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Building stones—their decay and preservation

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Building stones have been used for mansonry work the world over since the dawn of history due to their durability and aesthetic appearance. These stones, of different types possess large variation in their decay-resistance towards natural and artificial weathering agents. The decay of stones may be due to chemicals, physical or environmental factors which can be arrested, to some extent, if these buildings are periodically cleaned and renovated. Certain preservative treatments are also known which help in checking the decay and thus enhancing the life of the building.

Stone masonry has been in use since prehistoric times especially in prestigeous structures such as forts, palaces, bridges and monuments. The ancient monuments of Greece and Egypt as also the other historical monuments of the world speak themselves of the strength, durability and architectural aesthetics of natural stones. India is one of those countries which has a rich heritage which is well documented by innumerable archeological monuments still existing.

Though many of these structures have withstood the rigours of weather for thousands of years yet there are many monuments which have been badly damaged and ultimately grounded due to the weathering effect of nature. This is because there is a wide variation in the durability of various stones with respect to natural climate and aggressive environments. Some stones may be resistant to the attack of physical agencies while others may have better chemical resistance. The decay of building stones depends not only on their chemical and physical properties but also on the chemical, physical and environmental weathering agents such as the effect of heat, light, rain, wind, frost, air pollution, ground water rise, chemicals present in the mortar, micro-organisms, vegetative growth etc. However, if the probable causes of stone failure in a particular case are ascertained in the beginning and proper precautions taken, most of the troubles can be prevented.

Various methods of cleaning the exposed surface and different preservative treatments have been recommended from time to time but a perfect treatment for such buildings is yet a dream. The paper attempts to describe the various kinds of natural stones used in structures, causes of their decay, methods of cleaning and preservative treatments developed from time to time.

Building stones

A vital factor in the durability of stone buildings is the judicious selection of the most suitable stone with special reference to its availability and environmental conditions, apart from architectural appearance. The more important criteria in selection of building stone are hardness, strength, porosity and texture, colour and grain, resistance to chemical attack, workability, durability, ease of quarrying, and, of course, availability.

From the point of view of geological origin, the rocks that provide building stones can be divided into three classes:

(*i*) *Igneous rocks:* Igneous or primary rocks are formed by the cooling and solidification of magma. These are very hard rocks. Granite is the most common of igneous rocks. They are composed of quartz, alkali, feldspar, mica, etc. Their colour varies from white to light grey, bluish grey or pink.

(*ii*) *Sedimentary rocks:* Sedimentary rocks or secondary rocks are formed as a result of disintegration and decomposition of the igneous rocks and subsequent deposition and compaction of the end products. Sandstones and limestones are the most common sedimentary rocks. Sandstones are composed of sand, quartz, iron and lime. Silica is the cementing medium and the strength of these stones depends mainly upon the cementing medium and also on the degree of compaction. Sandstones vary in colour depending upon the composition of the cementing medium. Ferruginous sandstones are red to brown, argillaceous, earthy to buff, siliceous, white, and carbonaceous, black. Limestone vary widely in their composition, porosity, texture and hardness. Essentially they are composed of calcite and dolomite along with various impurities including silicates. Their colour varies from light grey to dirty black. Travertines are also sedimentary rocks composed mainly of calcium carbonate. These were formed on the earth surface through the evaporation of water from hot springs.

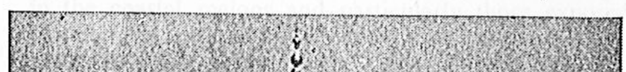

Fig 1 Taj Mahal, an excellence in white marble—will it survive the atmospheric pollution created by the Mathura refinery?

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(*iii*) *Metamorphic rocks:* Metamorphic rocks are those which have been transformed from the igneous or sedimentary state by the action of heat, pressure or magmatic solutions. These rocks are generally hard and strong. The most commonly known is marble, which is metamorphosed limestone, or sometimes dolomite, and which is one of the most attractive building stones. Depending upon the impurities, its colour varies from white to grey, red, pink, blue, yellow, green and black. A judicious combination of colours can produce natural and beautiful patterns on cutting. Marbles are essentially composed of calcite and dolomite with small amounts of quartz, mica and other silicates as impurities. White marbles composed of pure calcite are the strongest and most durable while their durability decreases with increase in various silicate impurities.

Stone masonry

Building stones are used in stone masonry after the rocks are converted into required size and shape by chiselling. Depending upon the fashion in which stones are used, the masonry is classified into three types.

(*i*) *Dimension stone or cut stone:* This type of stone masonry has been used in most of the historical monuments. These are stone blocks cut and dressed to desired shape and size conforming to drawings and specifications and ready for installation in building. Granites, limestones, sandstones and marbles of high strength are normally used as dimension stones, while basalts, diabases and other dark igneous rocks are generally not much used.

(*ii*) *Rubble masonry:* This masonry is composed of stones in random size shape as taken out from the quarry and laid with the help of mortar. An advantage with this masonry is that it can utilize all dimensions of stones which are otherwise unfit for use.

(*iii*) *Ashlar masonry:* It is composed of rectangular dressed stones laid in uniform or random courses. Different patterns or designs may be created by jointing the stone pieces in continuous or discontinuous and uniform or random patterns. Care should, however, be taken that limestones and sandstones are not laid together since calcium sulphate, which is formed by the action of sulphur acids in the atmosphere on calcite in limestone, has a disintegrating effect on sandstone.

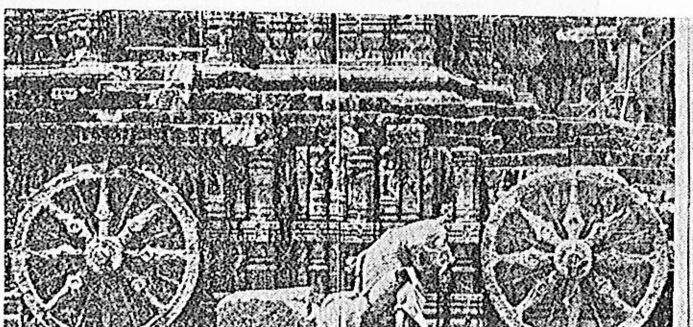
Causes of decay

Stone decay may be the cumulative effect of a large number of weathering agents apart from use of inappropriate quality of stone, bad wokmanship and poor maintenance and cleaning. These weathering agents may be both natural or artificial which can be classified into chemical, physical and biological.

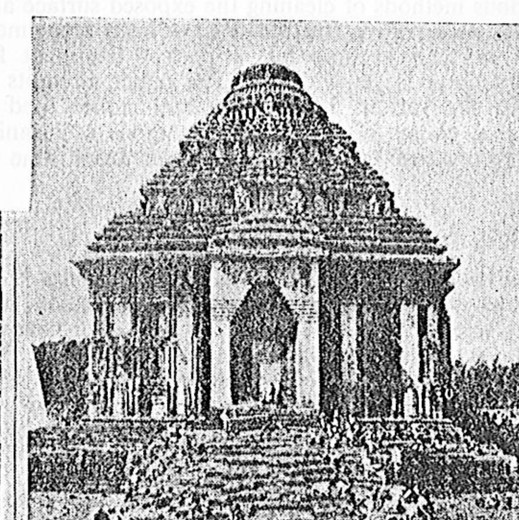
(*i*) *Chemical and environmental:* Among the chemical and environmental causes of stone decay are the chemical composition and structure of the stone itself, atmospheric pollutants and soluble salts present in stone masonry or brought by water from the foundation.

Composition and structure — Softer grades of stones containing partially soluble or reactive minerals are more susceptible to decay. For example, certain lime stones containing loosely compacted calcite minerals are easily attacked by rain water which is normally contaminated with sulphur dioxide and carbon dioxide. The surface of such stones are washed away in course of time and give a worn out and pitted appearance. Pyrites, if present in the stone, are slowly decomposed into ferric hydroxide and sulphuric acid. Ferric hydroxide produces brown stains and sulphuric acid dissolves calcium or magnesium in the stone converting them into their respective sulphates. Common stones, if used particularly in buildings exposed to sea water, get badly damaged, hence, attempts should be made to use only stones resistant to sea water in such situations.

Stones with uniform and homogeneous grains also exhibit regular pattern of weathering in comparison to those with marked difference in size of component minerals and uneven bedding of irregular minerals. The rate of weathering is also irregular if the composition of the matrix and cementing substances are much different as in the case of certain sandstones. Stones of high porosity, if used in the exterior undergo repeated cycles of water soaking and drying. The pores also absorb salts dissolved in water in the form of chlorides, nitrates and sulphates which cause efflorescence on the surface.



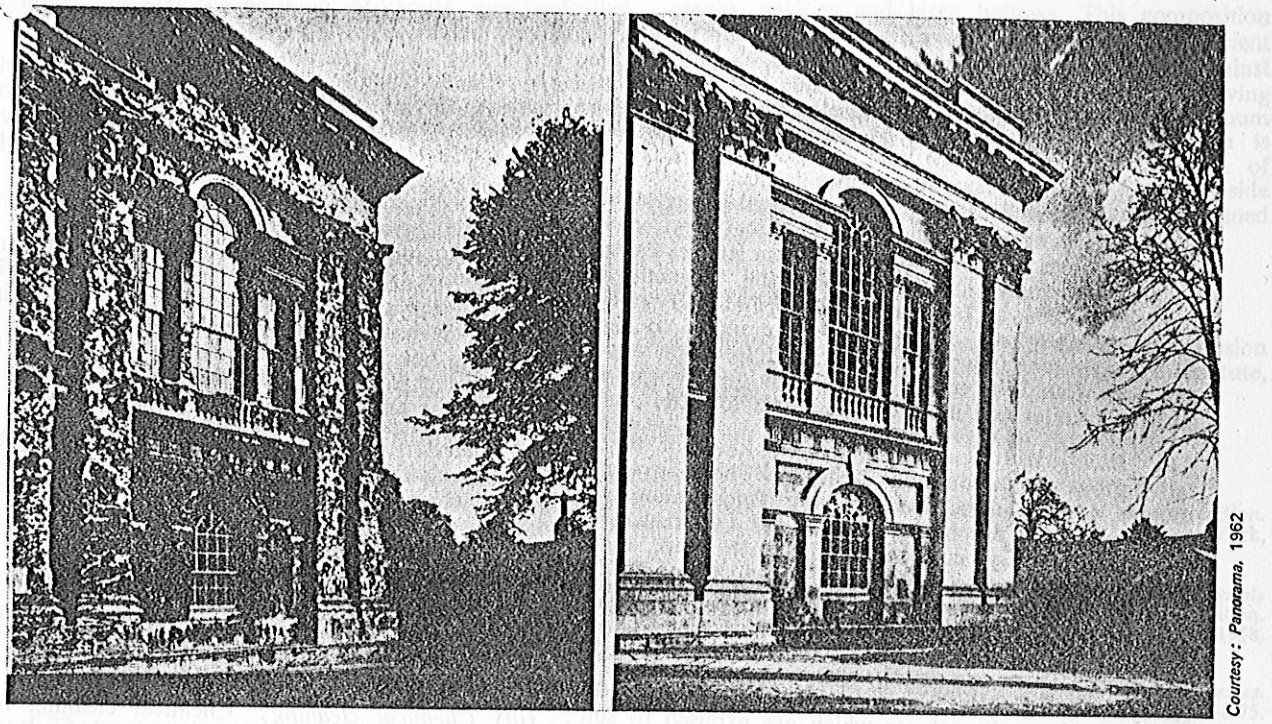
(*a*) A poetic legend



Courtesy: Percy Brown, *Indian Architecture, Vol 1, 1942*

(*b*) front view — on way to grounding

Fig 2 Sun temple, Konark



(a) badly damaged by air pollution and decay (b) renovated with more durable stones

Courtesy: *Panorama*, 1962

Fig 3 Christ Church library, Oxford

Atmospheric pollution — Atmospheric pollutants in the form of dissolved gases are a great hazard to stone structures. The atmosphere contains smoke and dust and harmful gases such as carbon dioxide, carbon monoxide, sulphur dioxide, sulphur trioxide, chlorine, hydrochloric acid, etc., in industrial areas. The gaseous products of incomplete combustion of coal in industry and home get bound with the siliceous matter in the stone in the form of sooty deposits, and tarnish the face almost permanently.

The industrial gases are carried by rain water into the pores and thus get access into the more vulnerable parts of the stone. It is more so in the case of more porous and softer stones which allow greater depth of penetration. Sulphur acids travel deep into the stone reacting with calcite to form calcium sulphate. The latter crystallises both in the pores and on the surface. Since the crystal size of calcium sulphate is very large, the pressure develops inside the stone which can ultimately break it. Calcium sulphate, due to its poor solubility, is not washed away by rain water. In case of dolomitic stones, magnesium sulphate is also formed along with calcium sulphate. The former is a more deleterious substance but its high solubility allows it to be washed away from the surface during rains. Magnesium sulphate, which remains in the pores and that which is entrapped between calcium sulphate crystals is, however, not removed. The calcium and magnesium sulphates which get deposited on the surface slowly form a hard impermeable skin which may result in blistering or exfoliation of the surface.

Soluble salts — Building stones may themselves contain deleterious soluble salts before quarrying or may get contaminated during dressing or transportation. The contamination may also be due to absorption of sulphur acids from atmosphere or chlorides from the sea. Sometimes it might be due to the use of salt-contaminated sand used in the mortar. Soluble salts may also creep in through rising capillary action of ground water if damp-proof course is inadequate. Due to the evaporation of water from the stone surface, salts get deposited in the pores, as well as, on the surface. These salts may also attack the stone surface if they are any suitable reactive minerals. The disruptive effects of these salts in the form of crystallisation and erosion are continuous and progressive and they cause the stone decay at a very fast rate. Stone buildings, in the coastal regions and particularly those exposed to sea water, are badly affected by chlorides.

(*ii*) *Physical:* The many important physical factors which cause decay of stone buildings are rain water, attrition by wind, frost action, rising dampness, thermal stresses, etc. Stone, if kept dry, is free from many hazards of weathering. Pure water, though in itself is not harmful for stones, acts as the vehicle for carrying pollutants and exposing the stones to corrosive attack. Rain water itself is always carbonated and acts as a mild solvent for calcium carbonate especially for the softer grades of limestones and sandstones.

Buildings, particularly in coastal areas, deserts and dry sandy lands, face an attack of high velocity wind loaded with sand. This causes sand blasting resulting in erosion of the surface. Frost is another big decay hazard, particularly in case of porous stones. Its effect is more severe in colder countries and fortunately it does not bear much relevance to this country except for stone buildings at high altitudes. Rain water entrapped into pores of stone masonry freezes in extreme winter. Water expands on freezing creating immense pressure in the stone masonry resulting in its failure. Resistance to frost depends on the pore structure of the stone and amount of water entrapped in the pore and it has been observed that fine-pore stones are more prone to frost damage than those with coarse pores.

Rising dampness from foundation is a major agent of stone decay in cases where adequate cut off between the foundation and the wall has not been provided.

The rising moisture brings dissolved salts along with it which have their own damaging effects as have been earlier described. The intensity of this factor depends on the local water table, soluble salt content of ground water and the capillarity of the stone and mortar.

Disintegration of building stones is also caused by differential internal thermal stresses caused by repeated cycles of heating and cooling due to climatic extremes during day and night, respectively. These stresses cause fatigue, ultimately leading to fissuring. Sometimes combined effects of heat and solution and recrystallisation of chemicals and minerals entrapped in the pores cause stone failure. Large variation in temperature has been found to convert even high quality stones such as granites and marbles into a friable state.

(*iii*) *Biological:* Sometimes different kinds of vegetative growth occur on stone buildings. These growths, though do not directly cause any deterioration of building stones, are to be avoided for two reasons: they give a very unsightly appearance; and, they become a seat for retention of water, dust, and other salts which damage the stones in their own way. These growths may be grouped into three main classes:

Algae — These are small vegetative growth capable of synthesizing their own food. They easily grow on porous and rough surfaces which are exposed to sun and are in constant touch with water. These are generally green but are also found in dark grey, dark green, blue or even red colours.

Fungi or moulds — These bodies lack in chlorophyll and depend on other dead organic matter for their food. They grow even in dark places in humid conditions. They penetrate deep into the pores of the surface and give a green, brown or even black colour to the surface. They generally grow on stones which already have algal growth or other organic matter on their surface.

Mosses and lichens — These are another class of vegetative growth similar to algae and grow in abundance when the surface remains constantly wet. They also attract the growth of mould around them and badly disfigure the stone surface in the form of dark green or grey patches.

All these vegetative growths, however, develop in clean environment, on the other hand, in places of high industrial pollution the dissolved gases prevent their growth or even distroy them.

Cleaning

Smoke, dust, chemicals, oils and other greasy and dirty accretions get deposited and form, in course of time a hard crust over the stone surface. These deposits get cemented with the stone surface and not only present an unsightly appearance for the stone building but also attack the stone surface from inside as they retain water in them. Apart from these, they also act as a seat for the vegetative growth. Cleaning of the surface is, therefore, the most important steps in revitalising the original appearance of the building.

Cleaning of stone surface should, however, be done very cautiously as any abrasion of surface or introduction of deleterious chemicals may do more harm than good. The method of cleaning has, therefore, to be selected after studying the type of soiling and the type and condition of the stone. The common methods of stone surface cleaning are washing, abrasive blosting and chemical or mechanical cleaning. Among these washing with water is the most common method of cleaning.

(*i*) *Washing:* The wall is first properly wetted, followed by jet washing with water. Oil or greasy deposits can be removed by the use of organic solvents and finally washed with the help of detergents. Dust accumulated on marble and stains made by the constant touch of hands can be removed by this treatment. Efflorescence can also be washed off with water. One disadvantage is that dust accumulated inside the pores comes out again after cleaning, thus staining the stone surface. Another disadvantage is the introduction of unwanted water into the stone structure. This can, however, be taken care of if the washing is done in hot weather. Steam washing at high pressures gives better results.

(*ii*) *Abrasive blasting:* The soiled surface is exposed to sand blasting. It is especially useful where there is heavy soiling and chemicals have been converted into hard crust with the passage of time and are difficult to be removed by other simple methods. This method should, however, be used with caution as it may be harmful for soft stones as well as old and partially decayed stones. One drawback of this method is that it re-exposes fresh surfaces for weathering which may be a disadvantage with soft stones.

(*iii*) *Chemical cleaning:* Chemical cleaning has to be resorted to where washing does not help. It can be successfully carried out with the help of acids, alkalies, ammonia, zinc silicofluoride and a number of commercial formulations. The choice of chemicals depends on the type of soiling and nature of the stone. Acids can be used in mild concentration but it has been observed that out of them all, hydrofluoric acid is most effective. It can be used on hard stones such as sandstones and granites but it must be handled with great skill and precaution as it is a highly dangerous chemical. It has an added advantage that it does not leave any soluble salt on the surface or in pores. Though caustic soda is not used as such, most of the alkali cleaners are based on it. These can be used for softer stones with lesser soiling on them. Chemical cleaners are applied on prewetted surface and then washed with a jet of water. Every effort should be made to remove the cleaner completely lest it causes efflorescence or other damaging effects.

(*iv*) *Mechanical cleaning:* This method makes use of power tools of abrasion for removing hard deposits from the surface. It should be resorted to only if the deposits are insoluble and if washing and chemical cleaning fail to remove them. The power tools used in this technique make use of various abrasive or grinding systems such as carborundum heads, rotary wire brushes or other abrasive stones. This method is suitable for flat hard stones and should be carried out by expert hands or else it may irrevocably damage the stone surface.

Preservation

Construction of stone buildings using most appropriate stones and correct construction procedures followed by cleaning at regular intervals and avoidance of contact with water, soluble salts and polluted atmosphere ensure long life without any preservative. These are, however, very ideal conditions and are seldom obtained at site. Under the non-ideal conditions, preservation is needed to enhance the durability of the buildings. Experience has, however, shown that it is almost impossible to make a stone building permanently weather resistant while, at the same time retaining the colour and ppearance of the building. Moreover, any protective coating which can give an impermeable barrier may be more harmful, because any water which may enter from any point will get entrapped behind the coating where it may dissolve the salts and create damage to the stone masonry. It is, therefore, advisable to have semi-permeable coating, such as silicones, diethyl silicates, etc., which check the ingress of water but at the same time allow the stone to 'breathe'. Further, these preservatives should be completely colourless so as not to affect the original colour and appearance of stone building. Such preservative measures have been tried and it is observed that the decay of stone can be arrested if the measures are taken in time.

As with any other treatment, the surface preparation is a pre-requisite for preservative treatment on stones. The surface should be well cleaned and any loose particles or vegetative growth should be removed by pressure washing or brushing and then allowing the surface to dry completely. In case of surfaces prone to vegetative growth, the cleaned surface should be given a treatment of chemicals such as ammonia, or sodium pentachlorophenate or salts of zinc, lead, copper, mercury, arsenic, etc. All the spalled edges must be first repaired. Cracks, if any, should also be repaired or filled with silica seal, a silicone based formulation.

The preservative selected should not react with the stone surface, and at the same time it should fill the pores of the stone instead of forming a film on the surface. Some of the oldest preservatives used were based on paints or boiled linseed oil. These materials, though offered good decay resistance, suffered from a serious drawback of destroying the original colour and appearance of the building. Paraffin wax emulsion is effective, to some degree, if it is driven deep into the interstices of the stone. It, however, possesses poor durability in exposed weather.

In one process, known as the Kuhlmann's process, the stone surface is coated with a solution of sodium or potassium silicate which absorbs carbon dioxide from the air and formed a hard and durable protective layer. Ransome's process is an improvement over the earlier process in which the first coat of sodium silicate solution was followed by a coating of calcium chloride solution. The two compounds reacted in the pores as well as on the surface to form calcium silicate which prevents the ingress of moisture in the stone. Some other siliceous formulations with different trade names are also now available.

Some investigators have observed that barium chloride solution can strengthen limestone buildings partially decayed by sulphurous atmosphere. A number of historical buildings in Britain were given a new life by this treatment. Barium sulphite and sulphate which were probably formed during the process may be responsible for the binding action. On such surfaces silicofluorides of aluminium, zinc or magnesium can also be used to react with calcium carbonate and deposit silica and calcium and magnesium fluorides on loosened particles and reconstitute them into a hard mass.

Partially decayed stone structures with cracks, cavities, hollows, loose particles etc, need special treatment. An acetone solution of epoxy resin when used in conjunction with colloidal silica and fillers was found to be very effective on stone surfaces with deep cracks, cavities and large hollows. This composition gets hardened in the cavities and gives a very efficient protection to the decaying stone surface against moisture and atmospheric pollutants. Stones having open cavities can also be strengthened by a vacuum coating process. In this process, a liquid resin is introduced deep into the cavities with the help of vacuum impregnation. The resin sets and hardens inside the cavity giving strength to the otherwise weakened stone.

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