the City Gate of Seville (Carmona) are currently showing good technical responses thanks to constructive solutions suitable for the original rammed-earth walls. Nevertheless, other restoration work, even where technical solutions are working appropriately, have failed to observe and follow the constructive patterns of the original wall, since, for example, the dimensions, measures and chromatism of its constructive elements are utterly distinct. Work undertaken on the City Walls of Sanlucar la Mayor show sequences of putlock holes totally different to those of the original wall; at Castillo de las Guardas lime mortars were supposedly used to repair losses of mass, but no constructive or even aesthetic criteria were applied. For other examples, as in the Hacienda de los Quintos, rough fired bricks were used all over the rammed-earth surfaces, thereby totally enclosing and hiding the perception of the original wall. Finally, other restorations, such as that of the Castle of Paderne (Cóias & Paulo 2004), chose to project earth into the hollows, hence generating an unsuitable texture to the original rammed earth.

In general, there is a certain trend towards a greater respect for original rammed-earth constructive characteristics, and a greater focus on restitutions and consolidations of a more controlled and limited nature.

2.4 *Rendering/coating*

When rammed earth is appropriately protected, it may be unnecessary to render the surface. Classic coverings may be applied, such as lime mortar and limewash, after the wall is built, or even during the construction process as crusting layers of lime mortar (calicastrados), which are more commonly found in military buildings.

Although earth rendering may be the most suitable material for rammed earth, it is not widely used for repairs in military rammed-earth walls. Lime mortar rendering is the most frequent technique under these circumstances, and should be spread in several layers; the first layers being thicker and with an embedded mesh to reinforce where necessary, and with less lime to adapt to the original wall. External layers should be thinner and more resistant in order to obtain a longer-lasting surface (Doat et al., 1991). In the same way as for restitutions, surfaces should be clean and free of loose chunks before any render is spread. Lime mortars provide the correct protection since they guarantee adequate hygrometric performance due to the ability of these mortars to transpire and their similarity in rigidity to that of rammed earth.

In general, the responses in the case studies of lime mortars are satisfactory. For instance, the mortars of The Golden Tower, the Castle of Los Molares and the Tower of Saint Antonio are currently preventing any new pathological processes. On the other hand, lime mortars used for the restoration of the City Walls of Niebla (2010) have recently shown new damage due to infiltrations of water from the back of the wall. In other cases, such as in certain sections of the City Walls of Écija, the incompatibility of the technical solution is evident since extensive areas of the rendering are coming off and revealing a rusty mesh. For the same sample, the formal solution criteria of the new covering do not match the constructive parameters of the original wall, since proposed courses, location and shapes of needles do not correspond to the original wall.

Other rendering than lime mortar has been observed in certain analyzed interventions, and has resulted in a variety of responses. Brickwork is a common alternative technique to mortars when the protection of a military wall is needed, although Compressed Earth Blocks could have been used instead. Rough fired brick, with typical Islamic dimensions, 28 × 14 × 4 cm, inherited from the Taifal models (Tabales 2000), is normally used. When brickwork is carried out with a prior cleaning of the original wall and breathable mortars, a new suitable surface can be achieved, although the real constructive identity of the rammed-earth wall shifts into the background. In certain cases, as in the Tower of Saint Antonio, brickwork is limited to restricted areas where it was required as a structural reinforcement or simply to rebuild the original shape whereby restored areas are evident. However, there are other kinds of repairs whose responses are controversial. This is the case of the restoration of the Southern sector of the wall of San Juan de Aznalfarache, where both formal and constructive parameters from original rammed earth have been utterly ignored, since a new covering made of dark stone and cement mortar has generated a barely transpirable skin, which, as a consequence, has led to further damage in the rammed earth due to water gathering.

Finally, a special rendering made of lime mortar is worth mentioning, which is reinforced by means of an embedded steel mesh in both sides of the wall, which are stitched together with steel bars through the thickness of the wall. This rendering aims to increase the compression strength of rammed earth, and it was put into practice in the Hacienda de los Quintos in order to reinforce a load-bearing wall faced with an increase of vertical loads. Other similar interventions in adobe or CEB walls have chosen nervometal (AIS 2009) and plastic meshes (Vargas et al., 2007) in order to improve seismic performance. Nevertheless, these experiments have never been carried out for military rammed-earth walls, partly owing to the inconvenience of their great thickness.

2.5 *Crack and fissure repairs*

Rammed earth tends to suffer from cracking due to the scarce tensile and shear strength. Thus, vertical cracks are more frequent since horizontal cracks are linked to compression and buckling.

It is necessary to start repairs by analyzing the state and evolution of the crack or fissure in order to determine whether it is due to a degenerative damage process in order to assess not only its scope and severity but also whether the crack is going through the thickness of the wall. These parameters will help to define the most suitable repair method, which may be classified as soft and hard methods (Jaquin 2008). Soft techniques are appropriate when the crack is not under any kind of tension, while hard techniques are more suitable if certain tension or movement is likely. In any case, these methods are not applied until the wall is completely stabilized since they are not designed to properly withstand and transmit the tension caused by unexpected movements (Pearson 1977).

Soft methods consist of simply filling up the crack in order to prevent weathering agents from attacking and progressively eroding the core of the wall, and hence structural continuity of the rammed earth is not completely achieved. New filling material should have similar characteristics to those of rammed earth in order to prevent or minimize differential shrinkage. Before any application, cleaning should be undertaken. Narrower fissures and cracks are easily repaired by successive injections of limewash (Goreti 2005). When the opening is wider, a denser material is needed; to this end first a fluid lime mortar might be used and afterwards the aperture could be finished with a limewash. If the aperture is significant, say of 5–10 cm, it will be necessary to first apply lime mortar containing ceramic, brick or adobe rubble or even small chunks of rammed earth.

In the restoration of the Castle of Alcalá de Guadaría in April 2010, cracks were sealed up with a lime mortar leaving an inner void. Several plastic tubes were then placed at various heights which entered the mortar inside the cracks, and these were used to pour a fluid lime mortar into the wall until the cavity was completely filled. Finally, these tubes were cut off. The main inconvenience is the major lack of control in the application and the great loss of fluid mortar that this technique involves. As an alternative, in the Macarena sector of the City Walls of Seville, crushed chunks from the original rammed earth together with lime mortar were used to fill the widest cracks. Although a simulation of original textures and colours was intended, aesthetic results remain questionable.

Hard tying techniques are developed from soft techniques by means of embedding a connector that stitches the crack and improves the structural continuity. Several authors suggest cutting a horizontal chase into the face of the wall, across the crack. Reinforced courses of adobe or CEB are then laid (Ashurst 1988; Pearson 1997; Hurd 2006). When the hollow is narrow, mesh-reinforced layers of mortar may be used instead (Keefe 2005). As an alternative, Guillaud (2004) suggests using various types of wooden staple. However, none of these techniques have been carried out in the case studies. For instance, in both the restorations of the Castle of Lebrija (Torrecillas & Romero 2006) and the walls of Sanlúcar la Mayor (Callejas & Martín 2005), steel staples were set across the cracks, and sealed by an epoxy mortar, showing how techniques designed for other materials are indiscriminately used in earthen building repairs.

3 CONCLUSIONS

From the analysis and comparative evaluation of the case studies, it may be concluded that there is a need to establish certain criteria that reflect the different responses of each intervention, thereby allowing objective comparisons and improving future technical strategies of rammed-earth walls. In order to accomplish a more precise classification of interventions, the selected criteria may be gathered into three categories according to formal-constructive, pathological-risk, and technical reliability responses. To this end, characterization and classification of the interventions is intended under the same perspective, in order to obtain reliable and consistent conclusions.

In reference to the formal-constructive response, it is concluded that evaluating formal and constructive parameters of the intervention is essential, setting aside issues of style or aesthetics since they are subjective and hard to measure. In fact, any coherent intervention should deal with the chronotypology of the original rammed earth in order to properly match its constructive parameters (Graciani & Tabales 2008). Other significant issues, such as the type, location and the approximate distance between consecutive needles should be borne in mind, as well as the dimensions and form of the rammed-earth wall, the height of the courses (module of rammed-earth box) or the length, the type of joints between rammed-earth boxes on the same course and the recording and study of formwork traces or other kinds of decorative elements. Conclusively, this analysis points out whether the constructive correlation between old and new is consistent.

The pathological response and the state of conservation of restored rammed earth are assessed, through the identification of new damage, whether it be material, structural or superficial. Furthermore, the presence of a certain risk factor can be evaluated as a way to indicate how effective the corrective, preventive and maintenance actions are.

Finally, it will be essential to analyze the suitability of the material of the technical solutions to the repair carried out in the particular case on military rammed-earth walls. In this way, the physical-chemical compatibility of construction materials can be assessed, as well as the technical viability of the proposed solution.

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