Repair, Restoration And Retrofitting of Masonry Buildings with ADO's Convac System

The recent April 2015 Nepal Earthquake caused large-scale damage and destruction to many historic monuments, structures and especially residential buildings. Apart from buildings that collapsed in the earthquake, over a million buildings were damaged; such buildings need minor to major repair. Needless to say that simple and superficial repair to buildings does not restore the lost strength of the structure; it only superficially hides the cracks, leaving the building in a weakened state. Such buildings become vulnerable to after-shocks and future earthquakes even of lesser magnitude. Consequently, it is necessary especially in earthquake prone countries like Nepal to take appropriate action in order to achieve not only the restoration of the lost structural strength to pre-disaster level, but also to upgrade the structure for earthquake resistance by retrofitting to the level envisaged by Building Codes.

In earthquake engineering terminology, Repair, Restoration and Retrofitting mean the following:

Repair: Actions taken for patching up of superficial defects and doing the finishes.

Restoration: Action taken for restoring the lost strength of structural elements.

Retrofitting: Actions for upgrading the seismic restoring of an existing building, so that it becomes safer under the recurrence of likely future earthquakes.

Repair and restoration are applicable to damaged buildings. Only "Repair" will leave the building permanently weak. Restoration and Repair will bring the strength of the building to pre-earthquake level.

Retrofitting is relevant to "Restored" as well as existing undamaged buildings, which are otherwise weak against earthquake forces likely to occur in future according to Indian Standard Building Codes.

It is suggested that the three types of action are taken in the following order:

- First, restore the building
- Next, retrofit the building
- Last, repair the building.

Now if we focus on the general repair of buildings then we find that at least 60% of the repairing has to be done in plaster segment and remaining 40% is to be done for structural restoring.

In this technical paper we will focus on the materials used for plaster i.e., mortar.

Mortar is a material composed of one or more inorganic binders, aggregates, water and admixtures used in masonry to provide bedding, jointing and bonding of masonry units, or used for functions like plasters and renders. A binder can be defined as a material with adhesive and cohesive properties, which bonds mineral fragments in a coherent mass.

The use of lime, $Ca(OH)_2$, dates back to pre-historic times even the Egyptians used burned gypsum ($CaSO_4.½H_2O$) as a mortar in between the limestone blocks for the construction of pyramids. The first example of lime as a binder in mortar dates back to 6th century BC in Greece. The Romans developed a new type of (pozzolanic) mortar, a sort of concrete, with hydraulic properties. Vitruvius describes the Roman knowledge of lime technology, with details on different types of lime binder, process of calcination and slaking as well as recipes for mortar composition and origin of the best sand.

Towards the end of 19th century, this type of mortar was replaced by cement based mortars. This occurred mainly because cement binders can harden and develop strength much quicker than lime binders. Incompatibility problems in the use of cement based mortars for conservation lead to the rediscovery of lime based products. Currently lime mortars are increasingly popular in conservation because of their good compatibility (physical, chemical and mechanical) with materials present in ancient buildings.

Deterioration and Damage Mechanisms

The most important factors influencing degradation and damage to masonry are related to environment, materials, building design, craftsmanship in the construction of the building and its maintenance.

Examples of environmental factors are: presence of moisture and salts, air pollution, temperature changes, dynamic loads and soil settlements. Moisture may come from natural sources like rain penetration, capillary rising damp or floods. Salts may also be originally present in the material (for example, a mortar which has been made using sea water or beach sand), they may come from the environment (aerosol, de-icing salts, etc.) or from the use of the building in the past (for example, chloride from salt storage, nitrates in the case of stables). Temperature variations may give rise to degradation phenomena in masonry due to differential thermal dilation, whereas dynamic loads resulting from earthquakes and vibrations provoked by wind or traffic may cause crack patterns.

Material factors are mainly related to composition of the mortar (binder/sand ratio, grain size distribution of the aggregate) and the properties of the masonry unit/mortar combination (porosity, capillary moisture transport, adhesion, mechanical strength). Many degradation processes may only occur in the presence of water; consequently the speed at which a material absorbs and releases water has a strong influence on its risk of degradation. Therefore, moisture transport properties, which are related with porosity and pore size distribution, are of primary importance when considering the durability of a mortar and the masonry as a unit.

The design of building, i.e. its shape, orientation, etc., and the stated details may strongly influence the occurrence and the severity of the degradation. Also craftsmanship in the form of quality of the execution and of adequate conditions for hardening of mortars is an important factor that affects the susceptibility of the mortar to damage.

The degradation processes (chemical, physical and mechanical) exert stresses on the materials, which weaken the material until it fails and damage becomes visible. Degradation can be defined as an increase in decay, which corresponds with a decreasing performance of the material. Thus, damage can be defined as an un-acceptable reduction of the performance of the material, affecting its durability.

Some of the most important damage processes will now be discussed. For processes in which water is involved, the crystallization of soluble salts is probably the most widespread cause of damage to historical masonry buildings. Salt damage can only occur in the presence of both salt and water. Salt moves in the capillary system of the material and accumulates where evaporation occurs. Salt accumulation and crystallization create pressures, which can exceed the mechanical strength of the material and consequently lead to damage.

The mortar (e.g. bedding or pointing mortar, plaster, render, etc.) and brick or stone are used in masonry in combination with each other, the risk and location of salt damage will depend on the pore size distribution of the mortar/substrate combination. Since moisture (and salt) transport by capillarity moves from larger to smaller pores, a fine porous mortar applied on a coarse porous material will have a larger risk of decaying than a coarse mortar applied on a fine porous substrate (this does however not necessarily imply that a fine porous mortar on a coarse porous substrate would be the wrong choice). Some of the most important damage causing salt is sulphates (for example Na_2SO_4) and chlorides (for example NaCl). Salts precipitating in the pores of a mortar may create pressures, which may lead to damage. As a consequence of salt crystallization, a mortar can show damage in the form of sanding, scaling, exfoliation or crumbling, whereas the masonry units may show damages like powdering, exfoliation and spalling. Sometimes salt crystallization causes damage to a lime bedding mortar because a physically incompatible pointing mortar was chosen. This is the case of a too dense pointing applied on a more porous lime mortar. Because of the hindering of the drying caused by the new cement pointing, crystallization of salts that were already present in the masonry occurs at the bedding mortar-pointing interface. This results in the detachment of the pointing (also called push-out) and also in a form of loss of cohesion (crumbling or sanding) of the underlying lime bedding mortar.

Overview of the most important damage processes and related damage types.

Physical / Chemical	Most Important Damage Types
Moisture Salts Frost Pollution	Biological growth Efflorescence Spalling Exfoliation Powdering (Black) crust
STRUCTURAL	
Overloading, creep Settlement Thrust arches / vaults Earthquakes	Crack patterns Displacement / deformation

Push-out of cement re-pointing due to crystallization of salts at the interface of new pointing and old bedding mortar.

Apart from pure crystallization, the formation of expansive compounds due to the reaction of salts with mortar components may also cause considerable damage, not only to mortars, but to the masonry as a whole. Sometimes the resulting crack patterns may be mistaken for structural damage, where only after drilling cores from the masonry it becomes clear that the cracks originated from swelling of the mortar inside the pier. Additional investigations with optical and electron microscopy revealed the presence of secondary ettringite concentrations, initiating the cracks. Sometimes the pointing mortar is bursting, i.e. it looks like it swells because of an increase of volume. In this last example, the damage in the form of bursting of the pointing was shown to be due to the formation of trichloride.

Other examples of such expansive compounds, which may cause damages, are thaumasite and ettringite. Thaumasite and ettringite are the results of the reaction of sulphates (coming for example from the air or from bricks) with components of the hydraulic mortar. Thaumasite ($CaCO_3 \cdot CaSO_4 \cdot CaSiO_3 \cdot 15H_2O$) may form by the reaction of water with calcium carbonate, calcium sulphate and hydrated calcium silicate, which again are present in concrete or mortar mixtures as binders. The composition of hydrated calcium silicates, which may vary within a relatively wide range, is indicated by the generic formula C-S-H. Ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$) may form by the reaction of water with calcium sulphate and the alumina bearing hydration products ($4CaO \cdot Al_2O_3 \cdot 13H_2O$, $3CaO \cdot Al_2O_3 \cdot 6H_2O$, $C_3A \cdot CaSO_4 \cdot 12 \cdot 18H_2O$, etc.). These products, sometimes indicated as C-A-H, are formed by hydration of Portland cement or other binders, such as hydraulic lime or mixtures of lime and pozzolan.

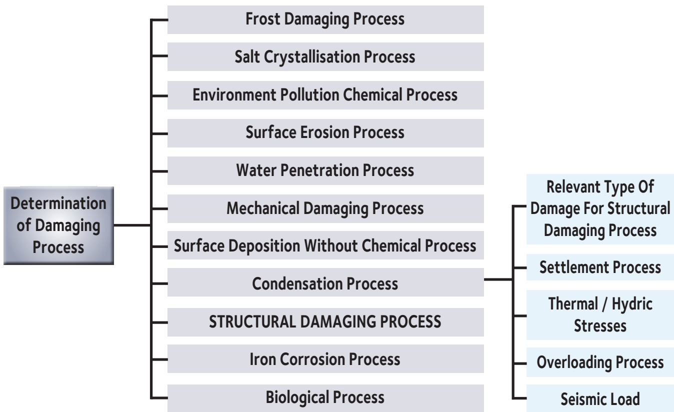
Hydrated lime (air lime) mortar cannot be affected by the reactions described above. In this case another form of expansive reaction, the one consisting in the conversion of the $CaCO_3$ into $CaSO_4 \cdot 2H_2O$ (gypsum), can take place. Sulphates present in the polluted air or coming from the brick react, in the presence of moisture, with the $CaCO_3$ in the mortar to form $CaSO_4 \cdot 2H_2O$, i.e. gypsum.

(a) (b)

(a) Crack pattern in masonry, looking like structural damage but caused by expansive reaction in the internal part of the mortar; (b) Bursting of pointing mortar due to the formation of $CaO.Al_2O_3.3CaCl_2.31H_2O$ (trichloride).

Damages due to structural causes are generally showing as cracks, often in combination with deformations. The first important step to make a diagnosis of structural damages is the survey and interpretation of the crack pattern. However, the possibility of damages occurring due to non-structural causes has also to be taken into account. The signs of damages given by the crack direction and opening have to be well evaluated.

The crack patterns may be caused by structural failures like overloading, settlements or due to extreme events like earthquakes. The major structural failures that may cause damages affecting the structural stability include: (i) dead load in heavy massive structures; (ii) soil settlements; (iii) horizontal actions due to thrust in arches and vaults; and (iv) extreme events like earthquakes or landslides. The position, the direction and the width of the cracks indicate where the local stress value reaches the strength of the material and hence, indirectly, the type of stress to which it is subjected. Knowing typical causes, which can produce damage to the structure such as vertical and horizontal actions, soil settlements, interactions between walls and floors, roofs and walls, can help understand the visible effects (cracks, deformations, leaning, etc.) of these actions on the structure.



We confidently present Convac Plus (PP Strength) which is a patented Integral 100% waterproofing admixture for concrete and mortar as a complete solution to the above stated problems. It is based on a blend of surface active agents and refined chemicals. Convac Plus (PP Strength) is a permanent solution, especially for water leakage / seepage, dampness and saltpetre treatment on concrete, mortar and masonry wall. Convac Plus (PP Strength) exhibits excellent bonding properties with the substrate. The major product solutions are:

1. Integral 100% Waterproofing Compound
2. An anti-saltpetre waterproofing system in counter pressure (from within the wall and outside the wall)
3. Hardens and consolidates a surface deteriorated by damp and saltpetre

Convac Plus (PP Strength) is the only patented product in India from ADO's product range.

Benefits of Convac Plus

- Provides complete resistance to water ingress whether under hydrostatic pressure or capillary action

- Increased durability
- Prevents saltpetre attack
- Reduced efflorescence
- Improved cohesion, reduce segregation
- Minimize rebound loss
- Improved and durable surface finish
- Reduce shrinkage cracks in plasters
- High gain in compressive strength

Mechanics of Convac Plus

Calcium silicate hydrates (C–S–H) have a large number of structural sites available for cations and anions to bind. The C–S–H phases are materials, which have ability to toxic ions immobilization. Immobilization mechanisms for C–S–H include sorption, phase mixing, substitution and precipitation of insoluble compounds. By the addition of Concav Plus into the C-S-H gel phase it forms a semi crystalline structure within the mortar and acts as an extra pore / capillary fillers in mortar matrix.

Thus the moisture/liquid transport mechanism in mortar gets interrupted in the presence of this semi crystalline structure of cement paste. The density gets improved as there are now fewer pores in the matrix and resultant of this phenomenon give us direct positive effect on compressive strength. Microbiological growth is mostly due to sorption technology onto the mortar matrix. Convac Plus also prevents the mortar matrix system for long time from microbiological attack.

Depending on the nature of the use or application the proportion of Convac Plus is determined. For example, to make brick wall, plastering, concrete roof, flooring and pillaring in a new building, ratio of the composition to the mortar is 250-300 gm per 1 bag (50 kg) cement. Slight deviation in proportion as prescribed would not make much difference in the end result. But in case of repair work, to increase the gripping property, the ratio of the composition to the mortar is 500 gm per 1 bag (50 kg) cement to be mixed with water.

To make de-saltification in new concrete construction, Convac Plus is recommended to be used as cement additive. But in case of repair of old concrete buildings; site visit and technical guidance is recommended. For repair we suggest Convac Plus system to be first used as a coating system on the affected surface. Plastering of the affected surface with Convac Plus as an admixture will ensure better grip, consolidate and harden the surface. For damp-proofing of new and old concrete constructions same method of application as in the case of de-saltification is to be followed.

In case of repairing crack(s) in a building or roof, Convac Plus acts as an adhesive. Firstly, the affected area needs to be cleaned. Then Convac Plus is spread to have a thin layer coat. After the same, the mixture of Convac Plus with cement and sand etc. is plastered on the area. For heat proofing, a thin layer of the composition is applied on both the outer and inner surface of the walls of the existing building. In case of new building, the plastering is recommended to be done with Convac Plus added to cement and sand as per standard practice. But in case of old buildings the treatment as in the case of de-saltification is to be followed.

Convac Plus prevents hair cracking and definitely increases the density of plaster. Using this innovative product it is possible to make the floor strong and durable like stone, it can be used for white cement wash also. It can also be used for cement colouring outside and inside the building with all beneficial qualities as mentioned before. It can also be applied to plaster of pans over wet surface.

By using Convac Plus with cement, sand etc., there occurs a polymerization, resulting in increase of density of the plaster and minimization of the gap between the sand particles. This process helps to increase the strength of the concrete. In mortar, salt does not absorb environment water or moisture. Because of this minimum pores phenomenon; damp proofing of structure is almost 100% in comparison to structures where Convac Plus is not used. By the same mechanism, because of the increase in the density of the plaster using Convac Plus and reducing the gap between sand particles results in reduction of heat transmission through concrete surface is also possible. To repair crack(s) on the wall(s), and roof in any construction, Convac Plus acts as an excellent adhesive. Similarly, when white cement is mixed with this Convac Plus, the resulting mixture prevents hair crack(s). The extra gripping or increase in intra sand particles bond strength is due to polymerization and electronic bonding of the substances used.

Convac Plus has long shelf life under normal temperature, light, air and standard storing conditions. It is non-toxic, non-corrosive, non-odorous and white in colour and also is eco friendly. Ado Additives Mfg Pvt. Ltd. is confident that the innovative product Convac Plus is not only a complete solution provider in case of repair, restoration and retrofitting but it will surely help modern construction sector immensely.

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