Virtual Archaeology Review

An Investigation of Shear Wall of Moen-Jo-Daro Using Mechanical Properties

Investigaciones sobre los muros de Moen-Jo-Daro usando propiedades mecánicas

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Resumen

Esta investigación se basa en los eventos que afectaron a Moen-Jo-Daro entre los años 2000 y 2012, pues por el deterioro en la pared de Moen-Jo-Daro tuvieron que reemplazarse ladrillos dañados por nuevos. Varios fueron los factores que produjeron el deterioro de los ladrillos que, junto al continuo empuje producido por el comportamiento estructural, dieron como resultado una progresiva inestabilidad en la pared lateral asi como la formación de grietas de menor y mayor envergadura. Hay varias paredes que se enfrentan a problemas similares, por lo tanto, un modelo cúbico de arcilla a escala 1/4 fue construido e investigado en condiciones de servicio. Usando elementos finitos FE, se generaron modelos para simular la respuesta de la estructura, el comportamiento y la seguridad del prototipo.

***Palabras Clave**: MOEN-JO-DARO, ELEMENTOS FINITOS, SAL.*

Abstract

This investigation is based on the event that occur in 2000 and 2012 at Moen-Jo-Daro the extensive decay of Moen-Jo-Daro wall that replacement of bricks with new over damaged bricks. Damaged bricks due to the formation of various generated forces, continutiy of thrust resulted in the progressive instability of the lateral wall and formation of minor and major cracks. There are several walls which are facing similar problem, hence, a cubical clay model in 1/4-scale was built and investegated under service conditions. Finite-element FE, Models were generated to simulate the response of the structure, behaviour and safety of the prototype.

***Key words**: MOEN-JO-DARO, FINITE-ELEMENT, SALT.*

1. INTRODUCTION

Mohenjo-Daro is most popular and first urban centres in the world that germinate five thousand years ago. Based on the judgement of a famous archaeologist Sir John Marshall and EJH MacKay, few of its areas were refreshed during 1930 and 1935. During the study, the problem is related with the effect of salt on the wall. This problem is also analysed based on

scientifically but still we have some viable reasons like how, where and why it the salt attacks. The research community did further research and try to use the experimental consideration to justified the outcome and give us the possible endorsement. The gap is still exists and need to proposed the justifications and less expensive services to the bricks and to maintain the authentic in increasing the longevity of Mohenjo-Daro brick masonry. The current research is taken in to account with all walls, main street, mud brick, chief house, mud brick wall and rest of focused for doing sampling. After which the prompt atmosphere of the Mohenjo-Daro were also previewed where cultivation is regularly exercised. This activity has dreadfully devoted the crystal clear problem that it has increased the sanity and water level at the top surface of soil that has eventually developed into the considerable origin of salt generations. A applicable miimum low cast plan has been given; if its ok then the fruits will be immense.

2. SALT PRODUCTION ANALYSIS

Recently, in 2012, the wall in the main street of Moen-Jo-Daro damaged due to the applying various reactive forces causes damages of lateral wall and the formation of minor and major cracks as well. The others Wall which are bearin the same problem, hence, a cubical clay model in 1/4-scale was built and tested under well defined service conditions and also performed the analysis based on the capillary action of the wall. Regarding this we developed the Finite-element FE models to simulate the feedback of Wall structure and lastly to capture the prototype behaviour and their safety.

The goal of this article to study the most contributed hazard is associated by soluble salts kill specifically the sodium sulphate.

The especial type of salt that is Hygroscopic salts, sodium sulphate, which draws from water into the air that pour into solution, The concept behinde the hydration and dehydration generated due to the different temperature cycles. Due to happening of this, it produces high pressure applied on brick and mortar. As a reaction we obtained poder. When the process of evaporation is very slow then due to it not only does powdering take place but also chunks of bricks fall apart. In winter seasons, salts tend to maintain their structure and their geometry, normally at northern and western part of elevations. Its not only but sometimes at eastern faces but also for the favourable temperature of crystallization process at 32 °C. During summer seasons, the process takes place inside the brick that consists of different attached layers that we call it fabric. The result that masonry moves to subflorescence. The Mud slurry is one of the excellent choice and very cheap alternative for caring the fired bricks from hard wáter and their moisture. Moreover, the most effective thing is the mud plaster against of subflorescence. It can reduce the heating effect to the different structures at resonable. The most contributed salt is Nacl (Sodium Choloride), and the compounds of potassium, calcium, magnesium, carbonate, bicarbonate, nitrate, nitrite, chloride, and sulphate. The quantity of salt ie reduces with increase in depth, it means that their intensity is higher on the Surface due to the process of evaporation.The direction and the coordinates approximately for the location of Moen-Jo-Daro is 27ºN and 68º8´E, the climate is arid, and the average rainfall not mopre than 5 inches annually. The deformation of these walls at annually experienced some irregularities or deformations with the reason of the ground surface subsidence movement with underground varying water table. The contribution of wáter in subsoil is almost 90%, and at the top side the 50 feet height of soil profile being comparatively heavier soil[1]. Based on these reasons the impact of base and walls are disturbed that may conclude the distrubance and structural deformations. Despite of these, cyclic intreptions generated the deteriotion in structure and to change of ownership requirements to upkeep of archaeology have become more severe.

[1] Mohen jo Daro preservation plan, S-1, Summary 1972

Fig. 1 The exo skeletal support

'I' sectioned trusses installed at the chief house to prevents the buckling effect for only one side (Fig. 2). This intreuption compromised the building structural scheme as shown in (Fig. 1).

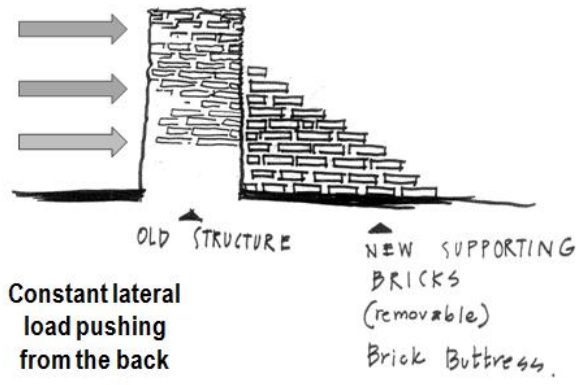


Fig. 2 The brick are being attacked by the salted water from the back, of the inclining wall

It creates an excessive amount to increase the thrusts in the direction of lateral position wall through externally. It were balanced by columns and roof buttresses as it was in 5000 years ago. Furthermore, the most basic and fundamental design was consistently transfering the loads and balancing. Finally, the amount of weight at the upper side is normally shifted in the lateral wall upon the pier with an offset. Currently, The behavior of this isolated wall is not following with respect to others. The the entire load is being shifted to the bottom side of the Wall. It has to fit in the cramed street area. Multiple combination of reactive forces using the thrust of continuity concluded in consistantly instability for lateral Wall. The generation of minor and major cracks, at the relatively weak area of the wall.

Fig. 3 The brick are being attached by the salted water from the back, of the inclining wall

As a result, the failure generated due to the excessive horizontal displacements. As far as, the critical crack behavior generally follows as shown in (Fig. 3). The longitudinal cracks generate at the extrados parallel to the edges. This pheomena has been generated doing the inspections of damaged structures but no there is no crack propagation or the distribution of the loads during failure.

The aim of this paper is to study the main deformation affecting Moenjodaro Chief House wall, an archaeological site that prospered from 2350 to 1800 BC, thermal stress causing walls to lean and decay structurally.

3. STRUCTURAL DESIGN

The end structures facade in (Fig. 5) that consists in majority of walls. It has a function that consists of longitudinal thrust. While, If we are dealing with transverse thrusts then the supporting beam were used at initially but their formation is more than 45 degrees angled support. While for their thrusts, it can be transmitted to more supports along the wall. The kind of this support is adopted from the origion for a safe solutions to tackle the uncertainties associated with the performance of top most structure. In 19th century, The upper structure is also remodelled, most probably with plain quadripartite ribbed exo- structure.

The geometric signs instability during the studies, the application of external buttresses, which backing the behavior of the wall springing above at about 0.3 of its total height. Due to

having the thrusts, the weight of upper structure would be shiffted to the piers through the lateral wall.

4. Perpendicular Basement of South Street

This support for the south room, that consists of square compartments having the height of their vertices reaches in the middle of the lateral elevation as shown in (Fig. 4).

Fig. 4 Showing salt penetration: into the pours of the bricks.

The outer edge it is supported on the wall and attached. Whereas, the edges of support along the wall rest upon the main foundation (Fig. 4). Transverse pointed angle support mark the edge between the neighbouring bays. The diagonal ribs and the transverse wall have the same plain cross section and they spring from a low buried foundation, while the pockets created between the supports of the wall reach the third of the height. The wall is made of load bearing masonry, composed of long thin slabs of regular thickness.

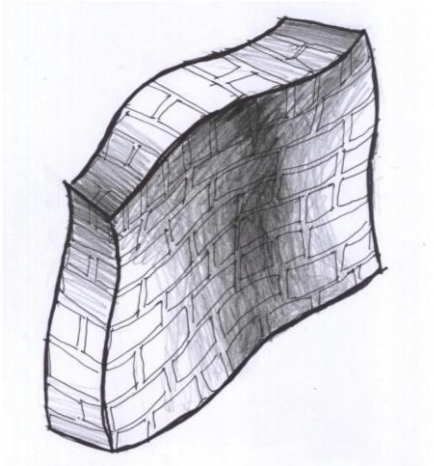


Fig. 5 The deformation in a curvilinear form, since the material is tired and is bending with the load

5. Damaged of 2012

In 2013 the consistent decay of wall prompted the restoration of bricks with new over. Finally, the wall become thick and accelerated to already not in safe state of walls. The scientist and research community surveyed the fabric in 1964 and mentioned in severals of walls and piers at a height of 5 to 8 mm towards the north side. They also finalized that, "the pillars and walls will behave like an inclination in terms of figure values it may be seven or eight inches from the perpendicular that is at the greatest height" H.J. Plenderleith 1964 UNESCO observed that "Only one wall has fallen down but the other just ready to drop away. It bent for many places and the overall structure and chasing the ruin at swift pace. "

Fig. 6 the view of the deformation

Base don the different types, the signs of ground surface motion that makes more different impact on buildings being determined (Fig. 6). For horizontal tensile deformations the cracks are generated in external walls and the nature of

cracks are in inlined but they are symmetrical compare to the centre of the wall. Column bending and shearing phenomena are typical of curvature of convexity as part of creation the cracks. As far as the cracks that associated with flexible walls their crack length exceed their heights more than th thrice. The compression deformation phenamena for cracks are regularly generated, for more specific of two-storey and higher walls than bending crack and its curvature of concavity are inclined. As far as the horizontal cracks, they are generated inside the walls that located symmetrically compare to the centre of plan.

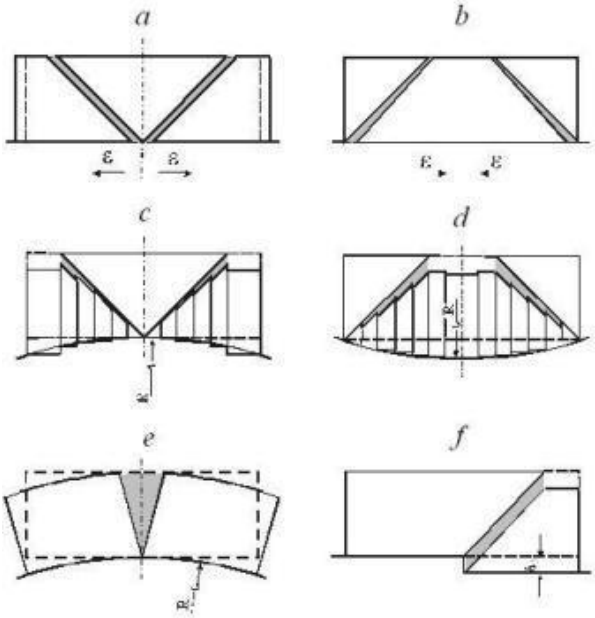


Fig. 7 The generalized structural deformations of the walls induced by: a – horizontal shear due to ground surface tension; b – horizontal shear due to the ground surface compression; c – vertical shear due to the curvature of convexity; d – vertical shear due to the curvature of concavity; e – bending due to the curvature of convexity; f – vertical shear due to the bench formation

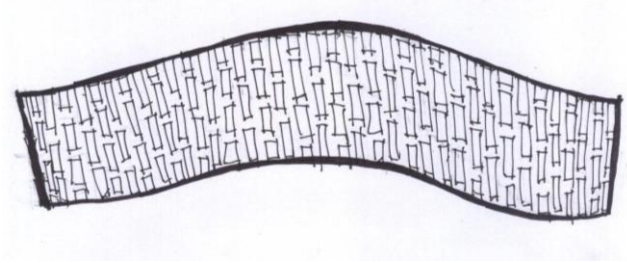


Fig. 8 Exaggerated deformation pattern

For this purpose the following assumptions are taken. Plain deformation of a wall in longitudinal or transverse directions is considered; walls represent homogeneous deformable body; undisturbed contact of wall continuous base being deformed is assumed; principle of independence of the influencing factors shall be used. As we know that the importance of the current software so we find out the structural deformations of horizontal shear, vertical shear and wall bending induced by ground surface horizontal movement and curvature shall be determined separately.

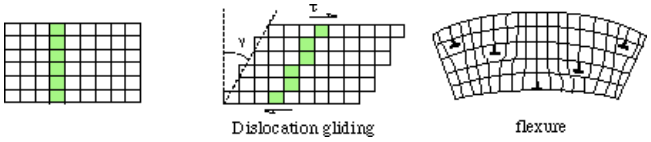


Fig. 9 The deformation patterns of buildings and indexes of deformation due to the tension and the curvature of convexity

In (Fig. 10) the walll shearing stress shows the complete description of Mohenjo-daro typical shear wall analysis. It shows the stress orientation and their intensity.

6. Phenomena of Stress Using Plotting

Here we have the both magnitude and direction of stress field. The (Fig. 10) describe the close-up of a stress field.

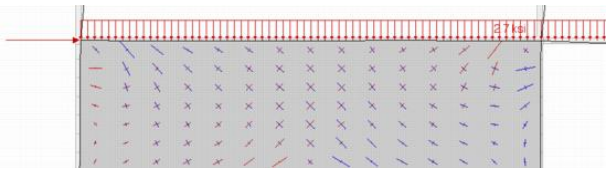


Fig. 10 Average stress state at different point

In (Fig. 10) small crosses are the average stress state. While the crosses are tilled base don the principal directions state of stress. In every leg the cross is drawn having the length of proportional to correspond the principal stress. Blus is for compression while red is for tensión.

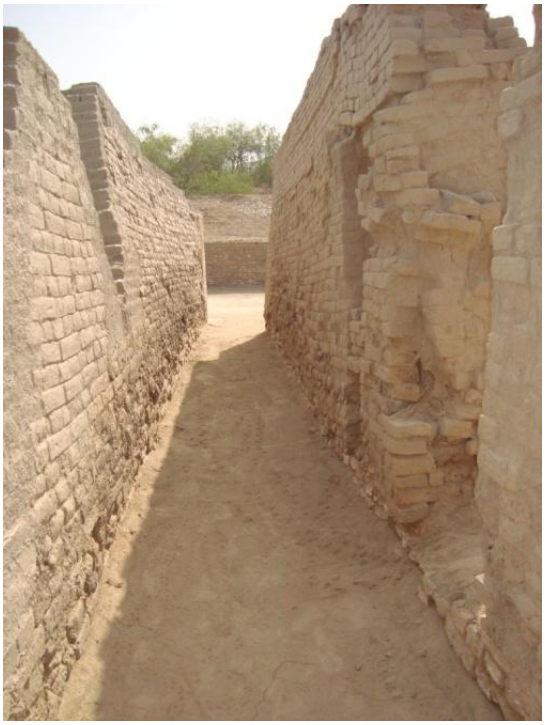


Fig. 11 The deformation is seen in the perspective from the other side

In (Fig.10) using plotting the lines then shear stress is not parallel to maximum in-plane while the direction of tensile stress. Its length is directly proportional to maximum magnitude of tensile stress. Where as, the cracks might be generated in materials that is sensitive to tension. Moreover, the selecting of maximum shears that want to plot the stress which are linked using the different directions for maximum shear stress. It can mention yielding capabilities in non brittle brick.

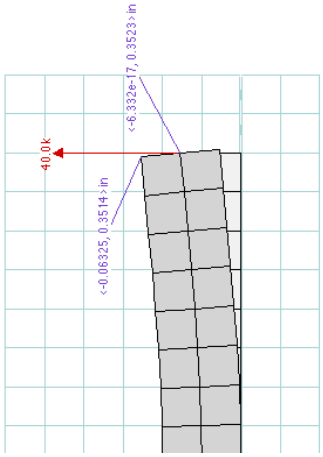


Fig. 12 Dead constant load of the brick, and bucking effect due to torque

In (Fig. 12) the displacement figures within the wall nodes it can be found either by fixing the labels as origionally shown in (Fig. 11) at a very casual manner by selecting them using select tool. It will generate the comparitive results it appears in results pane for specific identification. The result can also be evaluated by using the inspector pane. The different test cases describe the basic performance of present wall elements. Currently, its very easy as differentiate to every issues that specified on this explanatory example. It highlight the different situation that apply forces with differences in between the current elements. For an individual bricks it has not the rotational degrees of freedom due to bond. In (Fig. 13) that shows the output that obtained by the standard uni-axial loading and boundary condition configuration (P = 24 k).

The upcoming result is the similar configuration as above (Fig. 12), as far as the case that are more optimized to set the boundary conditions that applied at the wall so corresponding stresses can be focused.

7. MECHANICAL PROPERTY

In Mohen Jo daro, static and dynamic forces are continuously applied on the brick. The other property like flexure, compression, flexure, tension, bending, abrasion, impacts. Finally, the wall has changed their shape with bending moment phenomena.

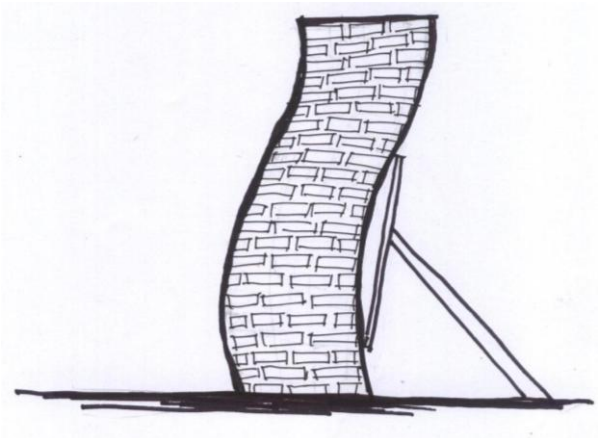


Fig. 13 Exaggerated deformation pattern in the sectional view, along with the support

We have other additional constraint and related issues that are linked with using these elements:

The forces are distributed in different área and loads of bricks for 40 kg per square feet, is assumed, for transversely loading walls that have not been applied for this release. By the help of multiple loads are applied on nodal area dragging as explained above above that can be used as a workaround.Simulation of Mohen jo daro wall are deformed[2] in a brief analyzed that were performing the graphical display of those brick masonry walls. This function is usually applied on the calculations that involved for the evoving the deformation. As per (Fig. 13) that is possible for specific zone identification to subtle torsion at the surface, that were located across the boundary in between between the non vertical lines. The basic programme that does not incorpórate niether compaction base don burial Fromm 2000 B.C nor diffusion equation. Finally, its an ideal simulation of sedimentation tectonic below the water level in shallow burial depths of wall, except foundation. [3]

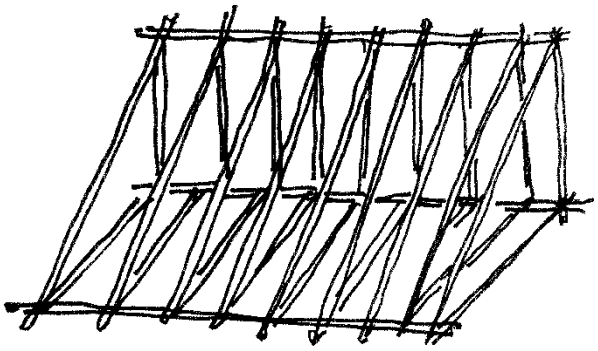


Fig. 14 individual Bamboo truss, mobile design, simple low cost solution, to support the falling wall.

8. Consideration into Account

On urgently, the buttress is applied, it could be easily installed, to support the inclination, as shown in (Fi.g 14) and (Fig. 15) support. This support is made up of wood or bamboo, could be fixed easily, using local people, within low cost material.

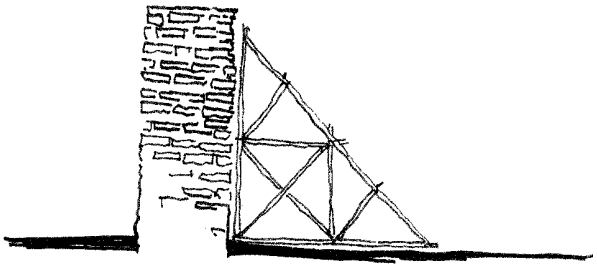


Fig. 15 the instillation of the buttress to support the falling wall

For serviceability, full repair is needed for 350 walls and also for engineering support systems. Continuation of repair is based on locational appearance to uplift the change without seprating its structural elements, (cladding replacement, "face-lift" refers to sweet water blasting the surface only).

9. Recommendation

The main advantage is related wih Bamboo is that it has a low cost material. It can easily replaceable and relocate. It can be applied for support to scaffolding and buttress. Sometimes, its very difficult to hold the complete weight properly despite of local development of brick it could be used to gives external replacebable foundation in order to créate the strengthen of unfortified Wall that reclinined at Mohen jo daro.

10. The Partially Collapsed Wall

There were no remedies and countermeasure taken and for lateral walls that collapsed on March 2013. It followed probably later due to the deterioration of brick that destroying the whole of northern side. The upper portion of façade that most probably the progressive collapse that started from the north side. The neglected rampant walls were more severely weathered and weakened there than in the southern area, and the failure of one wall buttress would be sufficient to destabilize the

[2] Using Dr. Frame 2D © Dr. Software, LLC 1998-2005

[3] Geology Department, Royal Holloway,University of London, Egham Hill, Egham, TW20 OEX, Surrey, U.K. E-mail: mathematiker@yahoo.com

transverse equilibrium, disproportionally releasing the thrust of the south side. Consequently, the weight of the falling wall would crash onto the remaining buttressing wall, causing the failure of the rest of the upper structure.

Fig. 16 View of deformation Shows the crumbling bricks

11. Absorption Process

The vitrified bricks have a capability to accept the dampness slowly as shown in (Fig. 16). This action is due to only path for the humid and moisture is the mortar. In account of this, the following action is helpful;

- Material strength and deterioration formed loose of brick
- The process of soil salinity
- Due to monsoon precipitation and poor drainage rising damp is occur
- Through termal stress structural decay are formed
- The phenomena of Manmade damage

Dissolvable salts and swell cause results in disintegration of surface. Salts here are coming from soil, clay, mortar and polluted marine environments.

12. Entrance of Salt and Water Inside Enters the Brick

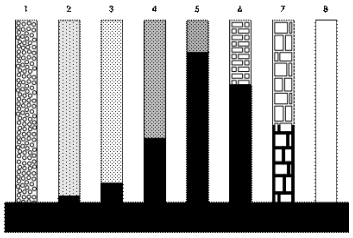
1. The damage causes due the process of infiltration or geometry of the walls.
2. By capillarity action through basement.
3. The process of condensation and humidity on walls
4. Through wind, the rain water pushed on the walls.
5. The process of condensation and filtration

Hydrous characteristic of the brick

Capillarity – the movement of a liquid in the interstices of porous material due to surface tension at the border of solid and liquid; the parameter of capillarity is a height of water movement **h**

$$h = \frac{2\sigma \cos\theta}{rg\rho_p}$$

σ - surface tension; θ - interfacial angle; g - free fall acceleration; r – capillar radius; ρ - density of a liquid.



Capillarity in different materials:
1 – gravel, crushed ; 2 – coarse sand; 3 – fine sand; 4 – slush; 5 – clay; 6 – brick wall; 7 – masonry of dense brick; 8 – monolithic dense material

Rapidly, through salt migration and the process of crystallization that break down into chlorides, sulphates, nitrates that coming from the ground.

The water moves through capillarity action that depends these aspects:

• Material capillarity size of material.
• Wall thickness.
• The process of evaporation across the wall surface through capillarity rise.

The probable origin is oxides of alkaline from mortar. The oxides that are instable and that is to be react using sulphur to generate the compounds of sulphates.

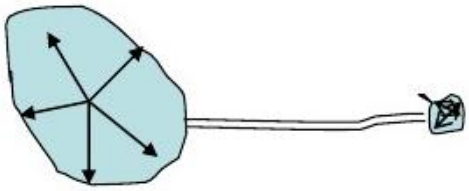


Fig.17 Expansion pattern of the salt and water solution, inside the brick pour

Calcium sulphate CaSO4·2H2O Gypsum (CaSO4·1/2H2O, CaSO4)

The conversion Na2SO4·10H2O Na2SO4 produce in between the regular transformation of environmental conditions.

The process of deformation in a brick which shows as a raw materialsas shown in (Fig. 17) and different physical actions that may cause delay:

- Deteriotion in brick material and its strength.
- Sailinity cause by soil.
- The process of precipitation and poor drainage during the seasons of monsoon.
- Due to the formation of termal stress the structural decay appears.
- The process of manmade cause damages.

In salt solution, the process of swell will make the result of disintegration into the surface. The appearence of salts that are coming from clay, soil, mortar finally polluted marine environments.

The landing of plane is also the imoortant factor to créate damages across the vicinity, creates surface defects, the happening of process of cracking, and finally the displacements cracks due to differential settlement that may involve in distortion of ancient brick.

Fig. 18 The wall brick deteriorating

In Fig.18 as we can see that the wáter material height that is highly porous bricks with high open porosity.

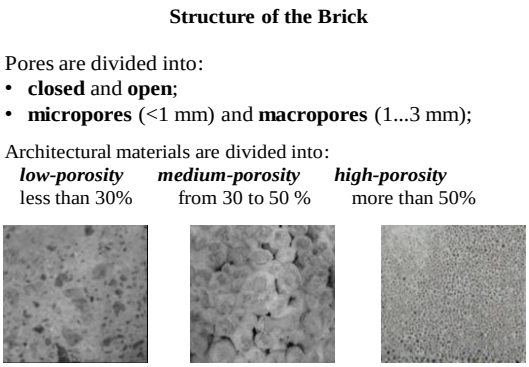
13. PHENOMENA OF DECAY

Salt has a property to dissolve in wáter to become as a soluble. The process of the crystallization that may occurs within the pore that may generate the pressure that we calle dit the cystallization pressure. It generated against the pore walls may result to break. The process of evaporation is start then the phenomena of recrystalization is start inside the porous. Therefore, if water is accumulated inside the pours of bricks then due to temperature, it créate the phenomena of expand an contract continuosly. It occurs in the summer night while in winter it may contracts. In the season of monsoon, the temperature falls at night, below zero, then the process of formation of crystal development is occur inside the bricks. The porosity level also varies, some bricks parts are highly porous some are lesser dense. This constant contraction and expansion over the seasons and over the night and day, has made this wall tired and the bricks are completely exhausted, and as a result the bricks crumble in the form of powder.

Fig. 19 The penetration of the water vapour, and expansion, inside the pour.

This presence of water and expansion as shown in (*Fig. 20*) of the pours is visible in the close up of the bricks, as shown in the below picture, the wall disintegration is visible, where the bond broke.

Fig. 20 The deterioration of the wall



14. CAUSE DAMP

1. Without resistance, direct contatct with rainwater.
2. Increasing the height of damps like aise water from the ground conducted by capillarity.
3. The phenomena that may apperas hygroscopic salts that is usually initiated as the result of rising damp.
4. The process of condensation like coming water from the air inside the building.

Unbalanced settlement creates in complete fracture as shows in (Fig. 21). The Fractured joints could be cut out then flushed, finally tamped and re-pointed. Furthermore, based upon the different situation the special kind of resin like epoxy resins. It is adhesive to repair cracks among the bricks.

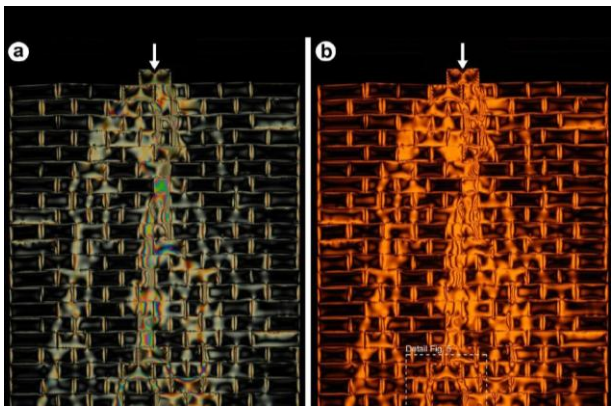


Fig. 21 The electrolysis analysis of the salt travel on the Moen-Jo-Daro wall.

15. EXPERIMENTAL RESULT

In the presence of wáter the salt is soluble and to mobilize and behave like a catalyst. The salt is to become a solution then the process of evaporation is due to thermal quality. The process of crystallization within the porous of mortar and brick that brings this new surface. While in the next phase, if the process of crystallization is occurs inside a pore that always produces the pressure that we call it the crystallization pressure. It presses against the pore of entire wall. When the process is completed the similar salts can be obtained by the state of hydration. Finally, volumen will increases and crystals increase as well. The Wall breaking phenomena is due to the generation of pressure in terms of reaction of pore walls that can break easily theentire wall.

Repetation start again and again and the water comes again then salt is dissolved and mobilized to crystallize in some other part. The cyclic process in salt repeating the existence with water as much more in dangerous but the only presence is either by salt or only water. The more degradation occur in the area is between the two fronts of walls reached by water during in summer and winter seasons.

The absorbtion of water inside the material likewise masonry, mortar, that have the capability to grasp the water that expand upon the introduction of water and contract again on drying.

Fig. 22 Experiment of submerge the clay cube into salted water.

The experiment has conducted through making the clay cubes having the dimensión of 7 cm by 7 cm. It has dipped within the water at 5 percent salt. It kept during overnight and the salt is being recrystallised and moved as shown in (Fig. 22).

Few salts have a composition of mortar type and very often the type of these salts are generated as a reaction with other brick material. The others chemical that come to more regular in buildings are the 7 and 6 hydrated forms

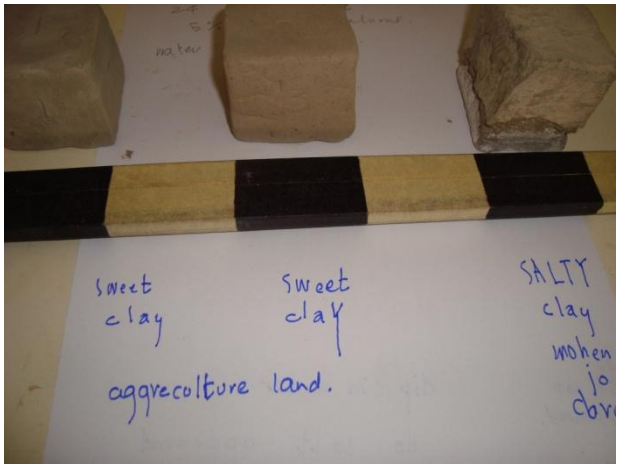


Fig.23 Water penetration analysis the ways water, travel through capillary action

The chemicals that are associated with it are as under; Nitrates: $Na_2SO_4 \cdot 10H_2O$ vs Na_2SO_4 Thenardite Mirabilite

$K_2SO_4 \cdot nH_2O$... Plus complex salts even non-stekiometric

Nitrates: $NaNO_3$, KNO_3, etc.

Normally associated to organic matter and its N and alkaline decomposition, since it contains elements (mainly potassium associated to plants, but also Na is some others).

Sodium chloride:

$CaSO_4 \cdot 1/2H_2O$ and $CaSO_4$ forms are remains of the production processes of mortar.

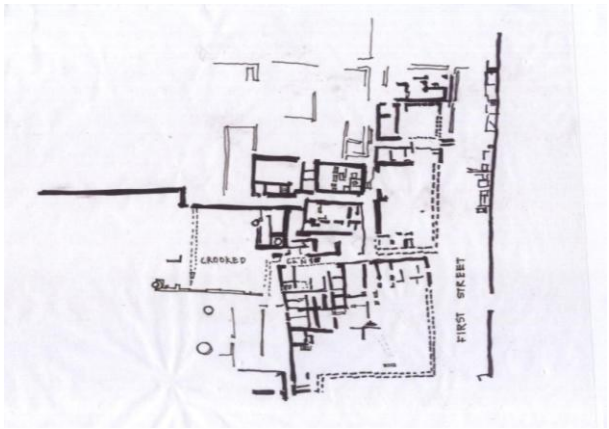


Fig. 24 Map of the DK area marked where the picture is taken.

16. THE WAYS THE WATER AND THE SALT ENTERS THE BRICK WALLS OF MOHEN JO DARO

Fig.25 Shows the salt travel effects

In (Fig. 25) the few aspects that we have been studied in a location of Mohen Jo Daro. The

nature of constructive materials like wise the phenomena of crystalline structure of brick. It creates the resistance to salts damage and the quality for morter that used clay. The other aspect as the historic aspect of the material. Finally, the environment of the monument: that is the environment is humidity origin, clime, and partially windy.

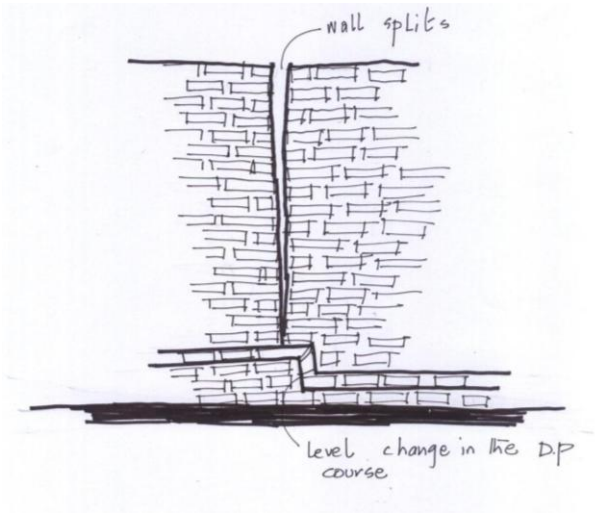


Fig.26 The elevation diagram of the wall

17. CONDESATION

Water will condense from warm, moist air on contact Air + Water vapor (moisture)
Absolute humidity = weight of water vapour the air contains (g/m3, given / at T°C)
Relative humidity (RH) = ratio of actual moisture to possible moisture content (saturation, same T°C) with cold surface.
Subsoil water is driven upwards by capillary action through the structures and in so doing it carries soluble salts. Such salts effloresce on the brick surface if the evaporation is slow and subfloresce if the evaporation is fast.

18. CONCLUSION

Since Sindh has a five thousand year old history of irrigation hence, this paper revolve around the study of the main threats affecting Moenjo Daro, an archaeological site that prospered from 2350 to 1800 BC. The major hazard for the preservation of the site was the rising water table. Here the Master Plan and the solutions were presented to maintain the equilibrium of the permanent vegetation and forest, as well as irrigation which wrap the site. The major causes of the decay is soil salinity, hence Moenjo Daro the phenomenon of soluble salts decay takes place in a twofold way: Subsoil water is driven upwards by capillary action through the structures and in so doing it carries soluble salts. The low cost solutions are presented to stop the water from entering the site.

Hence, in this study, I have tried to scientifically analyse asking basic but viable questions like how, where and why it the salt attacks. The research was taken mainly in the DK area where high and thick walls incline at the main street, chief house, mud brick wall and other were considered for sampling.

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