Structural Analysis of Historic Construction – D'Ayala & Fodde (eds)

Structural faults in earthen archaeological sites in central Asia: Analysis and repair methods

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ABSTRACT: The first aim of this paper is to study the main symptoms of structural decay of earthen archaeological sites, with special reference to those located in the central Asian loess clay belt: Kazakhstan, Kyrgyzstan, and Tajikistan. The Silk Road sites considered in this paper are mostly located in extreme environments with temperature reaching −20°C in the winter and 50°C in the summer, and such conditions provide an ample background for studying structural faults. Before the collapse of the Soviet Union archaeological excavations in central Asia were neither followed by conservation work, nor by backfilling. The fact that none of the sites considered in this study was previously conserved adds value to the research because it shows the behaviour of soil in its natural environment (especially mud brick and rammed earth). The study explains that the main causes of decay can be broadly classified as: rheological (or water mismanagement), man-made, and due to high content of soluble salts.

The second aim of the paper is to propose structural repair methods and guidelines for the most common mechanisms of decay. This is drawn from practical experience in the field as attained by the author in several central Asian projects managed by UNESCO. The existing literature on the conservation of archaeological sites shows scarce information on the structural consolidation of earthen structures. It is therefore crucial to transfer such practical knowledge to those practitioners and conservators working in similar projects elsewhere. In order to do so, the paper provides a thorough explanation on: stitching technique for cracks, conservation of leaning walls, repair of basal erosion, and shelter coating. Another important aspect is the use of emergency conservation activities, these being especially useful when resources are limited or when sites are located in remote areas.

1 INTRODUCTION

The information described in this paper was gathered between 2002 and 2007 during several missions carried out for the conservation of three central Asian sites located along the Silk Roads. The projects, funded by the Japanese Funds-in-trust for the Preservation of the World Cultural Heritage and coordinated by UNESCO, deal with a wide and multi-ethnic archaeological heritage: Buddhist monasteries and temples, fortified Islamic cities, Nestorian churches, Zoroastrian settlements, and oasis systems with wide irrigation canals. The work was started after distinct lack of literature on the building materials of central Asia, this being one of the initial obstacles that were encountered in when developing new attitudes and future directions in conservation. Other difficulties were mainly due to the remoteness of some of the sites and also to the shortage of conservation skills. A short summary of aims and activities is provided in the following sections for every project.

1.1 *Preservation of the Buddhist Monastery of Ajina Tepa, Tajikistan: Heritage of the Ancient Silk Roads (2005–2008)*

The site was excavated in the 1960s by Soviet archaeologist Boris Anatolevich Litvinskij and the plan shows two distinct areas: the temple and the monastery. The site is entirely built of earth, partly of mud brick and partly of *pakhsa* (rammed earth) and at the time of excavation a 13 metres long sleeping Buddha was discovered in one of the corridors. The Buddha, made of soil and mud plaster, was cut into pieces and transported to the National Museum of Antiquities of Tajikistan (Dushanbe) where it was conserved and displayed (Fig. 1). It is considered as the largest Buddha in central Asia after the destruction of the Bamyian

Figure 1. Dushanbe, 2005. The 13 metres long sleeping Buddha after conservation as displayed in the National Museum of Antiquities. Picture: Yuri Peshkov.

statues in Afghanistan. The site of Ajna Tepa is of great importance especially in terms of spread of Buddhism in central Asia as the plan was a blueprint for other monasteries in the area (Litvinskij & Zejmal 2004, Turekulova & Turekulov 2005).

The main objectives of the project are: scientific documentation of the site, setting up of a master plan for the site, application of appropriate conservation and maintenance schemes, promotional activities at both national and international level, training in the maintenance, conservation, and monitoring of earthen archaeological sites (Fig. 2). The project is of great importance to Tajikistan especially when considering the shortage of skills that resulted after its independence from the ex USSR and the civil war that went after, when the majority of heritage experts left the country. Training was conducted by a team of international experts on: three dimensional recording, damage assessment of structures, laboratory analysis of building and repair materials, and conservation work. Trainees were selected from the Academy of Sciences of Tajikistan (Institute of History, Archaeology and Ethnography, the National Museum of Antiquities), the Ministry of Culture of Tajikistan, and the Tajik Technical University.

Conservation work primarily concentrated on the most endangered structures. The main conservation method employed consisted in the repair of eroded walls and shelter coating, and this was applied as follows:

i. construction of a mud brick shelter coat. The mud bricks employed for the encapsulation are clearly legible as a modern intervention;
ii. filling of gap between the mud brick skin and the historic fabric by employing dry soil;
iii. plastering of the mud brick shelter coat with a mix of soil and straw.

Figure 2. Dushanbe, Tajikistan, 2006. Picture showing one archaeologist from the National Museum of Antiquities and one student from the Tajik Technical University during a training session on analytical methods for earthen materials as carried out in the conservation laboratory.

Figure 3. Ajina Tepa, Tajikistan, 2006. Test walls construction in the project house yard. This was an essential tool for the selection of best performing repair materials.

Another important conservation method was the structural consolidation of leaning walls by building massive buttresses. Some walls were so endangered that it was necessary to build such support to avoid collapse of parts of the historic fabric. This was done after extensive experimental analysis (Fig. 3).

1.2 *Conservation of the Silk Road Sites of the Chuy Valley, Kyrgyzstan: Krasnaya Rechka, Ak Beshim, and Burana (2004–2007)*

The objective of this project was to undertake a conservation programme at Krasnaya Rechka, in particular of the Buddhist Temple II (Fodde 2007a), and emergency conservation work at the sites of Ak Beshim and Burana. Other project objectives were: docment and research the sites, which is essential for their better understanding and for that of the region as a whole; identify the best means towards the sites conservation and preservation; give training and build national capacity, Kyrgyz specialists being trained by the best international experts; draw up a Master Plan for the sites conservation as a preparatory step to the potential inscription of the Chuy Valley on the UNESCO World Heritage List. A multidisciplinary group of experts and trainees was formed so that to include architects, engineers, conservation chemist, and archaeologists from: the Academy of Sciences, the Museum of History, Kyrgyzrestoration, the University of Bishkek, the Slavonic University, and the Kyrgyz State Commission on Cultural Development.

Burana Tower (10th–11th century AD) provides a clear view of the approach to architectural heritage conservation in central Asia before the collapse of the Soviet Union (Goriatcheva 1980, Genito 2002). It was heavily consolidated by adding a fired brick skin and an octagonal base (Figs 4–5). This treatment is characterised by hydraulic cement mortar that is too strong for the brick, with the result that moisture evaporation does not occur over the whole masonry, but takes place through the external face of the brick. The exposed faces then tend to flake off, either through the freeze-thaw cycles or the crystallization of salts, resulting in a masonry where the mortar face stands proud (Fig. 6). Humidity patches were noticed in the lower masonry and this seems to be due to water leaking through the parapet. The question to be answered was whether it would be feasible to remove all new bricks that were laid with cementitious mortar without damaging the historic fabric underneath. Being the cementitious pointing mortar too strong, it was advised to leave it into place to erode and fall out rather than attempt to rake it out, otherwise extensive damage may be caused to the brick. Another question is related to the structural stability of the tower. Both archival records and the documentation carried out during the project show a lean and it was suggested that constant monitoring be carried out regularly.

Figure 4. Minaret of Burana (10th–11th century AD), Kyrgyzstan, 1927. Archival picture showing coving effect at the base of this fired brick structure.

1.3 *Conservation of Otrar Tobe, Kazakhstan (2001–2004)*

Otrar Tobe (Fig. 7) is considered to be the most important of a system of six medieval towns located in the loess clay belt of South-West Kazakhstan at the confluence of Syr Darya and Arys rivers (Buryakov et al. 1999, Turekulova & Turekulov 2004)). The common name of loess is Aeolian clay, and as this name implies, it is produced by the action of wind erosion on igneous rock, and this explains its fine range of the particle size. The site flourished between the 1st and 15th century AD because of its location at a junction on the Silk Road. Otrar was the center of a vast farm land and was considered as a caravanserai for the nomads, and the actual site shows the remains of an elevated citadel (*shahristan*) and a lower town (*rabat*). The excavated portions of the citadel revealed a so called palace (14th century AD) and two mosques (14th and 15–16th century AD respectively): the first is made of fired brick bedded with earthen mortar, whilst the second is made of fired brick bedded with *tes ganch*, a mix of soil and gypsum. The lower town revealed numerous kilns and a bath house (14–15th century AD). A small portion of the mud-brick city wall (10–15th century AD) and several earthen houses were also excavated (Fodde 2003, Fodde 2004, Fodde 2005, Fodde 2007b).

Otrar Tobe was first excavated in 1904 and is now inscribed in the UNESCO World Heritage Tentative List. As part of the project a laboratory for the analysis

Figure 5. Minaret of Burana, Kyrgyzstan, 2006. Picture showing conservation work as carried out by Soviet conservators: heavy reconstruction of wall base and facing with fired brick. The main criticism to this kind of intervention is that reconstruction was undertaken without documentary evidence.

of building materials was purchased and set in the Test House (Shaul Der), near the site. The UNESCO project was carried out in partnership with: Ministry of Science and Higher Education, Ministry of Culture and Tourism, Institute of Archaeology, Institute for Scientific Research and Planning on Monuments of Material Culture, Otrar Conservation Authority, and Otrar Museum. The central Asian regional training course 'Conservation and Management of Archaeological and Earthen Structures and Sites, Otrar/Turkestan, Kazakhstan, 23 August – 1 September 2004' was organized as conclusion of the project. It was attended by 45 international and regional scholars, experts, and officials from Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan, the President of ICOMOS International, the President of ICOMOS Kazakhstan, the representatives of the UNESCO central Asian Almaty Cluster Office, the UNESCO Tashkent Office and the Division of Cultural Heritage.

The main objectives of the project were five:

i. Documentation and research. State-of-the-art recording and documentation and the setting up of a scientific documentation system;

Figure 6. Mausoleum II, Burana, Kyrgyzstan, 2006. In the Soviet period reconstruction was often carried out with fired brick bedded with cement mortar. This caused two major decay patterns, both due to water infiltration and lack of breathability of the mortar: erosion of brick face and bulging of reconstructed parts.

Figure 7. Otrar Tobe, Kazakhstan, 2003. Bird eye view of the elevated citadel or *shahristan*. The area around the citadel, *rabat*, was predominantly residential. Picture kindly provided by Renato Sala.

ii. Conservation of the Otrar Tobe archaeological site and its protection for present and future generations, and emergency safeguarding actions at Kuyruk Tobe, Altyn Tobe and Kok Mardan;

iii. Master plan for the conservation and maintenance of the archaeological site of Otrar Tobe and for its surroundings;

iv. Training. Building of national and regional capacity in the management, preservation and conservation of cultural heritage through the provision of in-service training to national experts and craftsmen in conservation to international standards.

v. Promotional Activities. A Web site, publications, visitor leaflets and information boards and a video on Otrar will all help make the site better known.

2 MAIN SYMPTOMS OF STRUCTURAL DECAY OF EARTHEN WALLS

2.1 *Rheological decay and water mismanagement*

Before the collapse of the Soviet Union excavations were on the whole carried out with low budget and without providing proper drainage to the areas near the structures. Earthen sites can occasionally respond well to basal water collection if this is uniform, but dramatic collapsing of parts can occur in presence of localized ponding. The city wall of Otrar Tobe (Fig. 8), an earthen structure of average five metres of thickness, shows how structural cracks can be caused by localized collection of water at the wall base. The plastic limit of the soil can reduce the load bearing capacity of the foundation and hence the cracking. It should be also mentioned that vertical shears can take place every 10–12 metres because movement due to the expansion and contraction of earth walls is absorbed without failures for only that length.

Another form of rheological decay is that caused by precipitation and the formation of typical erosional patterns (Fig. 9). These can be uniformly distributed, but it is often common to observe water collecting along erosional channels that tend to deepen until more serious structural faults happen.

Animal and insects activity can increase with high levels of rising dampness. The softer the substrate, the easier it is for rodents and masonry bees to create a system of channels that can considerably reduce the load bearing capacity of the earthen structure until collapse.

Figure 8. Otrar Tobe, city wall (10th–15th century AD), Kazakhstan (2004).

Figure 9. Sauran, city wall (14th–15th century AD), Kazakhstan, 2002. Deep preferential channels on mud brick walls are visible in the city wall of this medieval city. Picture showing coving effect at the bottom due to combined action of rising damp, soluble salts, and wind erosion.

2.2 *Man-made damage*

Direct inspection carried out by the author showed that central Asian sites are rarely fenced or provided with guardianship. National or local authorities often do not make an effort to ensure proper site management, and in many cases local communities are not even aware of living close to an ancient site. The main threats are typically posed by illegal quarrying of soil, grazing of cattle, encroachment, and black archaeology. Discouraging such activities can be an intricate task due to the extent of the sites and to their remote locations.

2.3 *Soluble salts attack*

The problem of high soil salinity is widespread not only in the central Asian loess clay belt, but beyond (Fodde 2007c). One of the outcomes of salts attack is coving. It is the product of the combination of soluble salts rising from the ground which destabilises the build material, and of wind erosion. A decrease in tensile and compressive strength and in frictional quality of soil particles can take place when the base of the wall is saturated with water. Salts can effloresce on the surface of the wall base and when this is accompanied by the combined action of wind and windblown sand, the area affected by efflorescence is easily eroded. When this is repeated several times, the section of the wall base can become thinner and eventually lose its load bearing capacity, causing collapse of the structure.

Average soluble salts content of historic earthen material as calculated in the three sites is: 4.7% (Tajikstan), 3.8% (Kyrgyzstan), 5.6% (Kazakhstan). This should provide an idea of the extent to which salts can affect the preservation of earthen structures.

Figure 10. Karakhanid Palace, Krasnaya Rechka, 2004. The phenomenon known as 'petrification', represented in the upper part of this earthen wall, consists in the natural creation of a protective hard crust of clay. This can be directly inspected in several earthen structures in Central Asia, but a scientific study of the phenomenon is still at an early stage.

3 REPAIR METHODS

3.1 *Buttress construction*

Buttressing may be considered as a temporary or permanent device for those walls that are leaning or close to collapse. In the context of earthen sites conservation they are extremely useful especially for implementing urgent consolidation measures. Mud brick buttresses tend to be bulky and cumbersome and their employment should be considered after proper assessment. It is important to prepare the area where the buttress is going to be built so that to avoid water collection at the wall base after construction is completed. In this sense ground drainage should be insured before construction. Buttress dimension should be proportional to the size of the wall to support. Length of wall is also important in the dimensioning and it may be necessary to construct more than one buttress, as in the example on Figure 11: in the site of Ajina Tepa (Tajikistan) the structural consolidation of leaning walls was carried out with the help of earthen buttresses by employing local materials and techniques. Special attention should be paid to the connection between the buttress and the historic wall. It is advised not to excavate niches to form a key, nor to use mud mortar if possible. Dry packing should be employed instead so that to make the intervention reversible. Maintenance should be ensured so that to divert water away from the foundation. If water is allowed to pond near the buttress, the ground may reach the plastic limit and make the buttress settle because of its own load.

3.2 *Shelter coating*

The encapsulation of decayed walls with shelter coats is often necessary for the following reasons: ideal against vandalism and for repairing walls that are heavily thinned by erosion (Fig. 12).

Figure 11. Ajina Tepa, Tajikistan, 2007. Mud brick buttress construction to support a leaning wall. In order to have reversible interventions the buttress was built without inserting any bricks into the historic fabric, but by making sure that the connection was well packed with dry soil.

Figure 12. Buddhist temple II (XI century AD), Krasnaya Rechka, Kyrgyzstan, 2003. Shelter coat construction. From left to right: new mud bricks, sand infill, geofabric, and historic earthen wall. Picture: Jumamadel Imankulov.

It is suggested that only buildings of particular importance be shelter coated. The wall base should be archaeologically cleaned so that to find the extent of the foundation before erosion occurred. Shelter coating is a complex activity and therefore it is suggested that only craftsmen specialised in mud brick masonry construction be allowed to carry out such work. As for methods to be used, it is suggested to employ the following: application of geotextile, construction of mud brick skin and filling with sand. Plastering or mud slurrying to be carried out as finishing layer. In any case plaster or slurry coat should make the new intervention legible as new by providing a clear and intentional finishing. It is important to clearly differentiate between finishing coat for the reconstruction of lacunae and that for the historic masses (even if covered by shelter

Figure 13. Mosque of Al Jahili, Al Ain, UAE, 2007. Structural consolidation of coving by inserting mud brick masonry.

coating). Shelter coating may need constant maintenance after heavy precipitation, especially the top part to be inspected and monitored with photographs. Top part of mud brick shelter coats (capping level) may be affected by erosional loss allowing future water to penetrate inside the membrane and affect the stability of both historic wall and shelter coating.

3.3 *Consolidation of coving*

When the combined action of salt crystallization and wind-blown sand is so high that walls are heavily eroded at the bottom and show severe coving effect, these can be repaired with a traditional system that is widespread from vernacular Pakistan (where the method is called mud *pushta*) to other building cultures such as that of Sardinia (Fodde 2007d) and the UAE (Fig. 13).

Such reinforcement, made of mud brick set in a stepped pattern with mud mortar, is applied along the perimeter of the decayed wall. This procedure foresees a preliminary brushing-off of all loose earth of the ground surface. A sheet of geotextile should be inserted before laying the first brick course.

Construction is carried out so that the last course ends just in the upper area of deterioration. The intervention is then mud plastered and it has the advantage of being clearly legible as a new. Firmer connection of the new masonry to the historic fabric can be achieved by inserting a grid of wooden pins.

The traditional repair method for deeply eroded single mud bricks consists on the extraction of damaged bricks followed by replacement with new ones. The extraction of mud bricks is sometimes difficult because further damage can be caused to neighbouring bricks. It should be noted here that replacing mud bricks works well from the structural point of view but has the disadvantage of making the identification of new bricks sometimes difficult, especially after the weathering process occurs. A solution could be the insertion of flat bricks, or bats, that are more easily identifiable because of their different size than the historic brick. Maintenance of repair work should be ensured regularly. Monitoring of repair work can be carried out by inserting plastic pins in the new masonry so that to measure erosion patterns.

3.4 *Repair of cracks*

Cracks are characterised by the fact that the two parts of the wall regularly move separately and therefore it necessary to stitch the two parts together. The stitching method foresees the cutting of chases followed by the insertion of pre-shrunk earth tiles called clay bats. Chases are cut into the area where the crack occurs, and should be complemented alternatively into the interior and exterior sides of the wall. Chases should also be characterised by two returns for each stitching end. Once chases are cut, the mending is carried out with the insertion of clay bats. It is important at this stage to avoid the mud wall to take stitches made of rammed earth because detachment can occur. This is due to different coefficient of expansion or to shrinkage after drying.

Clay bats are the most adequate material because they have been already pre-shrunk and their application should follow the moistening of the inner part of the chase. Clay bats are then bedded with mud mortar and the courses are tightened together with steel laths in order to make the stitch coherent.

The introduction of the lath is important in order to reinforce the wall and achieve monolithicity, allowing the building to move and be flexible as a whole, especially when the crack is large. The bed of steel lath should be employed as follows: one in the bottom course, one in the middle and one before the last course. Steel has a different coefficient of expansion than mud but it seems that the high thermal capacity of thick mud walls holds any detachments. The disadvantages of employing steel are twofold: from the philosophical point of view, metal is not traditional, like clay; from the practical point of view, because if galvanised metal lath is employed, in the long term it may rust, then burst - and therefore expand - but at this stage it is only a theoretical problem. The alternative would be to employ stainless steel, especially on the outside of the wall, this being the wettest side. Another option could therefore be the use of scrim (cloth with wide mesh, made of yuta, on strips) and, when the crack is located at the corner, reinforcement by using square wooden elements.

The last course is the most important of the whole mending process and it is advised to wait for between five days to a week before the last course of bats is put in place, allowing the previous layers to set. In order to

get a tightening effect, the last course of bricks has to be very dry and with a high content of straw. After the last course has dried, wood wedges and pegs should be inserted and hammered in. This is then followed by filing in the holes with dry mud that has to be tamped (dry packing) to achieve a tightening effect. Dry packing can be undertaken with a bit of moisture too because the bricks around each course, being pre-shrunk, can absorb the exceeding moisture quickly. The pack has to be hammered in also between the joints and then left to dry.

It is important to suggest briefly some notes on the manufacturing of clay bats for the stitching technique. The soil can be recycled from the cutting of the chases themselves and should be mixed with straw. The use of straw is necessary because otherwise clay bats might become brittle, with consequential loss of tensile strength. Amongst available types of straw, wheat is considered to be adequate; flack and barley may be used, the latter being the most suitable as it has hooks that help the mud lumps to hold together. During the moulding stage two different sizes of clay bats might be planned. These could be of future use when filling in the cavity. It should also be stressed that clay bats production should start well in advance because of the time it takes to manufacture; also, the traditional skills and expertise in tile and brick making should be considered by approaching older craftsmen.

4 CONCLUSION

A comprehensive and systematic study of structural faults and repair methods of earthen archaeological sites is still to be carried out, but this paper provides the beginning through which such future research can proceed.

It is important to stress that this paper attempted not only to provide practical proposals on structural consolidation of earthen structures, but also to make general suggestions as to how matters can be improved for the better. It is hoped that these suggestions can form the basis for the future conservation of the earthen built heritage of central Asia.

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