LIME MORTAR IN CONSERVATION FOR HISTORIC BUILDINGS OF PAKISTAN

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ABSTRACT: This piece of research was conducted to provide guidance and help to the conservation architects for the preparation of appropriate lime mortar for the conservation of stone masonry. A comprehensive research and detailed examination of conservation works on significant historic monuments in Lahore was carried out in the Department of Archaeology and Museums, Pakistan. The results provided the analytical description of lime, types of lime and preparation of Kankar-lime followed by description and analysis of various compositions of lime mortars suggested by International and National experts of conservation. The mortars for conservation and repair work should include the same range and a type of aggregate particles was used in the original mortar. More particularly the original binder and pouzzolanic additives must be used. This must be ensured that new mortar should necessarily perform and appear in the same manner as the older performed and appeared.

Keywords: Lime, Mortar, Binder, Cement, Conservation, Historic Buildings.

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INTRODUCTION

The earliest documented use of lime as binding material is approximately 4000 BC, in Egypt during construction of Pyramids. Romans used lime-based mortars extensively throughout the Empire. They created hydraulic mortars that contained lime and pouzzolane such as clay brick dust and volcanic ash. Prior to the introduction of cement during 19th century, the lime has been used as the binding agent in mortars, renders, plasters, lime washes etc. Its presence is almost guaranteed in any historic building built before invent of Cement (Yaseen *et al.*, 2013).

The use of Cement mortar is extremely harmful which leads to unfortunate consequences as observed during the visual surveys Figure 1, which is as follows:

Injections of grouts with cement are used to stabilize the old masonry without considering its future behaviors. Portland cement is too strong because of its high compressive strength, and high thermal expansion coefficient. In case of thermal movement it discharges all stresses to old material (Hussain, 2011).

Portland cement mortar has low porosity, which hinders water evaporation through masonry. The dampness in masonry through capillary action thus accumulates moisture behind the cement layer and causes deterioration (Chandra, 2006).

The Portland cement also forms Sulphate-salts while setting which is dangerous for ancient mortar, containing calcium carbonate (Scannell, 2013).

Cement set by non-reversible chemical reaction. Once the cement is set it cannot be re-cycled where as lime mortar can be recycled and renewed easily. This study focuses on the valuable information by the use of lime mortar instead of cement in the conservation and restoration works of historic monuments.

MATERIALS AND METHODS

The presented research was carried out through explorative and analytical study of literature which was further supplemented by the interviews of conservation experts who were involved in the conservation of historic sites for the authenticity of the available literature and documents. Discussions with the conservation experts of the Department of Archaeology in addition to the national and international conservation consultants involved in the conservation projects all over Pakistan. The Kankar lime prepared for repair works at the conservation laboratory of the Lahore Fort under the guidance of Directors' and Deputy Directors' of the Department of Archaeology and Museums was thoroughly studied.

The detailed process of preparation of Kankar Lime was fully documented, explained and analyzed. The process included the burning of Kankar lime grinding, testing of lime and lime mortar prior to its actual use and finally mixing and placing. The whole lengthy process was documented following the ICOMOS documentation guidelines.

RESULTS AND DISCUSSION

Lime: At times the term "lime" was used rather confusingly, to refer to a variety of products made from Lime-stone and Chalks (both forms of calcium carbonate). In the context of building conservation, the

term was most commonly applied to types of binders used in plaster, lime wash render and mortar that were made by burning lime stone or chalk to make quicklime i.e. calcium oxide and slaking this with water, forming slaked lime i.e. calcium hydroxide. Slaked lime was used in the form of plaster or mortar, which starts setting and led to carbonation process, which changed it into lime again as has been suggested by (Taylor, 2000). The lime-cycle is given below:-

Calcinations Process:

Limestone = $Ca\,CO_3$ burnt in kiln at 900 $^0C \longrightarrow CO_2$ + CaO(quick lime)

Slaking Process:

$CaO + H_2O \longrightarrow$ heat + $Ca(OH)_2$ (slaked lime)

Carbonation Process:

$Ca(OH)_2 + CO_2 \longrightarrow H_2O$ + $CaCO_3$ (lime stone)

It could be re-cycled and renewed easily.

The lime was weaker and softer material. Because of its elasticity and plasticity. It has an ability to accommodate structural and thermal movements.

Lime mortars were generally more porous than cement, so they allowed moisture to evaporate through mortar rather than through brick or stone masonry. This prevents building up of moisture level in the walls, which in turn prevented the building up of harmful soluble salts in the masonry. These salts were mostly, the major cause of deterioration of building fabric.

The types of lime used as binder ranged from pure lime plus pure natural hydraulic- lime to lime mixed with pouzzolanic components. The choice of material depended upon the nature of work and its exposition to weather conditions. The application of lime-based materials in repair and conservation work needs appropriate knowledge, great care and patience. (Peroni, 1981 and Gil, 2014).

Types of Lime

Non Hydraulic Lime / Fat Lime: Hydraulicity is a term showing the extent to which a paste or mortar of lime would set under water (Syed, 1967). Non-hydraulic lime did not set but dissolved under water. It was also called fat lime because it swelled to two to three times its volume when slaked i.e. it increased in bulk when mixed with water.

Non hydraulic/ fat lime could be obtained by calcinations of nearly pure Lime-stone. Quick lime belonging to the variety of fat lime, when left exposed to the atmosphere, absorbed moisture and Carbon Dioxide and thus became air slaked. The product thus formed was an inert powder of calcium carbonate called hydrate of lime. It did not have any binding power (Ellis, 2001). This lime was used for white washing and lime putty. It was white in color and contained over 95% Calcium oxide.

Fat Lime Putty: It was the purest form of non-hydraulic lime (Hansen, 2008). For conservation works, fat lime was usually used in saturated form, known as "lime putty" or lime cream. It was produced by calcination of pure lime, in kiln. Quick lime so produced, is added to water pits/containers immediately after calcinations. Water was not added to quick lime but the quick lime was added to water pits in small quantities. The slaked lime was raked and stirred until the visible reaction ceased.

Lime was then soaked for an extended period of time. The time required for soaking depended upon the quality of quick lime, and could range from days to weeks. It was generally believed that the longer the fat lime was soaked, the better it would perform. The mix was stirred with bamboos, and fresh water was added daily. After one or two weeks, the milk of lime was sieved (passed through a 120-mesh) in a container or pit in order to remove any large pieces, as the larger particles may cause problems. Putty can be stored for years if kept safe from atmosphere by covering it with a shallow layer of water. The longer the putty absorbs water, the longer it will retain that water when comes to be used.

Lime putty was found to be thixotropic substance, which means that when stirred, known as knocking up, the plasticity returns reportedly (Ashrust, 1997). This form stiffens and eventually hardens by reacting with Carbon Dioxide of atmosphere. Fat lime putty was ideal for plasterwork, lime wash, rendering work and binding masonry.

Hydraulic Lime: Hydraulic lime possesses the property of setting and hardening under water. Hydraulic lime was not a pure lime, but contained Calcium Oxide (CaO) 40 – 60 %, Magnesium Oxide (Mg O) 30 – 40% , Silica (SiO_2) 20 – 30%, together with some Alumina (Al_2O_3) and Oxide of Iron (Fe_2O_3) etc (Syed, 1967). It was obtained from kankar lime or clayed Limestone. Generally all varieties of hydraulic lime slaked slowly and took several hours or days without producing much heat, or change in bulk. In hydraulic lime the contents of Carbonate of Magnesia, Sulphate of lime, alkalis, metallic oxides etc. retard the slaking action, but they quicken the process of setting and hardening the mass after being made into mortar (Ashurst and Nicola, 1988) At around 40% Silica and Alumina, the maximum strength could be achieved, approaching Portland cement. The hardening of hydraulic lime did not depend on air, and therefore it should not be

slaked immediately after burning, but should be slaked just before use.

Hydraulic lime has relatively quick setting property. The more hydraulic the mix, the shorter would be the available working time. Hydraulic lime could be further classified as feebly, moderately and eminently hydraulic (Taylor 2000). The detail is shown in Table-1.

Pouzzolan for Lime: Materials which enable lime mortar to set more rapidly included ash and brick dust, known as Pouzzolan known as "Surkhi" in local language. Pouzzolan is Siliceous and Aluminous material, which itself possessed little or no cementing value but in the presence of moisture, react chemically with Calcium hydroxide at ordinary temperature, to form compounds possessing cementing properties (Marshall, 1923).

Preparation of Kankar Lime: Kankar is a nodular variety of Limestone and is extensively used for producing hydraulic lime for conservation purposes. Kankar is often found in large quantities in the beds of streams, beneath the surface layer of earth. Their size varies from ½″ to 4″ and they were composed of nearly pure compact Carbonate of lime, but their upper surface consisted of a mixture of sand and clay. Kankar usually contained 70% of Carbonate of Calcium and 30% clay, sand and other impurities (Marshall, 1923).

Burning of Kankar Lime: The nodules were cleaned of any mud sticking to them and broken to uniform size of about ¾″ - 1″ before calcination. The hydraulicity of the lime produced from raw Kankar lime was determined by kiln temperature, length of time in kiln and chemical composition of Kankar limestone (Kazmi, 2004). Fuel used for the calcination was generally coal and cow-dung cakes. The minimum effective temperature for burning Limestone for lime was 880˚ C, but overall temperature of 1000 ˚C was necessary (Marshall, 1923). The consumption of fuel depended on the nature of Kankar lime and nature of coal. In general, for every 100 cubic feet of Kankar lime, 15-25 cubic feet of coal was mixed. The mix was screened through 1/4″ mesh to remove dust or small particles, before setting in kiln (Figure-2).

A circular kiln was made with bricks, having diameter of 8–12 feet, and height 10–12 feet. Four fire-holes were made to lower side of the kiln walls. The kiln was plastered with mud from interior and exterior. On the floor of kiln, bricks were arranged to make a cross channel to connect all four fire-holes. The cross channel was covered with bricks and at the centre a vertical channel was made to exhaust the fumes of fire. The remaining floor area was also covered with bricks, laid on edge to make circular channels for heat (Figure-3).

These channels helped to produce uniform heat on all sides of kiln. The floor was then totally covered with cow dung cakes. Above that a thin layer of coal was laid (Figure-4). Kiln was then loaded with mix of Kankar lime and coal. The exhaust/chimney remains a little above from the top layer.

The complete operation of igniting and burning of kiln took place for 8–10 days. To check, if the limestone was fully burnt in the kiln, an iron rod was inserted from the top, which if it passed through to the bottom easily, indicated that lime was burnt completely. The kiln was then allowed to cool for 15 to 30 days before unloading. Kankar lime was then placed in a dry place.

Grinding: Kankar lime was used in mortar both in coarse and fine powder form. After calcinations Kankar lime was ground in power-driven mortar mill, fixed on the roof of a cabin. The granulated form of Kankar lime was collected below the roof in cabin (Figure-5). This powder lime was used as a substitute of sand in mortar.

Testing Lime and Lime Mortar: The mortar was tested before using it on actual restoration work. To test lime and lime mortar, samples were selected from burnt lime both in coarse and fine form. Mortar was prepared in the same proportion as expected to be used in the actual work, and tests were carried out as per methods of (Marshall, 1923) :-

Tensile Strength Test: A fairly good hydraulic lime should give results of about 80–150 lbs per square inch, in ultimate tensile strength. Fat limes were weaker with about 40 lbs per square inch in tensile strength.

Compression Test: A good mortar has a crushing strength of about 200 lbs per square inch after curing for 7-days, which increases to 400 to 1000 lbs per square inch after curing for 28 days.

Adhesive Strength Test: Two bricks of an ordinary size were joined with ½ inch mortar and left for curing. Tests were performed after 7 days and 28 days and load required to separate them was noted. The total load divided by the area of the brick on which the mortar was applied, gave the adhesive strength, which was generally 10–30 lbs per square inch.

In addition to above tests, mortar was also checked for its porosity, workability, setting time, color and volume-change on drying etc. Lime mortar of which the tensile strength was less than 100 lbs per square inch, was not to be used in conservation works. A practical and quick way of testing lime mortar on the work itself was to take a handful of mortar from the trough and after a minute or two, wash it off the hand, if the skin was left rough after washing, the mortar may be considered fit for use.

Mixing and Placing: The use of traditional lime mortar needed considerable skill on the part of the mason, as the following difficulties would occur:-

- Addition of water would improve workability but tended to reduce mechanical strength of hardened mortar. A good balance was necessary.
- Lime mortars were slowed setting and required a relatively dry environment.

For making lime mortar, Kankar lime was mixed in trough according to the requirements of the day, as much water was added as would make it into a stiff paste. Mortar was to be more like dough than slurry. The mixture was kept a little dry, rather than too wet as it was easy to add water if required. Workability could be achieved, without excessive loss of strength, through the use of water reducing agent (fluidizer), because they allowed the use of less water without affecting workability. Energetic mixing, resulting in air entering, also allowed improvement of workability without excessive addition of water. For stone masonry and thick plaster, the best course was to grind the Kankar lime being wet after its removal from kiln without any previous dry grinding. The grinding would be longer for fine class work and shorter for coarse work.

All the elements of good practice, such as thorough preparation of materials, adequate and appropriate preparation of backgrounds (including cleaning, dampening down to control suction and where appropriate, making good and keying surface) use of small volumes of mortar and slowed curing and protection from sun, wind, rain and frost for new mortars would be all important.

Composition of Lime Mortars specified by Conservation Experts: It was considered that new mortar should match with old mortar, not only to ensure continuity with the past but also to ensure that new work both visually and physically was to be compatible with the old (Torney, 2014). Therefore correct specification of the mortar for binding, plastering and rendering old building was vital. Mortar analysis could be carried out for identification of aggregates to match the new mortar with old one. In the buildings constructed during the Mughal Period, lime putty and Kankar lime (both fine and coarse form) was used extensively. The choice of other aggregates also had significant effect on the performance and appearance of lime mortar (Figure-6). There were several important factors that affected the condition and performance of a mortar and could not be revealed in analysis of mortar used in historic buildings. These included the original water binder ratio, the mixing and placing method, the rate of drying and organic additives such as eggs, urea, sugar, yogurt etc.

Compositions of Lime Mortars Proposed by Sir John Marshall and Bernard M. Feilden: Sir John Marshal and Bernard M. Feildenboth had suggested the same compositions in their manuals for conservation. The detail was as under (Marshall, 1923; Fielden, 1989).

The gum was first soaked in water and the other ingredients were grounded in the gum water to form a thick paste. The above quantity of mortar could be prepared by two men working for two days. When ready, it was kept in earthen pot well soaked in water and taken out as required. The binder would remain fresh for a week or ten days.

Mortar for Inlay Work

White lime of marble	½ Seer	(500 gm)
Powdered marble	6 Chittak	(360 gm)
Burnt zinc powder	5 Chittak	(300 gm)
Gum	1 Chittak	(60 gm)
Gur	1 Chittak	(60 gm)
Dal urd	2 Chittak	(120 gm)
Patacha	1 Chittak	(60 gm)
Mastagi	½Chittak	(30 gm)
Tukhm-I-Balanga	½ Chittak	(30 gm)

Plaster Stucco for Roofl: Following is a mixture that has been found successful for this purpose:-

Kankar lime	25 Seers	(25 kg)
Cement	2 ½ Seers	(2.5 kg)
Black slag from brick Kilns (roughly ground)	7 ½ Seers	(7.5 kg)
Black coloring matter extracted from the cooked fruit of the wild pomegranate	4 Chittak	(240 gm)
Black Sugar (Gur)	1 Seer	(1kg)
Hemp (San)	1 or 1 ½ Chittak	(60 or 75 gm)

It must be clearly understood that plaster such as that described above was only to be used on terraces, roofs etc. where the original plaster of a more or less like kind was preserved and was in need of repair.

Compositions of Lime Mortars Proposed by Talib Hussain: During the discussions with Mr. Talib Hussain, following compositions were suggested by him for plaster, masonry and stucco work (Hussain, 2011).

Base Coat for Plaster / Rendering Coat: Base coat was also called rendering coat. For the base coat white lime cream, fine Kankar lime and coarse Kankar lime were mixed in a ratio of ½ : 3: 2, respectively. Chopped Jute was also added in the ratio of 10 – 15 grams per kg for total Kankar lime. Dry ingredients were mixed to achieve uniformity and water was added slowly, until it became semi-dry. Modern mixer was not recommended to be used as the material would stick together and could not mix. It could be mixed with hands for small amounts but a mortar mill with two revolving wheels was ideal. .The surface being rendered was tightened with trowel. Key the surface with comb or scratcher. The rate of drying

could be controlled by misting the surface with clean water or limewater; until the shrinkage had stopped and the mortar had hardened sufficiently to receive second coat. Curing was done for 2 weeks. The base coat might had thickness of 1–3 inches, as per requirement.

Second Coat / Floating Coat: For the second coat white lime cream and fine Kankar lime were mixed in the ratio of 1: 2 or 1: 3. Sometimes marble powder could be used instead of fine Kankar lime as filler.

The second coat was ¼ inch thick. Any irregularities in the background must be dealt with good finish coat due to its thinness. Then it was left for 6–8 weeks, to get dry properly in order to straighten the surface at this stage, otherwise it would not be possible to straighten it.

Finish Coat / Butter Coat/ Glazed Plaster: Finish coat was not applied unless the base coat was dried totally. The thickness of finish coat was only 1/8 inch. It was a thin layer of pure lime putty, which set by absorbing Carbon dioxide from air and results in producing crystals of calcite (calcium carbonate). These crystals had unusual reflection of light, the surface thus glowed. Therefore finish coat was also called glazed plaster or "puccaqalai."

Fat lime cream, six month aged, gave excellent results. Sometimes a mixture of lime cream, and marble powder having 1: ½ ratio was also used for glazed plaster. The surface was tightened enough with slight pressing of trowel, from top to bottom direction. After that powder of soap stone was dusted on the surface with the help of muslin cloth and glazed finish was obtained by compacting the surface with steel float.

Glazed plaster was always finished in small portions / panels. For fresco work dusting of soap-stone was not required to be done on the finish coat; instead fresco was required to be made on slightly wet surface.

Mortar for Stone Masonry: The mortar used for base coat was also used for masonry work. However, for pointing a mixture of 1:2 one part white lime cream and two parts fine kankar lime was used.

Mortar for Stucco: For stucco work, a mixture of fine sand, marble powder and gypsum was used in proportion of 1: 1: 2 ratios.

Compositions of Lime Mortars Proposed by Abdur Rehman: During the discussions, Mr. Abdur- Rehman suggested following compositions for Munabat Kari, and plaster work. (Munabat Kari is an ornamentation of plain surface in order to break the monotony by providing relief with the mortar)

Ispagoal was soaked in water a day before. White lime cream was 5/6 month aged as per requirement. All the ingredients were mixed in a bowl. The mortar was in the form of paste as required. The water of Ispagole could be added to obtain required workability. The mortar could be used up to 10 days if not allowed to dry by keeping it under a shallow layer of water.

Mortar ForMunabat Kari

Belgium chalk powder	3 Table spoon
White lime cream	1 ½ Table spoon
White of egg	One
Ispagoal (seed of flewort)	1 Table spoon
Seep (sea shells) powder	½ Table spoon
White sugar	½ Table spoon

Mortar for the base of Fresco and Stucco Work

Fine kankar lime or marble powder	10 kg
Daal Mash (a kind of pulse)	250 gm
White lime cream (aged)	5 kg
Chopped Jute	250 gm
Gurr (Black/raw sugar)	250 gm
Powder of sea shells	2 ½ kg

The "Dall Mash" and "Gurr" were socked separately in water, 5–6 days before making the mortar. The dry ingredients (fine Kankar lime, chopped Jute and powder of sea shells) were mixed thoroughly, and small quantity of limewater was added to make it slightly wet. Thereafter white lime cream, paste of "Dall Mash" and paste of "Gurr" were added in the mixture and rammed thoroughly to get uniform mix for mortar (Hussain, 2011).

The mortar, as per requirement, was used on the same day it was prepared. During the day, the mortar was kept damped with limewater and rammed thoroughly, 4–5 times in a day. This mortar could be used for stucco, mirror work and for the base of fresco.

Compositions of Lime Mortars Proposed by Malik Maqsood Ahmad: During the discussions, Conservationist Architect, Mr. Malik Maqsood Ahmad suggested the following compositions for masonry and plaster work (Mubin et. al, 2013).

Mortar for Stone Masonry: A mixture of white lime, fine Kankar lime and coarse Kankar lime in 1:3:4 ratio was used for stone/ brick masonry.

Mortar for Plaster Work: For base coat, white lime, fine Kankar lime and coarse Kankar lime were mixed in 1:2:3 or 1:1:3 ratios. For finish coat, white lime cream and fine Kankar lime were mixed in 1:3 ratios.

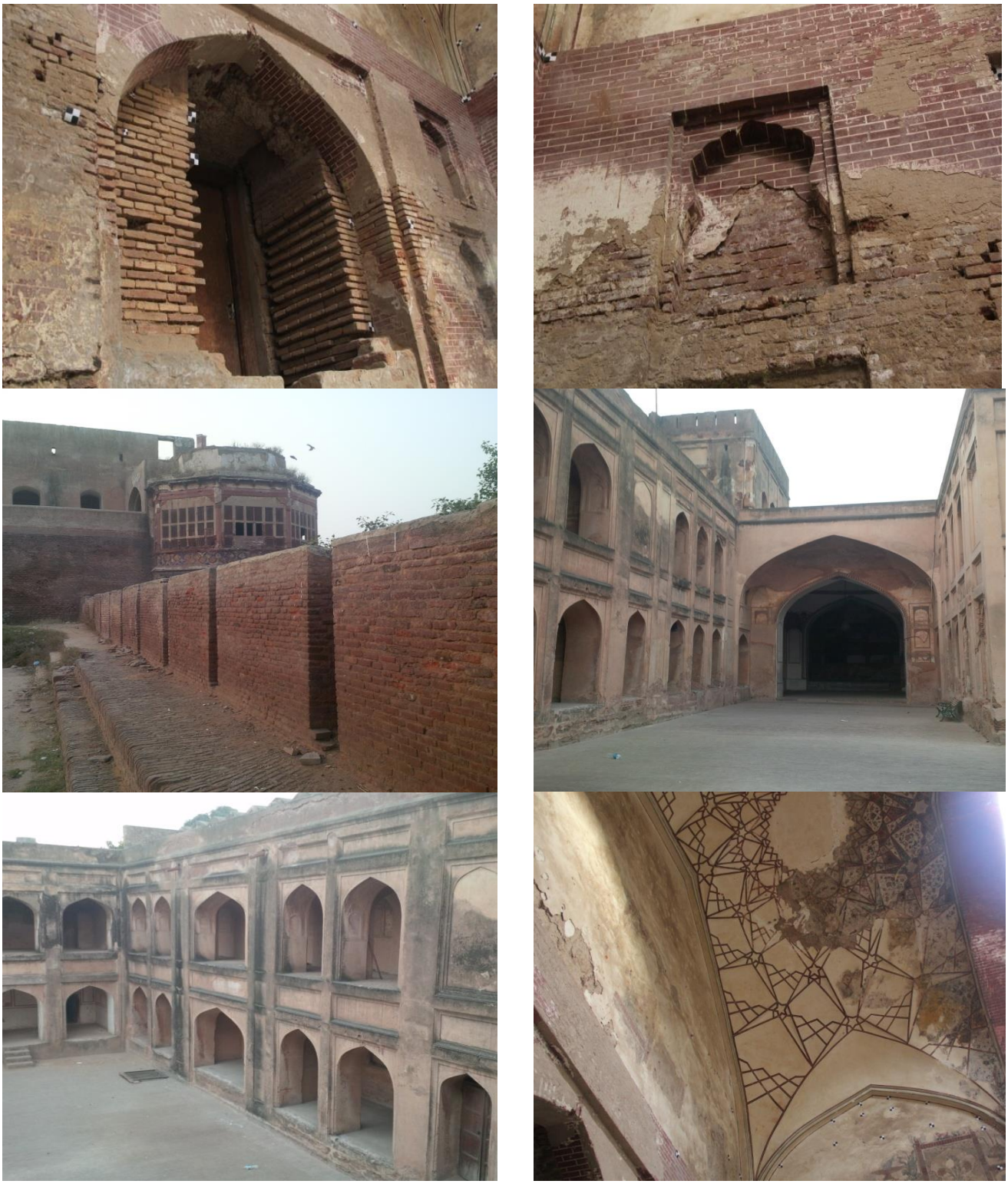

Figure 1: Historical buildings deterioration with the use of cement at different locations for repairs

Figure 2: Screening of kankar lime

Figure 3: Arrangements of bricks on floor area of kiln; having cross and circular channel.

Figure 4: A layer of fuel (cow dung cakes and coal) before loading the Kankar lime

Figure 5: The granulated form of Kankar lime collected below the roof in cabin

Figure 6: Ingredients of lime mortar

Table-1: Classification of lime with setting and slaking time

Classification of lime	Impurities of clay	Setting time	Slaking time	Color
Feebly Hydraulic	10 – 12 %	20 days	Very slow	Off white or Pale gray
Moderate Hydraulic	12 – 18%	15 – 20 days	Slow	Pale gray
Eminently Hydraulic	18 – 25%	2 – 4 days	Slow	Dark gray or Brown.

Conclusion: It became more and more evident that natural stone masonry could only be restored satisfactorily by utilizing lime mortars. Lime mortars were found to be the original substance used in the past not only for aesthetic purposes but also on technical grounds. The characteristics of lime mortars guaranteed durability and compatibility in natural stone masonry evident from the performance of historic buildings. Lime mortar could be used for brick and stone masonry, plaster work, decorative finish and pointing of the masonry instead of cement. The lack of standardization of mortar composition for different conservation works was found to be another factor in addition to various compositions of mortar based on the personal experience of different experts. It was also noticed that some experts used white lime, instead of lime putty; whereas fat lime putty was

found as essential ingredient for mortar in the conservation works. The white lime could not achieve the required strength, elasticity and bonding ability with old masonry in historic buildings.

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