Stone Cleaning of Heritage Buildings in Mumbai

A Handbook

M M R H C S

MUMBAI METROPOLITION REGION HERITAGE CONSERVATION SOCIETY

Information

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FOREWORD

Bombay was originally a cluster of seven islands inhabited by fishermen – **Smaller Colaba, Colaba, Mazagaon, Worli, Matunga, Mahim and Salsette.** These islands were originally part of the Mauryan Empire under Ashoka. They were later ruled by Hindu dynasties till 1348 AD when the Muslims from Gujarat attacked and captured it. In 1534 a treaty between the ruling sultan and the Portuguese saw the islands pass into Portuguese hands, who later presented them to the British as a dowry for Charles II when he married princess Catherine of Braganza in May 1662. The islands were taken over by the East India Company in 1668 and within a period of 250 years Bombay was transformed from a group of fishermen's islands into 'Urbs Prima in Indis'.

During colonial rule, the city grew to be a major urban commercial centre with an overwhelming collection of some of the finest Gothic Revival buildings. It was the wealth of the city, an enlightened patronage and an enthusiastic government that created the right environment conducive to innovation and change (Davies, 1985). This was also made possible by the availability of good building materials and skilled workmen well trained in western architectural details. Light-coloured durable stones were quarried from Salsette island and the railways assisted in cheap and fast transport from outside Bombay of softer stone for carving. The Bombay School of Art provided a steady supply of local skilled craftsmen who translated the grand colonial dreams into reality.

Each period in the evolution of Bombay – a humble fishermen's settlement, a port town, trading city of traditional *waada*s, a manufacturing giant metropolis– resulted in its own architectural expressions using the unique requirements and cultural styles of the period, and more significantly the materials and techniques that were available at that time. The present urban landscape of the southern and central part of the city, now called Mumbai, is composed of stately stone buildings, particularly in the Fort area, the mill area of Parel and a few other religious and public buildings in other areas.

The colonial architecture of Bombay is the legacy of the British Empire, consisting of buildings essentially European in design and vocabulary, but utilising indigenous craftsmen and materials for construction. The architectural history of the British in India has been described as one of constant search for the 'Imperial Architectural Style',

PREFACE

This publication is specifically written for scientific cleaning of heritage buildings of Mumbai and is part of the activities of the Heritage Grants Scheme of the Mumbai Metropolitan Region–Heritage Conservation Committee. It describes the weathering mechanisms of the building stones of Mumbai and their soiling patterns. It will serve as a reference book for professionals, decision-makers and owners to develop an understanding of the nature of the soiling mechanisms and their subsequent cleaning techniques. The main purpose is to equip the readers with the requisite information to make an informed decision regarding the appropriate cleaning system. The publication aims to explore the use of stone cleaning in urban conservation and to keep the argument on the debate alive — whether to clean a stone building or not.

The conservation principle in cleaning is that, while bringing back the original splendour of the building, it shall not damage the original fabric of the building. Thus the basic principle of cleaning is that the most gentle technique with the least possible degree of intervention should be attempted. Cleaning methods differ widely in their ability to remove the soiling, as well as to cause damage. Different types of soiling differ widely in their tenacity and ability to damage the substrate. In principle, the more tenacious the soiling, the more aggressive is the method of cleaning and higher is the possibility of damage to the fabric. For effective cleaning it is better to use a combination of cleaning techniques as historic buildings have a range of materials, detailing and different kinds of soiling. This has to be done under the strict supervision of specialists. It must also be remembered that it is not a one off solution to conservation, nor is it the solution for a better environmental control.

Stone cleaning is a useful strategy as it provides an opportunity to get a closer look at the building and solve critical problems at that time.

Chapter I

Building Stones of Mumbai

Like most historic towns, the issues facing architectural heritage in Mumbai are very complex. Legal problems due to multiple ownership, insufficient budgets for repairs and maintenance, non-availability of proper guidance on intervention to the historic fabric, polluted environment and general neglect are only some of the hurdles encountered in conservation of heritage buildings. In Mumbai, the high land values, particularly in the Fort area, threaten the survival of many historic buildings. The need for conservation of architectural heritage is recognised by professionals, but need further encouragement from the government and the citizens. The Heritage Regulations for Greater Bombay, 1995 is an instrument for the conservation of listed buildings, areas, artefacts, structures and precincts of historical, aesthetic, architectural and cultural value. Any intervention in the form of alteration, redevelopment and repairs of heritage buildings and precincts require prior written permission from the Municipal Commissioner in consultation with the Urban Heritage Committee of the Brihanmumbai Municipal Corporation (BMC), a statutory body formed in 1995. The Mumbai Metropolitan Region – Heritage Conservation Committee allots funds for research and documentation of architectural heritage through its Heritage Grants Scheme. Mumbai with its surrounding area is part of the peninsular shield of India. This triangular plateau lying south of the Vindhyan range is a very ancient tableland that is being continuously eroded since its formation. The *rock of the peninsular, the Deccan tra*p, is made up principally of very hard and compact volcanic rocks of basaltic composition. The Deccan trap is laid almost horizontally over a large part of western and south-western India. It exhibits a total thickness of over 2,400 m near Mumbai, though it is much thinner in other areas. The rock is more or less uniform in its chemical composition except for variation in the silica content from 48.6 to 52 percent. The rocks are rich in iron (up to 10 to 11 percent), calcium and magnesium. In a few areas, however, there occur a few other rock types, which appear to have been formed by localised differentiation of the basaltic magma, *e.g.* Malad stone.

Stone cleaning in context of heritage buildings in Mumbai

The stones used for the construction of the historic buildings of Mumbai are primarily igneous rocks (Kurla, Malad) and sedimentary stones (limestone). Other stones, such as sandstone have been used for decorative purposes. Basaltic rocks are quarried in Mumbai but limestone and sandstone were brought from outside. Extensive quarries in Salsette island have provided excellent building stones of high strength and durability for the historic buildings of Mumbai, *Fig 1 to* 4.
There are mainly two types of basaltic flows:

. Figure 1: The Western Railway headquarters building at Churchgate is constructed of Kurla basalt and limestone

(i) thick and massive flows, and
(ii) vesicular flows.

The massive flows have, in general, rough appearance and are not so amenable to dressing compared to the vesicular flows. This is the reason that the famous caves in Deccan basalt at Ajanta, Ellora and Elephanta have been preferentially cut through the vesicular flows (ISEG 1990). Basalts, in general, are very compact, highly jointed strong rocks with compressive strength of about 800 kg/cm 2. The average specific gravity of these rocks is 2.92.

The commonly used igneous rocks for buildings in Mumbai are:

Bluish grey basaltic rock: Basaltic rocks are grey to dark grey in colour and of fine to medium grain texture with some glassy component. A typical example is the

Figure 2: The grand civic architecture of Mumbai is a direct manifestation of itsimportance and wealth the empire; Bombay Town Hall, opened in 1833 was designed byColonel Thomas Cowper of the Bombay Engineers, using classical vocabulary andDoric style

Western Railway headquarters buildings at Churchgate. The dark colour is due to the presence of the ferro-magnesium mineral, augite, in addition to plagioclase of labradorite composition. These rocks show columnar jointing and spheroidal weathering. During the course of cooling the lava flows develop a variety of secondary minerals as alteration products, or as secretion fillings, imparting pale green colour to these rocks (Wadia 1961, Pascoe 1964). This enhances the suitability of these rocks as a building stone.

Buff coloured Malad stone or yellow basalt: This rock is also part of the Deccan trap. Though most of the lava flows of the Deccan trap are basaltic in nature, a few are sub-acidic. The latter are light coloured and are a better choice as a building stone. The famous Gateway of India in Mumbai, built from such a light coloured stone obtained from quarries located at Kharodi near Malovni, about 6 km west of Malad station in the island of Salsette, (Krishnan 1930), is the best example of this stone. It is fine grained with micrographic texture and is amenable to cutting and dressing. Geologically it is known as granophyric trachyte. This stone has some undesirable mineral constituents in minor amounts, like pyrite (iron sulphide) and calcite. Iron sulphide on exposure to moisture and air produces iron oxides and sulphuric acid. The iron oxides give a brown stain on the surface and the acid reacts with calcite, corroding the rock. Similar light coloured trap rock occurs in the Kurla area, in north-east Bombay, within the basaltic flows. The specific gravity of this rock is 2.43. It has crushing strength of about 1870 kg/cm ^{2} and, 3.14 percent porosity.

Stone cleaning in context of heritage buildings in Mumbai

White coloured limestone: It generally consists of particles of carbonate of lime cemented together by a similar material. Although most limestones have similar mineral composition, consisting mainly of calcite or calcite and dolomite with subordinate amount of other minerals, they show a great variety of texture and colour because of the differences in nature of the cementing material the impurities present, porosity and fossil content. Because of its relative softness it can be readily worked. Limestone weathers and spoils with a characteristic blackening of the surface in sheltered areas, and streaking in the water run off areas.

Miliolite limestone: The light coloured softer stone used in Mumbai is miliolite limestone, which is finely oolitic almost free from sand or other foreign particles; the

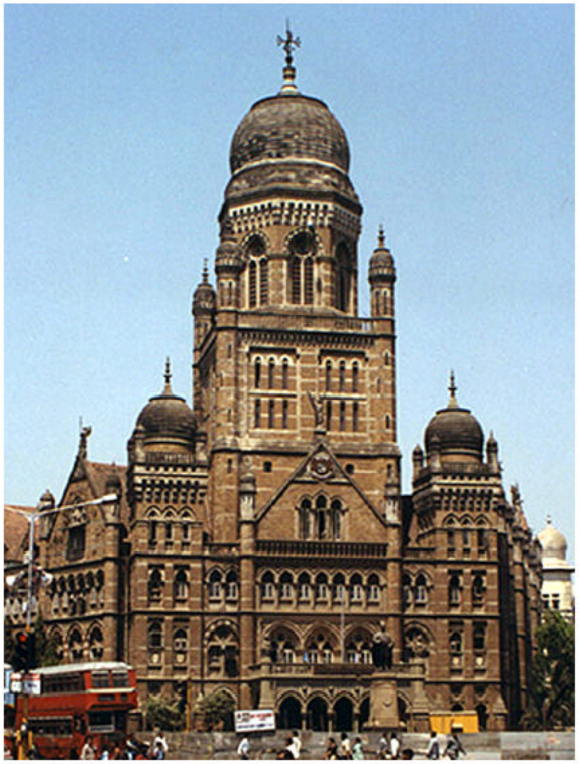


Figure 3: The BMC building with the statue of Sir Phirozeshah Mehta and the civic motto of Urbs Prima in Indis.

nuclei of the oolite grains being mostly organic. The quarries are along the base of the Barda hills about north-east of the port. The deposit there is very thick, and occurs in three parallel ridges rising one above another. It is white coloured and obliquely laminated at about 22, varying in different quarries. The miliolite extends out into the plains around Adatiana and Ranawu. The farther it occurs from the coast, the purer is the limestone. This stone or squared stone is extensively used as building material for many Hindu temples, mostly in ashlar work. It is readily workable and is of excellent quality.

Figure 4: Victoria Terminus, renamed Chhatrapati Shivaji Terminus, remains the crowning glory of the colonial architectural heritage in Mumbai

Limestone is also obtained in large quantities from Porbundar in Saurashtra and is well known by the name of 'Porbundar stone'. The effect of rain and weather on miliolite is to harden it and render it less porous. A much inferior stone is also quarried at Porbundar, fom a very open imperfectly cemented shore deposit, or raised beach, which is often palmed off as Porbundar stone.

Others: Apart from white Porbundar limestone, red sandstone, marble and other stones used in building construction are also brought into Mumbai.

The use of stone in buildings

A combination of stones is used in most historic structures. Basaltic stones are much harder and are employed for structural masonry units and sparingly used for elements like short columns. Limestone is used for decorative elements like in trellis work , cornices , sills , balusters , statuary , domes , arches , and other embellishments. Sandstone has been used in short decorative columns, voussoir of arches and rounding. The use of marble is also decorative for cladding and statues.

Stone facades, since time immemorial, have an inexplicable charm and reflect various qualities like strength, solidity, order, reassurance and perpetuity. Once a fashionable material, the use of stone nowadays has been relegated to a cladding material. Historically, stone has been used both as a structural and a decorative building material. The extensive use of stone as a building material in a grand fashion was popularised during the colonial times. This was perhaps due to the ready availability of both basalt and limestone, the latter of which could be carved with ease.

Most buildings built during the colonial period use ashlar masonry and sometimes polygonal walling for the buildings, while rubble masonry is used in the construction of the boundary wall and other ancillary structures. Various surface finishes ranging from rock cut, punched, boasted, pitched, tooled, reticulated have been employed. A few buildings have been constructed where stone is used more as a cladding material than for structural purposes.

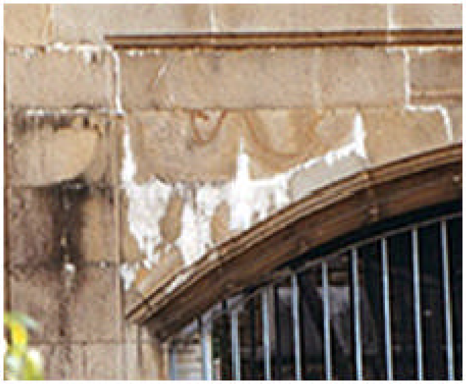
Mumbai had the advantage of availability of good building material of high strength and durability, pleasing colour , cheap, and limited average workability. The nature and interlocking texture of the mineral in the basaltic rocks contribute substantially towards the strength and the impervious nature of the building material. In sedimentary rocks, the variable nature of the cementing materials holding the minerals together results in a variable strength and the porous nature of the stone. Some volcanic rocks contain vesicles, while sedimentary rocks are characterised by planes.

Kurla stone buildings convey a sense of solidity and mass because of its dark colour. On the other hand, **Malad stone** buildings appear more attractive and lively having a lighter colour. On the other hand, because of its light colouring the soiling becomes more apparent.In the next chapter, we shall be talking about the mechanisms of soiling and decay of stone building facades.

Chapter II

Mechanisms of soiling and decay of stone surfaces

The degree and extent of soiling on the stone surfaces of buildings is a result of the particular characteristics of the individual stones, the weathering mechanisms and the environmental conditions, and the maintenance schedules. The physico-chemical non-equilibrium that the rocks undergo during their geological evolution determines the weathering of stone in buildings. Apart from the natural causes of weathering of stone, other factors such as climatical factors, erroneous construction practices and choice of materials, and a large number of destructive agents associated with pollution contribute to the decay of stone. The natural ageing process of stone is accelerated due to human activity and the lack of maintenance of the buildings.



The rationale for cleaning historic masonry buildings arises out of diagnostic, therapeutic and aesthetic considerations. It is necessary to clean old buildings to preserve them and give them an added lease of life. Soiling can not only disfigure but also be an active agent of physical deterioration. Cleaning to improve the aesthetic of a building is invariably based on restoration, or the intention to return the building to its condition at some previous point of time, usually when it was new. Contrarily, the process of restoration also removes the traces of history and the marks of time

STONE BUILDING FACADES
Surface characteristics of stone

Porosity and roughness of the stone surface play an important role in the efficiency of the particle deposition. Roughness of the surface modifies the local turbulence, substantially increases the exchange between air and the surface and consequently deposition, *Fig 5* Retention of the deposited particles on the surface depends on the roughness or the smoothness of the surface and the amount of sticky substances in the polluting agency.

However, deposition has also been observed on exposed surfaces of monuments by dry mechanisms especially under sills, cornices and the other surfaces protected from rain. The mechanisms that deposit pollutants constitute only the final steps in a chain of events between the source of pollutants and the receptor surface.

Durability of the exposed stone depends on its internal structure and petrographic composition, besides the environment in which it is exposed.

Figure 6: Water is involved in most types of stone decay. Here the penetrating damp is trapped in the masonry as can be seen by.... Hard pointing causes the moisture to evaporate from the stone surface causing deposition of salt and consequently its decay. Soft pointing is recommended to minimize decay of stone as the pointing can be periodically renewed

Weathering, is a natural process, which is initiated by the exposure of the masonry and its interaction with the natural environment. It is associated with the maturing of the stone in the building, mellowing down of the details and formation of a patina. **Deterioration,** a stage beyond weathering causes alteration of the appearance, strength, dimensions and the chemical behaviour of stone as an individual element or as part of the structure. However, accelerated weathering adversely affects the masonry. **Soiling** is an end product of the interaction of the stone surface with the atmospheric pollutants and organic growth. It visually alters the building facade and can further accelerate the decaying process of the stone.

Soiling, weathering and deterioration are inter-related phenomena. Cleaning cannot be done in isolation from weathering and deterioration of the stone substrate.

Mechanisms of decay of stone surfaces

Water is the chief cause of decay of buildings. Prolonged retention of moisture within the stone masonry can lead to irreversible damage in the long run.

Physical mechanisms

Effect of temperature: All stones tend to crack and spall when subjected to high temperatures. This is because they are poor conductors of heat. Varying coefficients of thermal expansion of the different minerals in the stone causes internal stress resulting in cracking of the stone. *Effect of water:* Water in its pure form and with its varying content of dissolved aggressive constituents is an important destructive influence, *Fig* 6. Another cause of damage is the absorption of water containing soluble salts. In dry weather, water evaporates and the salts crystallize inside the stone, setting up stresses. Capillary rise and subsequent evaporation causes formation of encrustations, leaching and abrasion of the surface.

Figure 7: The lighter side of the conical limestone roof indicates the direction of wind and rain, the leeward side left being soiled and infected with $CaSO_4$ encrustations

In Mumbai, the south and south-westerly faces of buildings are the most affected from the point of view of the stone soiling and decay, *Fig* 7. Polished stones resist weather as their surface offers fewer points of attack compared to a rough surface. Protection to the masonry from water, by provision of good drainage and detailing is essential.

Figure 8: and the erosion of the softer layers

Wind erosion: Wind laden with solid particles abrade the stone surface causing scouring of the surface, erosion of the softer layers and consequent disfiguring of the building. *Inherent defects*: Commonly occurring defects in the stone include shakes, sand holes/clay holes, mottle and vents. These defects accelerate the decay mechanisms of the stone building. The presence of clay and oxide of iron is apt to cause disfigurement of the stone, producing brown coloured bands that interfere with the uniformity in the colour of stone and diminish its durability. Uneven ridgelike appearances in limestone and sandstone are caused by the erosion of the softer layers, *Fig* 8.

Staining and cracking on most stones are also due to corrosion of the embedded dowel bars in the building stones, as in the Chattrapati Shivaji Terminus (previously known as Victoria Terminus) main building, *Fig* 9.

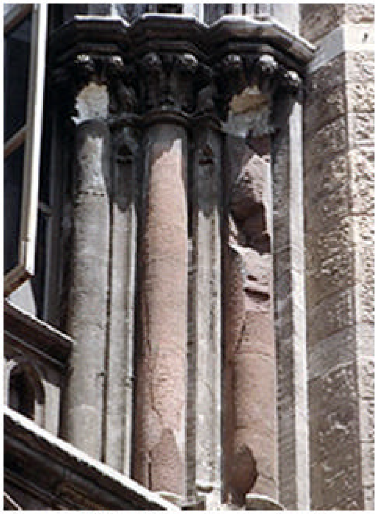


Figure 9: Splitting of stone due to rusting of the iron dowels

Chemical mechanisms

Acid attack: On the whole, stones are extremely durable materials. However, considerable damage can be caused, particularly to limestone by carbonic and sulphuric acids.

Efflorescence: This is used to describe the phenomenon shown by some crystalline substances of losing their water of crystallisation after being exposed to the atmosphere. In buildings, it describes the presence of white salts that sometimes appear on the face of new brick walls. This is due to the inherent water evaporating, leaving the white deposit of salt.

Environmental decay

The quality of the environment is heavily altered by the activities of development, particularly in urban areas. The extraneous substances that affect the quality of atmosphere are termed as pollutants. Different constituents of the atmosphere produce different degrees of deterioration on stones.

Action of particulate matter: The bigger and the heavier particles carried by the wind settle down on the stone surfaces. The small sized particles called the suspended particulate matter (SPM) remain airborne. The deposition of particulate matter over the years leads to accumulation over the stone, disfiguring the architectural features. When this layer peels off, it also take off a thin layer of the stone, further disfiguring it, and reducing its cross-sectional area and load bearing

Figure 10: Contour scaling of limestone. Crystallisation of salts is often confused with wind erosion. The mechanical removal of stone by wind borne particles occur only in exceptional circumstances. Any increase in the rate of decay in the areas that are particularly susceptible to wind is usually due to increased rate of evaporation which leads to an accumulation of salts in the areas together with a greater frequency of crystallisation effects

capacity.

Action of gaseous pollutants: The effects of gaseous pollution can be seen far away from the source. The extent of deterioration of the stone is due to pollutants present in the atmosphere and the nature of the stone. The effect of pollutants is very complex and is subject to much research. The main components of the air that cause deterioration due to chemical action include oxides of sulphur and nitrogen, hydrogen sulphide, oxides of carbon and chlorides. Mumbai is one of the most pollution-prone cities in the country according to the National Environmental Engineering Research Institute (NEERI). The environment in Mumbai is characterised by the accumulation of toxic materials in the air and the concentration of solid and liquid particles in the atmosphere. The widespread sources of atmospheric pollution mainly include automobile emissions, combustion of fuel and industrial wastes. Vehicle emissions, particularly diesel emissions, are largely seen as responsible for this rapid soiling with sticky particulate carbon deposits. Environmental attack needs a two-phase response, namely, reduction of the pollution level, and adoption of a scheduled maintenance program of inspection, cleaning, repair and/or replacement.

Corrosive action of winds

Airborne dust particles damage the surface of monuments by the abrasive action of the dust carried by it, *Fig 1*0. The winds from the sea are laden with salts from the sea. These salts abrade and/or corrode the surface of buildings as well as get deposited in the pores of the stones. This can cause salt damage to the masonry. The windward facades of buildings, particularly those facing the sea, experience full blast of these winds and are more likely to show advanced signs of such decay and soiling.

Effect of marine aerosols

Considerable amount of research has been carried out to study the effect of marine aerosols on the processes or mechanisms or phenomena of stone decay, *Fig 1*1. Increased weathering of building stones has been associated with the presence of marine aerosols through wet and dry deposition processes. The decay effects can not however be generalised due to other factors like geomorphological conditions, different ways in which the coasts are exposed to winds, storms, the distance from the sea and height above sea level.

SOILING PATTERN

Soiling of the exterior stonework is an inevitable phenomenon, which can largely be addressed through regular maintenance and care. Unlike objects inside a museum, buildings are subject to constant interaction with the elements of nature and the environment. This causes visible alteration of the exterior surfaces in the form of soiling and breakdown of the fabric. The agents that cause soiling and staining to the stone fabric also further contribute to the deterioration and decay of the surface.

Soiling is always caused by a combination of all the above mentioned factors.

Nature of soiling

Soiling can be classified into:

Foreign matter, not part of the original stone such as particulate and gaseous matter present in the atmosphere which have formed a direct bond with the substrate.

Figure 11: Erosion of limestone from wind, aerosol effect of sea water, leading to growth of microbiological activity.

Products of alteration, of the original material such as calcium sulphate formation on the surface of limestone. This is formed through the chemical combination of the original material with chemicals from the environment. Gypsum (CaSO4) is formed by the reactions of hydrofloric acid in the air with the CaCO3 and is deposited usually in the leeward side (protected side) of the stone. The term 'scruff' is often used to denote this. The removal of products of alteration from the surface of stone invariably causes the removal of some of the original surface of the stone. In fact, the removal of the foreign material may also cause a loss of the entire surface through spalling.

Soiling Pattern and Alteration of the Stone Surfaces

Soiling is often in an intimate bond with the mineral content of the stone and is rarely a superficial layer. It can thus be detrimental to the health of the substrate. If impermeable it would restrict the movement of moisture through the surface. It may act as a poultice containing soluble salts and pollutants and keep them in close contact with the masonry, leading to deterioration.

Attachment of soiling — bond characteristics

The attachment of the soiling to the substrate is due to the molecular attraction between the original stone and various atmospheric pollutants. The adhesion of solid, liquid and gaseous particles to the solid substrate depends on secondary bonds between the molecules. Primary bonds occur between atoms of the same molecule. In dry conditions the main forces of adhesion between stone and soiling are electrostatic forces, Van de Waals forces and hydrogen bonding. The energy of the hydrogen bond is lower than the covalent bond but higher than that of Van de Waals forces. In a humid environment, other forces like capillarity and surface tension become operative. In the daytime the fixation of pollutants on stone will be greater on the coolest parts of the exposed surfaces. The soiling pattern depends on the nature of stone, design of the building, the environment and previous interventions, if any. Igneous stones possess the best stability against an aggressive environment and they exhibit almost indefinite durability in the atmosphere, with some exceptions. Sedimentary materials show partially good weather resistance, whereas limestone is not resistant to acid attack. Limestone is also particularly susceptible to environmental pollution. The response of individual stone blocks will be the important determinant in the soiled appearance of masonry. It is not unusual to find different degrees of soiling between the adjacent blocks of stones subject to similar weathering conditions. It is essential to understand the properties of the materials and the variation in it before any decision to clean is made.

Figure 12: Loss of detail as a consequence of erosion of limestone.

Figure 13: Facades abutting major traffic arteries tend to be more soiled than sheltered facades.

Table : Weather resistance of important building stones

Type of building stone	*Density, kg/m³*	*Water absorption, percent by weight*	*Stability*
Igneous rocks			
Basalt	2,800-3,100	0.1-0.3	Good
Granite	2,600-2,800	0.2-0.5	Very good, harmed only when pyrites are present
Sedimentary			
Limestone (dense)	2,650-2,850	0.2-0.6	Good but not acid resistant
Limestone (other types)	1,700-2,600	0.2-0.6	Less good, but not acid resistant
Sandstone (quartz bonding)	2,600-2,650	0.2-0.5	Good
Sandstone (non quartz bonding)	1,700-2,600	0.2-1.0	Mostly not stable

Source: Knofel, Dietbert, Corrosion of Building Materials

Stone atmosphere interface: The environment in which the building sits determines the degree and the nature of the soiling. Rainfall provides the natural cleansing mechanism by the removal of the previously deposited pollutants, but promotes the subsequent deposition of soluble gases and particles to those areas that remain moist. The presence of carbon dioxide and sulphur dioxide in the atmosphere of cities results in the formation of weak acids such as carbonic acid and sulphuric acid, producing acid rain. The effect of the former slowly dissolves away the surface layers of limestone, *Fig 1*2. Sulphuric acid reacts with CaCO3 of the rock to form CaSO4 as mentioned earlier. A sulphate skin is thus formed on the surface of stone work often called 'scruff', which gradually splits off and falls away, a process called exfoliation, exposing in turn, fresh stone to further attack. On those parts of the building exposed to rain, the products of chemical reaction are washed away. In Europe, where buildings are largely built using limestones, the rate of decay that formally affected the buildings has now been reduced by strict zoning and pollution control laws.

Exposure and orientation of the facade:
Buildings abutting on to heavily used traffic arteries tend to become more soiled, *Fig 1*3. Pollutants generated from vehicular emissions are a major cause for stone decay and damage. The major attack occurs on the side exposed to the prevailing wind direction, rainfall or sources of atmospheric pollution.

Architectural detail and surface finish:
Soiling patterns are influenced by the architectural and masonry construction details like the kind of masonry and the finish of the face of the stones. Architectural detail, such as drip courses, rain water spouts, etc govern the pattern of rainwater runoff on the surfaces, *Figs 14,1*5. The areas with projections such as cornices, parapets and decorative surfaces tend to be stained darker than other surfaces, since these areas are directly related to the surface runoff of rainwater. However, limestone has a different soiling pattern. Wet areas tend to remain clean, whereas sheltered areas tend be darker and soiled, *Fig 1*6. A good design anticipates

Figure 14: Soiling pattern governed by the architectural detail. The darker masonry surface is due to the water thrown out of the spout.

Figure 15: Texture location and properties of individual stone contributes to differential soiling. Rough surfaces facilitate deposition.

the soiling of the building so that it accentuates the building detail by providing contrast instead of obscuring it.

Lack of maintenance programmes:

Most buildings lack comprehensive maintenance programmes. Years of neglect and accumulation of soiling and dirt render most historic buildings dirty. The soiling on building is often associated with historicity as one gets accustomed to seeing it that way. The accumulation of years of dust/soiling causes increasing decay of the stonework. Insensitive interventions in the form of surface coatings, repair, repointing, etc can sometimes be more damaging than the lack of maitenance.

Re-soiling: Re-soiling is a natural phenomenon that begins immediately after the cleaning process. It has been noticed that areas affected by surface runoff and dampness re-soil faster than others as biological soiling initially accumulates gathering particulate soiling.

Figure 16: Calcareous stones have a hard crust on the surface. The physical and the chemical properties of the crust and the stone are different. The crust has higher density, lower permeability to water and total or partial substitution of calcium carbonate by gypsum. Variations in volume and thermal expansion of the layer and stone lead to exfoliation of the crust.

Roughened surfaces due to harsh cleaning programmes provide an increased surface area for biological and non-biological soiling. The rate of re-soiling is dependent on the levels of air pollution, climate, stone characteristics and façade geometry. All these need to be monitored as they serve as an indicator to clean buildings periodically.

Figure 17: Bird droppings deface a wall.

Stone cleaning in context of heritage buildings in Mumbai

Organic soiling

The sources of organic soiling include excess moisture and bird droppings. The humid climate of Mumbai encourages biological growth on buildings. During the rainy season, which lasts for three to four months of the year, it is common to see green algae growth on the surface of buildings which dry up during the dry season forming a black stain or crust.

Bird droppings: Pigeon droppings on building facades is a commonly occurring nuisance, *Fig 17*. Areas affected by bird droppings experience a pitting on the surface particularly of calcareous stone by the action of corrosive acids present in the droppings. Recessed or projected areas that provide shelter to pigeons often experience whitish depositions that deface the building facades

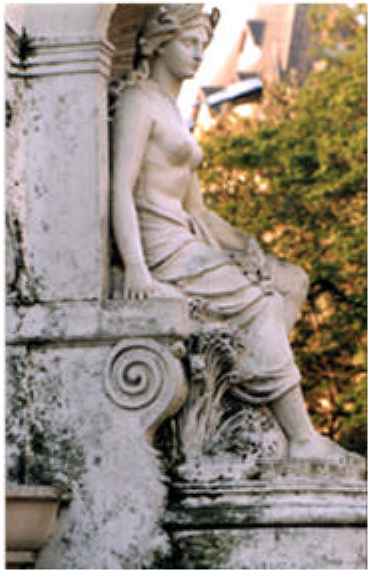


Figure 18: Algal growth on lime washed stone work

. Algae and lichen can spread over the surface and extrude acids that roughen the surface of the stone. As they store water, they increase the water content on the stone. If present for a long time, they provide the substrate for the growth of higher plants. In addition, bird excrement like pigeon and bat droppings are highly acidic and corrosive in nature and cause pitting of the affected area.

Biological soiling

This is caused by the colonisation of micro-organisms, like algae, fungi, lichens, bacteria and plants on the masonry surface wherever their specific needs of growth and propagation, that is, water content, light, temperature, pH and nutrition are available. They are not always harmful, but can be responsible for a range of stone deterioration from an aesthetic point of view to complete deterioration. It is, however, difficult to quantify their activity as the breakdown mechanisms are complex.

Algae: It is a primitive plant like organism, ranging in size from single cell forms to large seaweeds. It is capable of photosynthesis but lack true leaves, stems, roots and vascular systems. Usually green and slimy when wet and black and powdery when dry, it has a preference for dampness and is likely to be found in areas with high runoff and water retention, *Fig 18*. Apart from light, it requires carbon dioxide from the atmosphere for photosynthesis. Algae becomes darker as it entraps soot from the atmosphere. It is highly susceptible to alterations in the pH level and the lack of moisture. Removing algal growth is difficult since it can recur under favourable conditions. When dead it can be simply removed from the surface by low pressure rinsing. Although it does not break down the substrate of the stone for nutrition, it secretes organic acids which might lead to the dissolution of the constituents of the substrate. Damage is also caused by the growth of filaments into the masonry pores leading to micro cracking. Algae retain water on the surface and can bring about the increase in the water content of porous masonry. Dead algae also provides a substrate for the further growth of fungi and bacteria.

Research conducted on algal growth and the efficacy of biocides on buildings sandstones by the Masonry Conservation Unit, Robert Gordon University, Aberdeen, Scotland, has shown that following stone cleaning, algal regrowth on buildings can occur very rapidly and in greater abundance than what was present prior to the cleaning.

Fungi: Any of a group of unicellular, multicellular or multinucleate non-photosynthetic organisms feeding on organic matter and include moulds, yeast, mushrooms and toadstools or spongy morbid growth. They are generally black/ brown in colour and assume furry spots or patches on the surface of the substrate. They do not require light, and survive on organic material of the substrate or the dead remains of other organisms. The filaments of the fungi penetrate into the stone

Figure 19: Moss growth on a limestone parapet

surface in search of moisture.

Lichens: These are symbiotic arrangement between algae and fungi where the algae manufacture food and the fungi filaments search for water. Much of the body of the lichens is under the surface of the stone while some species (endolithic lichens) live completely under the surface of the stone. Lichens are more substrate specific.
They secrete carbon dioxide and acids and the network of the fine roots penetrate the substrate by attacking the material. Lichens survive better in non-noxious environment and thus are more often to be found in rural rather than urban areas. Algae form a predominant indicator of age of a building and can also contribute towards the decay of the stone masonry.

Moss: The growth of moss on stone, or in the joints, is usually indicative of abnormally wet conditions and invariably points to the onset of serious decay. Moss grows in those areas which retain water, *Fig 1*9.

Vegetative growth: This provides useful information about the health and the condition of the masonry facade, *Fig 2*0. Small plants grow in areas of sufficient dirt and moisture and weathered areas.

Figure 20: Dense Plant growth on stone

The surface chemistry of soiling

Surface deposition is generally attributed to chemical reaction caused by precipitation. However, deposition has also been observed on exposed surfaces of monuments by dry mechanisms especially under sill, cornices and the other surfaces protected from rain. The mechanisms that deposit pollutants constitute only the final steps in a chain of events between the source and the receptor surface.

Dry deposition

This phenomenon consists of the accumulation on the stone surface of airborne pollutants from the atmosphere. The mechanism of transport depends on the particle size. For small submicron particles (less than 0.1 mm) molecular diffusion (Brownian in the case of particles) is most important as gravitational settling and inertial impact are practically absent. Once they come in contact with the surface they are retained by the molecular forces of attaction (Van der Waals forces). Particles larger than 20 microns, are deposited by gravitational settling when the air is not in motion and by inertial impaction when the air is in motion depending on their shape and the structure of the surface at the point of impact.

All particles are subject to electrostatic forces that encourage deposition if either the particle or the receptor surfaces carry an electrical charge. The presence of temperature and thermal gradients near the surface also promote or hinder the deposition of particles.

Wet deposition

This mechanism comprises the inclusion of trace substances in cloud droplets (rainout) and the removal by precipitation (washout) leads to the formation of acid precipitation. The efficiency of rainout and washout depend on the intensity of precipitation, drop size spectrum, pH value, temperature of the droplets and vertical distribution of trace substances in the atmosphere. Chemical conversion processes in the atmosphere are important in precipitation chemistry and wet deposition. Both wet and dry processes of deposition can cause

Figure 21 : The use of limestone in buildings is primarily decorative element, as a carved and lending richness, opulence and affluence to the facades of the building. Limestone remains clean but gets roughened wherever rain washing is regular. The sheltered zones collect dirt and often a sulphate crust is formed. Maintenance could significant overcome this problem in sheltered zones.

significant deterioration of the exposed stone work, *Fig 21*. Wet deposition imposes sudden but infrequent doses of pollutants, most of which are in a dilute solution. Dry deposition is slower, but a more continuous process than wet deposition. Rate of deposition by dry mechanism is intimately related to the air quality in the immediate vicinity of the receptor surfaces. It is always possible that the precipitation will wash off the materials previously deposited by the dry process. Both mechanisms will be at the maximum when the concentration of pollutants is high in the air.

Stains and graffiti

Stains are a result of deep penetration of colouring agents into the stone pores, unlike soiling which occurs on the surface of the stone. Specialist techniques remove stains without reacting chemically with the stone. Porous masonry is susceptible to colour staining, the main causes being due to metals (iron, copper, bronze), asphalt, tar, *pan*, smoke, oil, grease, bird droppings and organic growth. Surface runoff from rain carrying acids get absorbed by the masonry below, where it can cause coloured stains and decay. Copper and bronze are corroded by water, acid rains, organic acids, and salts such as chlorides, acetates and ammonia. The surface runoff initially stains the masonry green later turning it black, *Fig 22*. Water marks due to rising dampness causes staining of the masonry at the bottom courses

Figure 22: Metal staining the masonry
(a)iron stains
(b) copper stains

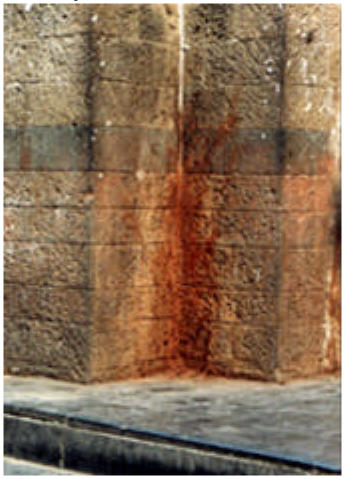


Figure 23: Pan staining of masonry

Figure 24: (a) Graffiti, using nails is

Figure 24: (b) In the case of paints, the pigment solvent which is absorbed in the pores is very difficult to remove.

of the stone masonry. Post-fire black soot deposits, post-cleaning stains and residue need to be removed. Vandalism in the form of *pan* spitting, and graffiti is a cause of unsightly and often irreversible staining,*Fig 23, 24(a) and 24(b*).

Watermark – The Stains over yearsof repeated dampness is nearlyimpossible to clean. This underlinesthe need for periodical cleaning aswell as preventive maintenance.

Coatings

The coatings on the stone surface can be in the form of lime wash and coats of synthetic paints. Synthetic coatings act as an impervious layer trapping the moisture within the masonry, causing condensation and salt crystallisation, *Fig 2*5. The surface finish of stone also governs the pattern of soiling. Textured or highly decorated surfaces are susceptible to soiling. Plain and smooth surfaces are less vulnerable to soiling and staining. It is also difficult to clean masonry with elaborate surface finishes or highly decorative facades.

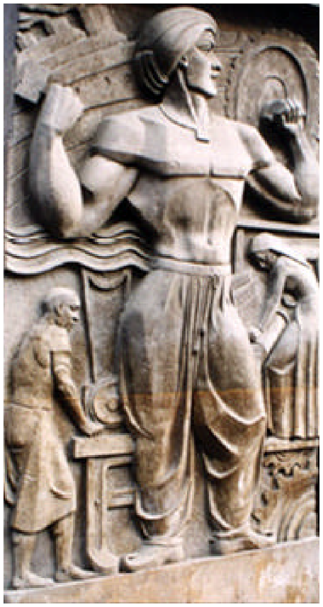


Figure 25: Protective synthetic surface coating causing discolouration of stones/facade

STONE DECAY

Decay of stone is the final stage in the deterioration of the stone surface. Stone soiling and staining, for various atmospheric pollutants and corrosive agents also contribute to the decay of the building facades. The constituents of the deposits on stone include mineral particles, industrial and household waste products and animal and vegetative matter. The decay occurs when the buildings are exposed to the polluted environment without maintenance and care for years together.

Black crust

Black crusts observed in flat highly exposed surfaces are due to slow deposition of uniform thickness. The crust in the sheltered areas is hard, rough and porous in appearance. When the crust comes off a new layer of stone is exposed to the environment and the process of formation of a new crust along with other associated processes is reactivated.

Sulphonation

The dark crusts on stones are associated with extensive deterioration of the calcareous component of the stone. This includes gypsum and carbon particles while calcite, quartz and metal oxides are also frequently found. Calcium oxalate found in the crusts is associated with the presence of lichens, whereas calcium and potassium phosphates occur, in association with pigeon droppings. In the deterioration process, iron particles both on the surface and in the air play a catalytic role in the transformation of sulphur dioxide into sulphuric acid that converts calcium carbonate into gypsum. Airborne particles and gaseous pollutants – airborne clay, soot, tar, and flyash particles are deposited and incorporated into a crust, which is in a state of continuous transformation. When these substances come in contact with a calcite surface, some solids dissolve and as the water evaporates crystals of the soluble salts are formed. With periodic wetting and drying cycles, the gypsum crystals are repeatedly etched and eroded by water due to their high solubility.

This gypsum crust can thicken infinitely though with a decreasing rate of growth and can be harder than the underlying strata. These differences in the chemical and physical properties accelerate deterioration. Gypsum, formed by the total or partial substitution of calcium carbonate by calcium sulphate, occupies greater volume than calcium carbonate leading to micro cracks on the surface accompanied by expansive stresses. The black layer of soot, which absorbs larger amount of radiation, further increases the difference between the thermal expansion of the crust and the stone surface. The surface crust reduces the permeability and increases the water retention in the stone. Presence of organic matter in the crust encourages the development of micro-organisms which cause further breakdown of the stone.

Soluble salts

The soluble salts present in air sprays, dirt, or atmospheric pollution directly or indirectly speed up the process of stone decay. Evaporation of water causes the crystallisation of the soluble salts. This occurs on the surface due to low rate of ventilation where the evaporation rate is lower than the replacement of water or just beneath the surface of the stone when the surface evaporation takes place in a relatively short time. The common salts present in efflorescence include sulphates, chlorides, nitrates and carbonates. The conditions which govern the process of crystallisation depends to some extent on the nature of the salts present but also on the texture of the material and the conditions of evaporation.

Chapter III

Stone Cleaning

The main objective of cleaning masonry is to preserve the inherent fabric of the building and improve its aesthetic appearance. Various processes available for cleaning differ widely in their ability to remove soiling/staining and to inflict damage to the masonry. Having established the need to clean in the previous chapter, the wide range of processes available and their suitability is briefly discussed in the present chapter. Cleaning masonry is not an easy task as it involves

Figure 26: Opera House Mumbai: a case for cleaning as a part of the restoration/ reuse plan

Stone cleaning in context of heritage buildings in Mumbai

Figure 27: The differential soiling is due to different material. The portion of the building on the left is Kurla basalt and on the right is cast stone. Soiling can add substantially to the structure and architectural value of the building. A case for not cleaning.

not only knowing how best to clean but also why one should clean, or not clean a building.

The practical reasons for stone cleaning revolve around the health of the fabric, the nature of soiling and its effect on the substrate. A balanced approach to stone cleaning should also involve the future performance of the masonry after cleaning. The nature and the degree of cleaning ideally depends on the building type and use, the health of the masonry and the desired results from the process.

The frequently asked question, "Why clean?" is based on the philosophical and the practical issues pertaining to the health and the aesthetics of the building. There are questions raised regarding the practice of cleaning of stone facades and the potential alteration of the masonry surfaces through cleaning. A balanced view taking both into consideration is crucial, *Figs 26* and *27*.

The main reasons for cleaning buildings are connected with restoration, surface preparation, further appearance and maintenance. Cleaning forms a part of the restoration programme including replacement of the decayed material, repointing, repair, etc. Sometimes it is necessary to carry out preliminary cleaning in order to determine the condition of the building, identify the constituent materials, expose the architectural detail, and to identify the best cleaning method. Cleaning is an essential process for the preparation of the surface that is subsequently to be treated. Masonry that is to be sealed, waterproofed, consolidated or painted must first be cleaned before the required treatment is applied. Cleaning is also undertaken to improve the appearance of the masonry or structure, as dark coloured, grimy, sooty, streaky and encrusted walls with graffiti are unsightly. General soiling may give the building a dull, uniform appearance. However, the degree to which it needs to be cleaned is a matter of judgement. Any improvement in appearance must be balanced against possible damage and cost. Cleaning is the most aggressive treatment received by masonry. Regular maintenance is a process which should include regular cleaning. However there is no general rule and any decision on regular cleaning must depend on the prevailing conditions, type and nature of the masonry and the environment in which it exists.

It is best to develop an understanding of the following before deciding to clean a building:
- masonry — its materials and its condition
- soiling — nature and effect on the material below
- attachment of the soiling to the substrate
- limitations of the cleaning processes and likely damage
- the finish to be achieved.

In conservation of a stone wall the causes for deterioration must be eliminated, or appropriate measures taken to protect the stone. In the process of conservation of the stone the following sequence is generally followed: inspection and diagnosis, preconsolidation, cleaning, consolidation, surface protection, reconstitution and maintenance.

Inspection and diagnosis: Exhaustive study of the deterioration processes provide the information base for intelligent and sensitive intervention to the building fabric, *Figs 28* and *2*9. Documentation of the building before the commencement of work is a pre-requisite for any conservation work.

Figure 28: Collection of soiling from the surface of the building stone

Preconsolidation: This is the superficial consolidation of stone and is applied before cleaning in cases of advanced decay where the cleaning could cause considerable and irreversible loss of the fabric.

Stone cleaning in context of heritage buildings in Mumbai

Cleaning: This is mechanical, chemical or physical removal of weathering crusts and dust deposition on the surface.

Consolidation: This is in-depth treatment of the friable masonry. It consists of impregnation of the weathered stone surface and the surface underneath.

Surface protection: This consists of the application on the fresh unweathered stone of a superficial film that acts as a barrier to rain and atmospheric pollution. This layer is applied after consolidation to extend its effectiveness. This step can be avoided if the stone surface, though eroded, is relatively sound.

Reconstitution: This is the reassembly of the parts of the old, consolidated stone by means of adhesives, or even substitute parts made of new or artificial stone. Ideally, substitution of the old fabric by new should be undertaken only after every other possible effort has been made to preserve the masonry.

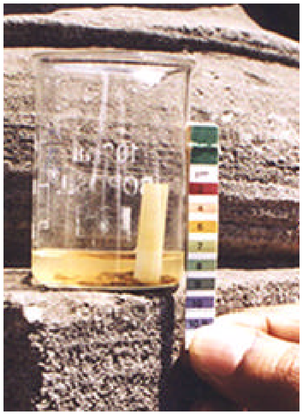


Figure 29: On-site testing of the pH of the soiling

Maintenance: Due to inappropriate past interventions and irregular maintenance, it is necessary to make major interventions in most cases to get the maintenance cycle back onto the right footing. The main aim of maintenance is to prevent further decay.

Theoretically, cleaning should remove soiling and leave the stone substrate intact. This, though difficult to achieve, remains the main aim of the cleaning process. The prime function is to enhance the durability of the stone surface by removing the soiling. The basis of the need to clean can be classified as aesthetic and good health of the substrate. Soiling alters the appearance of the building. Initially soiling, can positively contribute to the character of the building. Moderate soiling obscures the architectural details of the building. Heavy soiling causes uniform darkening of the facade with the soiling pattern completely obscuring the details of the building.

Heavy soiling is not only an aesthetic problem, it is also a major source of decay. Aesthetics, though important in the decision making process should not form the sole criteria for cleaning. Cleaning makes contributions towards the enhancement of the appearance of the building provided the historic character is retained. It is an attempt to upgrade rundown historic areas in order to revitalise them. Post-cleaning problems of staining, exposing of insensitive past interventions, etc should be taken into account before cleaning is undertaken.

CHOICE OF CLEANING TECHNIQUE

Improper cleaning can result in irreversible damage to the stone surface and heavy losses of material both of which are undesirable for the conservation of historic buildings. Cleaning techniques need to be carefully selected to minimise damage and loss of fabric. These must not cause direct or indirect harm to the stone surface, must permit the preservation of the patina and must not generate by-products which affect long term conservation. The degree of adherence to these criteria would depend on the value and the cultural interest of the building. The cost factor should be considered as secondary to the health of the stone surface.

Various parameters of the technique, *e.g.* speed must be independently controllable to permit selectivity during the cleaning process. After cleaning, the stone must be clean and smooth, free of crevices, pitting, etc.

Cleaning methods must be determined individually for each case. This is because of the different chemical and physical properties of each type of stone and specific weathering and soiling conditions. Other factors, like the mineralogical structure of the stone, porosity, state of deterioration, the constituents of soiling and its attachment to the substrate, also need to be considered.

In context of the historic buildings of Mumbai, masonry materials can be divided into:

• Stones entirely or partially acid-soluble carbonates or calcereous stones, such as limestone. These are normally cleaned with water and non-acidic chemical compounds.
• Stones composed of acid resistant materials such as basalt (although strong acidic cleaners can etch and seriously disfigure the surface)
• Cementitious products, including lime mortars and pointing.

It is acceptable that an old heritage building will be given an appropriate appearance and made neat, tidy, clean, attractive and durable. But the main principle of conservation is to conserve the heritage, preserve history and the salient features of the building. The 'neat and tidy' syndrome, which aims at making an old building clean and new is an indicator of the lack of understanding of conservation. Most old buildings in urban areas, with increasing pollution and poor maintenance, benefit aesthetically from cleaning during restoration/reuse as the unsightly blemishes are removed. After cleaning, the architectural unity may be returned, valuable details and colours revealed but the tendency for excessive cleaning must be checked. The improvement due to cleaning may be disappointingly brief in polluted urban environment. Also the use of an aggressive cleaning method on a building in such an environment is not good practice as repetition of cleaning causes damage to the fabric.

SURVEY OF THE BUILDING

Cleaning is a scientific and a technical process which requires skilled operation and strict supervision. It must be preceded by a careful survey of the building to identify the type and the condition of the masonry and the degree of the soiling in order to determine the desirability and extent of cleaning. This is followed by a survey to determine the best method of cleaning, assessment of the stone repair and critical judgement of the appearance of the building after cleaning.
The process of cleaning involves the following stages.

Facade survey

This involves the inspection of the stone type through visual inspection for identification of colour, grain size, banding, etc as observed through a hand lens. Next, is the assessment of the extent of deterioration, such as scaling, exfoliation, granulation, and soiling by algae, lichens, pollutants, efflorescence of the masonry. These investigations are crucial in deciding how to clean the surface. Localised problems should not deter the overall assessment of the condition of the facade. The design of the facade, poor maintenance and insensitive interventions should be given due consideration as these contribute towards further decay and soiling of facades.

Analytical investigations

The scope of these investigations include testing of the inherent qualities of the masonry units and the nature, attachment and the thickness of the soiling. These investigations include sampling and laboratory analysis.

Sampling: Samples should be taken from areas reflecting characteristic as well as localised decay and soiling. The location of these samples on the structure and their relationship to any failures or detailing must be noted. The samples must be carefully packed and labelled with all the relevant information. Ideally, the larger the number of samples, the more accurate will the testing be. However, limitations on the number, size and the location of the samples will be governed by the aesthetic integrity of the masonry. A small number of carefully considered samples can generate an adequate database provided the proper preparation and analytical techniques are carried out.

Laboratory analysis: While simplified analysis may be carried out at site to assist in sampling, detailed investigations need to be carried out in the laboratory. These investigations include physical, chemical and petrological analysis of the collected samples.

Physical analysis: The main external cause of decay and soiling as identified earlier is water. This is testing of the characteristics which govern moisture movement, *e.g.* capillarity, porosity, etc. This is important as water is identified as the main cause of decay and soiling.

Capillarity determination: This is calculated by the uptake of distilled water by the stone sample through surface contact with a wetted absorbent pad in similar conditions. The amount of water taken up is calculated against the dry weight of the sample, and a capillarity curve plotted and the capillarity coefficient for the sample determined.

Porosity determination: The effect of water within the stone depends on the pore structure of the sample. Two methods are used to determine the porosity of the stone sample. The first involves water uptake at atmospheric temperature and pressure. These tests are carried out under controlled immersion and saturation of the sample. An alternative method is by forcing mercury into the sample (mercury porosimetry), the amount of mercury intruded and the force required are indicative of the volume of the pores of the sample.

Chemical analysis: This analysis is carried out to determine the water soluble, acid soluble and the solvent soluble content of the stone.

Water soluble content identification: Analysis for the cations and the anions of the main classes of soluble salts known to inherently exist in the masonry or absorbed need to be carried out. The soluble salt content in the stone determines the porosity of the stone. The techniques are atomic absorption and inductively coupled plasma spectroscopy and ion chromatography.

Acid soluble content: This is relevant to stones having a calcareous content toassess its response to the environment

Solvent soluble content identification: This is mainly directed to the identification of the nature of the soiling due to pollutants.

Careful interpretation can provide valuable data regarding the materials and their degeneration.

Petrological analysis: This entails the careful examination of the sample in thin section using a polaroid microscope to identify and classify the stone type and determine the extent of deterioration. However, there will be limitations in magnification and resolution. This analysis, preferably needs to be supported by scanning electron microscope (SEM) and/or X- ray diffraction (XRD). Where the stone type is already identified, it is still advisable to confirm and report any variations.

On-site cleaning trials

Test cleaning of patches of masonry is good practice for finalising the programme for stone cleaning. Discreet locations which show characteristic staining on the masonry can be used to try out the various options for cleaning, *Fig 3*0. This helps in finalising the specifications and gives a realistic picture of the cleaned appearance of the building, very crucial in deciding whether to clean or not to clean.

Stone cleaning in context of heritage buildings in Mumbai

Specifications

Based on the survey and the results from on-site trials, choice of cleaning technique can be made. Before commencing with the task of cleaning, detailed specifications should be given to the contractors for carrying out the job. This will minimize damage to the fabric and ensure desired results.

Application

Once a suitable technique is identified it should be applied by skilled operators and the work closely supervised. Surface protection and consolidation of the vulnerable areas need to be carried out before the onset of cleaning. Adequate surface repair and treatment normally follow the cleaning process.

Figure 30: On site cleaning to test the appropriate method

Monitoring

It is crucial to monitor the performance of the cleaning technique, namely, its success or the failure and its long term effects. This could serve as useful information (data base) in further developing skills in stone cleaning and improving techniques.

CLEANING METHODS

Knowing the type of soiling is necessary for the selection of the appropriate cleaning programme. The cleaning methods can be broadly classified as washing, chemical cleaning, abrasive cleaning and special techniques.

Before cleaning, surface preparation of the masonry needs to be done. This includes:

(i) Sealing and packing openings with removable masking, or repairing all defective jointing and other openings in the work areas to minimize water, dust or solvent infiltration of the masonry surface.

(ii) Dry brushing and, if necessary, scraping all large accumulations of foreign matter from the masonry. Moderate pressure (50 lb/m ^{2}) dry air blasting can be used to remove all loosely attached soil and dust before starting on the main cleaning operation.

(iii) Thick encrustations can be presoaked to soften the soiling and the dirt accumulations.

Abrasive techniques

These techniques involve the use of mechanical force through handheld or mechanised equipment. Physical force or abrasion removes soiling from the substrate but in the process some of the fabric is also removed. The quantity of the material removed depends on the severity of the abrasive process and the susceptibility of the masonry damage by impact. The thickness and the attachment of soiling to the substrate needs careful analysis to avoid undesirable loss of material. Abrasive techniques are usually useful in the removal of soiling that is not water-soluble. Some of the common abrasive techniques are briefly described below.

Dry brushing: This is the simplest form of abrasive cleaning ideal for the removal of loose or lightly attached material like dust, and lined up moss lichens. Natural fibre, phosphor bronze and nylon brushes can be used to dust off the soiling. Stainless steel brushes should be avoided because the hardness of the bristles should be less than that of the stone. The shape and size of the brushes is also important as is the force with which they are used.

Dry abrasive techniques: A wide range of abrasives and equipment (including nozzle types) ensure selective application. However, there is high probability of damage to the stone. This technique can be reasonably applied to large plain surfaces but carved and decorative surfaces can get eroded. High skill is required for operation as inconsistent use can produce gun-shading or mottled effect. The operator requires to evaluate the effect on the soiling and the substrate during cleaning. There is high risk of dust penetration into the building and the cracks in the stone. After cleaning the treated surface needs to be pressure rinsed to remove the spent abrasive. The technique avoids the associated problems of saturation like staining or internal damage ,but requires extensive protection of the surfaces and is a considerable health hazard to the operator.

Micro abrasive techniques: This was developed for curatorial purposes and is increasingly being used for cleaning buildings. Very fine abrasives like aluminium oxide, sodium bicarbonate, silicon carbide, glass beads and crushed glass are ejected from pencil guns. It can be selectively applied to suit different degrees, thicknesses and the types of soiling. It requires highly skilled operators and associated dust problems make it a health hazard. The operators need to be adequately protected. This is a slow and gentle type of abrasion.

Wet abrasive techniques: This is an adaptation of the dry abrasive technique to reduce the free dust. Small amount of water is introduced into the air/abrasive stream to reduce dust; alternatively water and abrasive are mixed at source. The water reduces the impact making it a gentler technique than dry abrasive. This also reduces the quantity of free dust in the air, however the mist created is also a health hazard. The slurry deposited on the surface requires extensive water rinsing and the collection of the spent abrasive is difficult.

Abrasive techniques are generally harsh although the abrasive action can be largely reduced by the use of water, finer abrasive particles and custom made guns.

Stone cleaning in context of heritage buildings in Mumbai

Suction blast technique

Suction blast is a technique that works on the principle of suction. Dry blasting using suction has been successfully used for cleaning limestone. It is a relatively slow process. A higher grade of sand (quartz sand) is normally selected to avoid dust pollution. A gun is designed to facilitate adequate and precise flow of sand and air. The technique has worked well on Kurla basalt due to the hard nature of the stone but conventional sand blasting is preferred as it is faster. Suction blast is an ideal cleaning method for small delicate jobs and is very effective for cleaning limestone.

Water-based methods

These are useful to remove soiling which is bound to the substrate by water-soluble compounds. They can be applied in the form of sprays, poultices and pressure through lances. Water serves to soften the soiling which can later be removed by brushing. Brushing and scraping can be used for the removal of the heavier encrustations. These are often used in association with other techniques as well in the form of pre-wetting and rinsing.

In the application of water-based methods it is necessary to avoid the following:

- avoid unnecessary saturation of the substrate, the amount of water needs to be controlled
- penetration of water into the masonry joints and cracks which would lead to associated problems, *e.g.* rusting of iron dowels, damage to the interior, efflorescence, staining and decay of timber, etc.

It is essential to ensure that the water is free from iron salts and adequate provisions for the protection of the masonry are undertaken. Friable masonry is vulnerable as it can be washed away with water. The soiling on the entire facade may not be of a uniform thickness and localised interventions in the form of pre-wetting, poulticing and scraping to reduce the soiling thickness may be instead resorted to.

Figure 31: Misting with water.

Water spraying: Water is applied through a jet to ensure even wetting. Hot water is more effective to remove greasy and impervious soiling, for example, gypsum-based soiling. **Intermittent nebulous spraying** is a mist of water that is applied from a series of special fine nozzles to wet the soiling, *Fig 3*1. Excessive saturation of the masonry can be avoided by using this technique. **Pressure water washing** using low and high pressure lances can be used on areas of severe and deeply engrained soiling. For each surface, the maximum acceptable pressure cannot be exceeded. High-pressure washing cleans by cutting and there is insufficient time for the softening effect. The pressures are specified at pounds per square inch (psi).

Type of pressure	*Pressure (psi)*	*Damage*	*Cleaning ability*
Mains to very low	3.62	low	low
Low	15.93	low	moderate
Medium	15.93–31.86	damage to sandstone and limestone	moderate to high
High	31.86–42.00	damage to all but granite	high
Very high	42.00–579.29	damage to granite	high

The cleaning (and the erosive) power of the jet depends on the pressure, flow-rate,jet diameter and shape, and the distance from jet to the stone surface to be cleaned.

Steam: Steam generated on site is directed against the masonry. Steam and condensed water soften and swell the dirt deposits which can be flushed from the surface by the pressure of the steam jet. This technique is good for highly decorative work, softening oil and greasy/tarry surfaces, killing mould and algae and removing chewing gum and crayons. However, the operation and the application remain to be a problem due to poor visibility and the risk to the operator involved.

The main problem associated with water-based methods is flooding. Since water is associated with most decay mechanisms, flooding can cause vast damage to the stonework. Various techniques have been designed to minimise flooding and to maximise the effectiveness of the water-based techniques. Mist cleaning has been found to be particularly effective on the basaltic stone buildings in Mumbai.

Detergents

Detergents or other surfactants work by reducing the surface tension of water by making the hydrophobic (water repelling) surfaces act as hydrophilic (attracting water). Soaps are often not used in masonry cleaning, as they are rendered insoluble by the calcium ions invariably found in masonry and hard water. Once the insoluble soiling is worked loose it must be held in suspension. Detergents fulfil this function but often chelating agents (see below) are added to improve its effectiveness.

Detergents can be classified as anionic (electrically positive), cationic (electrically negative), non-ionic (electrically neutral) and amphoteric (either positive or negative depending on the pH of the solution). In masonry cleaning non-ionic detergents are preferred since they generally give better wetting. The non-ionic detergents help in the removal of lightly attached particulate matter by reducing the adhesion between soiling particles and the substrate masonry beneath. The usual after effect of this technique is patchy appearance on the masonry due to staining caused by water.

Chelating agents

These are used to remove metallic stains from the masonry by combining chemically with the metallic ions to remove them. They are molecules that co-ordinate metal ions in two or more places. The metal ions become attached to the chelating agents as a central part of the molecule, forming a metal complex that may either be soluble or insoluble in the solution. Proper control of pH is also very important for effective use of chelating agents The most commonly used chelating agent is ethylenediamine tartaric acid (EDTA) and its derivatives.

Surfactant cleaning

Surfactants are usually combined with other methods of wet cleaning to assist in overcoming the surface attraction that exists between the masonry and the soiling.

Chemical processes

The use of chemicals for cleaning requires close supervision as wrongly selected or used chemicals can cause irreversible harm to the masonry. Surfactants and emulsifying agents can be added to increase wettability and reduction in the surface tension.

Inorganic acids and acid salts react with the soiling and dissolve them. Some common examples are:

Hydroflouric acid (HF) based: Low concentration of HF acid is applied on pre-wetted surface of stone. It requires a relatively short dwell time and a thorough rinsing after use. The acid should not be allowed to dry on the surface. Reapplication is preferred in cases of thick and stubborn soiling. This method is used for cleaning sandstone, brick and unpolished granite surfaces. It is however not suitable for limestone, marble, lime-based mortars and renders as it may leave other soluble salts as residue. Streaks can be caused by uneven application and running of the chemical in the areas below. A high level of protection is required in those areas where the acid is not to be used. There is a high potential for chemical and physical alteration and retention in porous stones. It is frequently applied after a alkaline degreaser. It is also hazardous to the operator.

Another common acid used is *hydrochloric acid (HCL).* This is not recommended for general cleaning due to uncontrollable effects that generate stains, salt formation and change in colour of the stone. There is a obvious yellowing in stones containing iron compounds. Localised deterioration can occur due the residue remaining on the surface. It can however, be used for localised applications for the removal of lime-based stains. It must be applied on a pre-wetted surface which should be thoroughly rinsed afterwards. Careful handling and usage of the acid is essential.

Among the organic acids, there is an increasing use of acetic acid and its derivatives for the neutralisation of surfaces due to the high solubility of the salts produced. It cannot achieve further cleaning.

Alkali-based agents: Low concentration applications of alkali-based chemicals are made on thoroughly pre-wetted surfaces. High concentrations, repeated application and extended dwell time need to be avoided. There is high potential for salt crystallisation damage associated with the alkaline residue. This method requires neutralisation — acetic acid-based after wash on limestone surfaces and hydrofluoric acid-based after wash for siliceous surfaces. A high level of protection is required to prevent damage in those areas where the alkali is not to be used.

Alkali-acid processes: Low concentration applications are used on moderately soiled surfaces. For limestone, the surface is pre-wetted with an alkaline-based chemical and an acetic acid-based afterwash. Sandstone, brick and unpolished granite require an alkaline pre-wash and acetic acid, or HF acid after wash. There is high probability of chemical and physical alteration of the stone. This process requires a high level of operative skill and building protection.

Careful consideration must be given to using any chemicals and specialists must be consulted before finalising the treatment. The dwell time of the chemicals on the soiled masonry must be regulated. Thorough rinsing of the masonry after the application is required to wash off the residual chemicals on the building surface.

Special techniques

Poultices, packs and gels: Soiling, with limited solubility, accumulated over years and bonded to the surface of the stone, has to be subjected to longer soaking/ wetting before attempting to remove it. A poultice acts as a sacrificial surface that holds the solvent in close contact with the soiling and draws the soluble material from it. The main requirement for a poultice to be successful is that the soiling or the binding material should be soluble in the liquid being used.

Common poultices include plain clay aqueous poultices, clay-based aqueous pack with sequestering agents, alkaline aqueous clay-based pack, alkaline gels, etc.

Sponge blasting: An environment-friendly technique is being evolved in the western countries using particles of sponge. The technique used, in principle, is the same as sand blasting, where sand is substituted with sponge particles of about 3 mm and blasted through nozzles on the surface to be cleaned. The sponge particles get compressed at impact and during their recovery to original shape also remove the dirt/grime layer leaving behind a clean surface. This technique has many advantages and is eminently suitable to Indian conditions, as it causes no damage to the dedicate details of the building. The sponge can be collected and reused after cleaning and drying. It is environment-friendly compared to sand blasting. This system is yet to be used in India.

Modern techniques

The JOS system: This is a mechanical method that removes soiling on or in the surface pores without any change in the physical and the chemical/molecular structure of the substrate. It cannot remove staining below the surface. This is suitable for brick, terracotta, limestone, and sandstone. The main advantages of this process are that it is safer to the operator and it produces a more natural effect. This technique has been successfully used to clean many buildings in England, for example, the Rotunda at Stowe in Buckinghamshire.

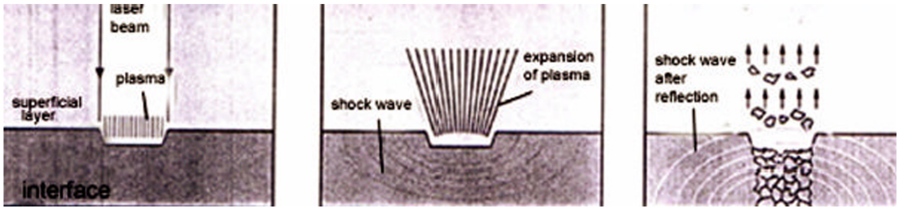


Figure 32: Action of laser beam in cleaning masonry surfaces

technique has been successfully used to clean many buildings in England, for example, the Rotunda at Stowe in Buckinghamshire.

The DOFF system: This is a patented system and uses steam and superheated water to remove any paint and other coatings, including thermoplastic and bitumastic materials without damage to the substrate. It is also said to be effective to remove algae, bird droppings and other unwanted organic matter.

Laser cleaning is the latest innovation in the stone cleaning industry. It is based on a photomechanical reaction caused by the interaction between an instantaneous high powered laser and the layer of pollutants (grease, oil, oxides, paints, varnishes, burnt residue, etc). The light impulse transforms the molecules of the pollutants layer, into a highly compressed plasma. The expansion of this plasma causes shock wave. When this shock wave reflects on the layer support interface, it ejects the pollutants as thin particles into the atmosphere. These particles can be then captured by a suction system, *Fig 32*. Once this layer is pulverised , the surface is protected against damage as there is no more interface: The shock wave is no longer reflected but only absorbed by the support.

This technique has many advantages when compared to traditional methods. It is environment-friendly since chemical solvents are not used. Further, the laser does not cause any abrasive action to the substrate, contrary to sandblasting, ice crystal blasting, or other mechanical methods,.

The laser beam, transmitted via a flexible fibre optics cable, is controlled to ensure that no damage is caused to the substrate while allowing precision cleaning up to 100 mm from the machine. A problem of using lasers for large area cleaning has been the fineness of the beam. But now with four beams being included in one machine this makes it more viable. It is generally considered that a laser using a fibre optics cable is better suited for external work while a laser beam transmitted by articulated arm is better suited for internal work.

Substantial benefits from either of the two systems in large area cleaning could be achieved if they could be fitted to the frames with the necessary mechanics and computerisation and left to get on cleaning a building manned perhaps with remote monitoring. Compared to the traditional cleaning techniques used in architectural conservation, the Q-switched solid state laser has proved to be a technically very effective cleaning tool as well a financially realistic solution. Since it possible to carry the high peak power beam within an optical fibre, and to do so with the reliability required when working under different conditions.

Italian physicists are warning that marble, like limestone, which was widely held to be safe under the laser beam may suffer damage to its protective patina. Research shows that granite and sandstone can be chemically altered at energy densities close to those required to remove the urban grime. Sandstone has been bleached and nobody knows whether it is a temporary or permanent phenomenon, or whether it affects the long-term stability of the stone.

Stone cleaning in context of heritage buildings in Mumbai

Special cleaning problems

Gypsum crust removal

Gypsum is a common constituent of urban grime and is particularly prone to form crusts mixed with soot, hydrocarbons and dust on the soffits of sills, cornices, string courses and parapets. Although the material is not very hard its removal is tedious due to its poor solubility in water. This crust can be removed by using a number of methods. Prolonged spraying of water and removal by brushing is a common practice on limestone. The crusts can be removed from a plane surface also by dry abrasive techniques using metal scraper, wire brush, etc though this can be damaging to the stone surface. Gypsum is soluble in potassium acetate or EDTA which is applied with a poultice.

Paint removal

Selection of the method to remove paint depends on the nature of the substrate. However, layers of different kinds of coating makes the task complex. Old lime wash or distemper can be successfully removed by washing and scrubbing though it is difficult to get rid of on rough/textured surfaces resulting in a spotty appearance.

Layers of oil paint need a vigorous chemical treatment which is preferable to abrasion as the latter damages the masonry. Commercial paint strippers may be effective on some surfaces.

Graffiti removal

Graffiti is written on the stone masonry using paint, spray, crayons, etc. The removal technique depends on the medium used for writing the graffiti and the stone substrate. Chemical methods of removing graffiti are normally preferred and wet or dry sand blasting is used as the last resort. However, the use of some acids may fix the stain more firmly and deeply. Faint residual staining may be treated with a bleach.

Salt removal

Salts, mainly chlorides, sulphates and nitrates of sodium, potassium, ammonium, magnesium and calcium deposited on masonry need to be removed as they accelerate decay and prevent remedial treatment. Surface salt can be brushed off as a dry powder and the salt level reduced by continuous sprinkling of a fine mist of water. Continuous wetting of the surface may cause deep penetration of the salt which may emerge on the other side of the masonry.

Stain removal

To remove iron staining the general principle is to reduce the compound from a ferric state to ferrous state (from insoluble to soluble) with a reducing compound (bleach). A poultice of ammonium or aluminium chloride with little liquid ammonia in water thickened to a paste with talc is very effective in removing bronze staining. Copper stains can be removed by any of the following methods:

(i) ammonia or ammonium chloride plus ammonia, as a liquid or poultice
(ii) 10 percent formic acid
(iii) caustic soda, plus detergent, sodium boroglucate, sodium ethylene diamine
(iv) 0.2 percent hydrofloric acid for a few minutes
(v) 10 percent aqueous sulphamic (amidosulphuric) acid followed by alkali treatment for neutralisation and intensive final washing.

Common defects associated with cleaning

Given below in table form is the common defects associated with cleaning

Method of cleaning	*Defect*	*Cause and notes on avoidance*
Washing, wet blasting pressure lancing	Tarry stains	Formed during wetting or drying out of pores can be reduced by avoiding prolonged saturation and by further washing; some tarry staining unavoidable
	Dry rot	The results of penetration can be minimised by careful sealing of all open joints and cracks before cleaning and
	expansion rust	Taping and sheeting all openings. watersheds and catchment sheets on rigid support with falls to gullies will flooding avoid flooding risk
Dry basting	Pitted surface	Wrong choice of method on soft stone, or careless operator, or the use of too much abrasive
Wet blasting	Blurred arise, Gun shading	Erratic movements of blasting gun leaves a mottled effect, slight appearance often unavoidable, pronounced appearance due to inexperienced operator
protection,	Blasted glass	Careless use of the gun and inadequate window glass should be coated with peelable protection
	Slurry deposits and film	All dust deposits and slurry should be hosed or jetted off.
Hydrochloric acid	Brown stains	Stone with high iron content acid combined with rust inhibitor should be used
	Etched glass	Lack of protection, or if occurring after cleaning, due to acid vapour on scaffold peelable plastic coating should be used on glass and scaffold boards washed and lifted, scaffold tubes should be sealed.
	Pavement staining White bloom	Splashes of acid not neutralised and washed away acid left too long very difficult to remove

Stone cleaning in context of heritage buildings in Mumbai

Alkali washing	Efflorescence	excessive number of applications used carelessly or wrong use on too porous a material
	Streak staining	First wetting and application carried out from top to bottom risk can be reduced by working upwards
Mechanical	Scour marks	Lack of skill or wrong use of method on moulded stone, can be improved with hand rubbing
	Wavy arises	Lack of skill or more probably wrong choice method on carved or moulded work

Source: Society for the Protection of Ancient Buildings (SPAB), Technical pamphlet 4, Cleaning Stone and *Brick* by John Ashurst.

Cleaning masonry is a complex and expensive task. Selection of the method depends on the nature of the masonry, degree of weathering, the type of soiling, degree of cleaning required, the health and safety considerations, requirement of time and costs. An inappropriate cleaning procedure will be ineffective, causing irreversible damage. Combination techniques may be a better idea than using a single technique.

It must also be remembered that removal of soiling without affecting the masonry substrate is very difficult. In developed countries, cleaning of historic buildings is a very advanced discipline and involves the use of state-of-the-art technology. In India the options for cleaning buildings are limited and it is not advisable to use the experiences abroad without detailed investigations and research of conditions in India. The selection of a cleaning technique depends on three variables:

- the degree of resistance
- the tenacity or the degree of difficulty of the removal of the soiling
- the cleaning ability of the method.

The interactions encountered in cleaning are very complex. The cleaning method must be carefully chosen for each location, taking into account the risk factors involved, the desired effects, the labour input and costs. Not cleaning at all should also be considered as one of the options while selecting a cleaning process. The table below shows the suitable cleaning techniques for various building materials. This is only indicative of the suitable method and

Figure 33: Preservative treatment — Surface coating

cannot form the only basis for the choice of the cleaning technique.

Suitable cleaning techniques for various building materials

Cleaning method	Acid soluble limestones, marbles, calcareous sandstones, sand-lime bricks		Acid resistant granites, siliceous sandstones, bricks, terracotta	
	soft	hard	soft	hard
Washing pressure jet	No	Yes	No	Yes
Nebulous spray	Yes	Yes	Yes	Yes
Acidic cleaners (formulations of acid surfactants, chelating agents)	No	No	Yes	Yes
Alkalies**	Yes	Yes	Only after test application	
Organic solvents**	Yes	Yes	Yes	Yes
Poultices	Yes	Yes	Yes	Yes
Chelating agents	Yes	Yes	Yes	Yes

**Certain limestone and shales may contain organic residue of bituminous or oily nature; such materials should be carefully tested before using organic solvents and alkalies.

Source: Conserving buildings : a guide to techniques and materials

POST-CLEANING TREATMENT AND MAINTENANCE

During cleaning it is likely the mortar between the masonry units gets eroded, thus repointing and some surface repairs and consolidation may have to be carried out. These items should form part of the cleaning process as later cracks and friable masonry can accelerate the deterioration process of the masonry.

As water is considered to be the major cause of decay and soiling, it would be logical to apply surface protection to the masonry after cleaning and surface repair, *Fig 3*3. The main objective of these treatments is to enhance the durability of the masonry. The success of these treatments depends on the following:

- effectiveness in resisting the processes from which protection is sought
- deep penetration and long lasting effect
- ease of removal from the masonry
- no negative side effects or long lasting effects like discoloration, darkening of stone, decay, etc
- time tested techniques.

Surface treatments are of two kinds—waterproofers and consolidants. Both work by filling of the pores of the stone with water insoluble deposit reducing the permeability of stone. Water and consolidants are used in an attempt to minimize the rate of stone decay and the strengthen the decayed stone. According to the Venice Charter, reversibility is the main criteria for selection for intervention to built fabric, however often difficult to achieve.

Waterproofers are normally used to prevent or reduce the entry of water onto the masonry exposed to rain and vulnerable to penetration, salt damage, etc. The prerequisite for application is dry masonry. Consolidation to help restore the strength of friable areas to resist the weathering agencies, must precede waterproofing treatment. The causes of failure of such treatments are generally attributed to shallow penetration. Moisture trapped behind the waterproofing layer evaporates rather slowly causing the crystallisation of salts causing spalling and powdering of the surface. Difference in the thermal movement properties of stone and the film can result in damage to the coating. Preservative treatments to control the growth of organic soiling are also available.

Figure 34: Application of improper surface protective systems which prevent beathing of the masonry.

A number of surface treatments are available and new ones are constantly being developed. Care must be taken in selection and test trials are strongly recommended, *Fig 34*. Consolidants currently in use include acrylics (both monomers and polymers), alkyl-trialkoxy- silanes, aryl-akyl- siloxanes, ethyl silicates, epoxy resins. The choice whether to use a surface treatment after cleaning is purely a matter of discretion of the architect. Incorrect applications and choice of the treatment can cause irreversible damage to the masonry, *Fig 35*. However, the correct use can be beneficial to the building facade.

Figure 35: Exfoliation of the stone surfaces due to failure of surface coating

CONCLUSION

Generally cleaning at regular intervals is considered beneficial. Basaltic rocks being harder and considerably inert can afford harsher cleaning methods. Preservative treatment in general cannot be recommended as it often leads to complications. The risks in cleaning are considerable and a flexible approach is recommended. Cleaning is a scientific operation and should always be based on careful analysis and interpretation.

Chapter IV

Impact of Cleaning Building Facades

Once the decision to clean has been reached careful consideration must be given to the selection of the cleaning method. The fabric of the historical buildings is of prime importance in conservation and particular care needs to be taken to avoid damage. The original surface of the building stone and its patina formed through natural weathering must be respected. Cleaning if not undertaken with care can cause irreversible damage through loss of fabric and staining.

Cleaning of historic buildings has been successfully employed abroad as part of the environmental improvement programme, though not without difficulties. After cleaning some buildings are seen to be pleasantly weathered, others showed signs of accelerated deterioration and increase in the maintenance, leading to further research of the effects of cleaning on stone buildings. As a result, the necessity and the desirability of cleaning is still under scrutiny and debate.

EFFECT OF CLEANING ON THE HISTORIC FABRIC

Uncontrolled stone cleaning in the past has caused severe damage to a number of historic buildings abroad. The damage has been attributed primarily to the lack of understanding of both the immediate and the long term effects the cleaning methods have on the building stone. Stone cleaning, as in a lot of cases, has been carried out in ignorance of its effect and its consequence on the stone surface. The removal of the soiling layer was generally perceived by the public, building owners and decision makers as 'a good thing' because of the belief that a neat and clean facade is a reflection of the image of the occupant and the urban environment in general. However, research conducted by Roberts and Urquhart (1995) of the Robert Gordon University, Abeerdeen entitled *'Stone cleaning and stone decay. Research Report to Historic Scotland'* conclusively proved that there is an increase in the incidence of stone decay in building facades which have been cleaned, in comparison to the stone facades which have not been cleaned. However, poor choice of cleaning techniques and of surface treatments are indicated as the prime cause.

CONSERVATION AND PLANNING CONSIDERATIONS IN STONE CLEANING

Considering the irreversible damage to the fabric by improper methods of cleaning this needs to be supervised by qualified personnel. The limitations under which cleaning is carried out also necessitates a regulatory mechanism. In most cases during the restoration or renovation of a building the budget allocation for cleaning is very small, causing the contractor to cut corners. The tendering system where the lowest bidder gets the contract, together with loosely defined specifications does not lead to quality workmanship.

Contributions to the urban conservation

Cleaning has a considerable impact on the visual appearance of the building so thatits richness of details, quality of materials, massing and style can be appreciated. If used sensitively it can contribute positively to the aesthetic appeal of the building. Thus in a historic precinct, it can positively influence the visual perception of the built environment encouraging urban renewal. This reinforces an increased interest in the built environment through broader trend of reinvestment in the area by the increase in the real estate values in the area. In the urban context, cleaning usually forms a part of the refurbishment, rehabilitation, conversion, restorations and even facade retention.

The perceived age of the buildings is significantly altered by cleaning. Stone cleaning makes a building look younger, *Fig 3*6. If undertaken on a number of buildings in the area it might lead to a false sense of the age of the area. In England cleaning requires 'listed building consent for listed buildings. For 'scheduled monuments', notice to the department of environment and also consultation with the local authorities is required when cleaning is proposed. At the city of Bath, the city council is considering incorporating stone cleaning into the regular maintenance programme for their historic monuments and housing stock.

TO CLEAN OR NOT TO CLEAN

There is considerable debate on the ethics of cleaning. Cleaning is much more acceptable today than it was earlier. This can be attributed to the development of sophisticated cleaning techniques and continued research as well as an increased environmental awareness. Soiling is just not an aesthetic problem, there is now scientific evidence that the build-up of soiling can cause the breakdown of the stone. The practical reasons for cleaning heavily soiled masonry has to be seen as a part of the general maintenance and repair programme. The opposition to cleaning primarily exists because of the way it is undertaken. Ideally buildings should be cleaned with the same care and attention to detail as in the case of art objects. But stone cleaning of building is a part of the building industry and is generally not carried out by conservationists. The practical risks in cleaning buildings can be eliminated by the use of reputed contractors who view cleaning activity as inseparable from the maintenance and the surface repair of the whole facade. In situations of

Figure 36: A comparison between cleaned buildings and one that is not

competitive tendering for the cleaning work with the obligation to award the work to the lowest bidder, it is essential to judge the capability of the contractor and provide detailed specifications for the cleaning work.While cleaning, the structural, physical and the chemical aspects of the building masonry should be treated as an integral system. It is important to bear in mind that one is dealing with the whole building and not just the facade. A thorough understanding of masonry structures, their construction technology, architectural detail and the process affecting decay of the stone is required. A detailed understanding of the nature and the mechanism of the decay process should be followed up by successful techniques of intervention. Omission or incorrect understanding of the diagnostic tests to determine the correct cleaning and consolidation methods can lead to further damage of the building. The surface has to be subjected to trial cleaning and consolidation prior to formulating the final specifications for cleaning.

Cleaning buildings can be undertaken by many processes, thus to protect the historic architecture and details from unified interventions, it is recommended to design a system for the building. In urban areas, particularly historic precincts, there is unity and consistency in details, storey height and fenestration which needs consideration. Cleaning of one building could lead to disruption of this unity. Cleaning of a historic building has often been criticised on the grounds that the 'appearance of age' is removed. Cleaning can change the 'character' and the 'distinctiveness' of the building. Some buildings due to their historical significance, or the level of soiling, or an interaction of the two, are better left in their soiled condition.

Figure 37: A certain amount of staining in somebuildings can add to the character of the buildings

A major debate can arise on cleaning a building or in leaving it to decay majestically. There are completely divergent views on the topic. One school of thought believes that there exists a correlation of stone decay to stone cleaning. Some may be justified in having grown used to seeing the pattern of soiling and subconsciously appreciate the graceful patina that gives the building its maturity and stature, *Fig 37*. In some cases, the soiling forming the patina is actually protecting the underside and removal of what is called the noble patina is undesirable, as it will expose the vulnerable interior of the stone to the aggressive environment. This is often the case with limestone and marble. Assuredly the age of the patina shall be criteria for removal. Older patina or the staining, such as watermarks on the soffits of arch, openings in wall masonry, corbelled areas and drip courses, is often more difficult to remove or control.

On the other side, stone cleaning enthusiasts and practitioners see merit in keeping the buildings in a fresh form by periodic and systematic cleaning. This is done at times to emphasise the importance of a particular building (or the owner/activity) or for perpetuating a positive urban response of proud maintenance. A case is often made for cleaning of building for the sake of a better control over the building health, for cleaning necessitates full access to the building parts facilitating a careful inspection of the fabric. Minor defects, sources of the perceived problems, structural dangers and pending repairs are made possible during cleaning operation, without which it is probably a wasteful exercise. Depending on the type of stone building, its use and the micro climatic changes it exists in, stone cleaning can be a part of long term maintenance process.

Furthermore, there is an equally conspicuous division between the protagonists and antagonists regarding the need for after-cleaning protection or consolidation and preservation of the stones. After cleaning, the rate of dust/dirt application is expected to be accelerated in the immediate post-cleaning period due to the possibly electrostatically charged surface, *Fig 38*. Also after cleaning, the real state of the stones or the archaeological monument will be known and its extent of preservation known and accepted materials and techniques can be decided upon. Replacement of stones can be an appropriate solution where the stones are degraded beyond redemption and when the purpose of restoration is more functional, than anything else. Some professionals feel that consolidation of the building fabric is more likely to cause long term damage than any specific good to the building. Irreparable damages can be caused by use of improper materials born out of insufficient understanding of the job. Sales literature of the companies that are marketing their various chemicals

Figure 38: Recurrence of soiling after cleaning

should not be totally relied on. Horrendous results have been noticed in Mumbai, where such chemicals have been used without much understanding of their long-term behaviour in the environment. Removal of these stains and residual salts can be tedious and expensive.

HEALTH AND SAFETY MEASURES

Many cleaning processes are unpleasant and even dangerous to the operator and the public. In India, adequate safety precautions are not used. Care should be taken in the handling of chemicals used in the process of cleaning, such as hydrofluoric acid, caustic soda, hydrocarbons, benzene, fungicides, etc. The application of acids is very dangerous due to high corrosivity. Instructions on medical treatment must be given to the operators and adequate first aid provisions made during the restoration. Operators should be provided with appropriate protective clothing. Suitable scaffolding for cleaning operations should be erected. Dry blasting produces a lot of fine siliceous dust which produces a risk of silicosis. Protective equipment, such as protective masks or ventilated helmets are required.

FUTURE DIRECTIONS

The field of cleaning building is ever evolving. With the development of new technologies and ongoing research, more sensitive methods are being developed. The understanding of the masonry and soiling is also increasing. The gap between conservation and the commercial considerations can be bridged by research and the provision of accurate specifications. However, one must remember that soiling of external stone masonry is inevitable. What one can attempt to do is to slow the rate at which soiling occurs and take steps to ensure good health of the masonry.

APPENDIX I:
Meteorological and air pollution data of Mumbai

Highest Windspeed and Direction
Year 1998

Month	Speed kmph	Direction
January	42	North north westerly
February	43	North north westerly
March	37	North north westerly
April	33	Westerly on 13th
	33	North north westerly on 25th
May	63	south south easterly
June	76	Southerly
July	58	South south westerly
August	48	South westerly
September	41	South westerly
October	67	South south easterly
November	66	North north easterly
December	37	Easterly

Source: Government of India, India Meteorological Department, Mumbai.

Monthly temperature, rainfall and humidity in Mumbai

Monthly temperature in 1998

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Max.	30.9	31.2	32.5	33.5	34.6	32.9	30.7	31.0	30.9	32.7	33.3	32.3
Mean Min.	17.9	18.0	20.5	24.9	28.0	27.3	26.2	25.9	25.4	24.3	21.9	18.8

Monthly Total Rainfall in mm.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1989	2.1	0.0	T	T	0.0	441.3	943.6	663.6	191.0	78.7	0.0	0.0
1990	0.0	2.8	2.9	0.0	133.4	740.5	399.0	888.0	564.8	95.1	T	T
1991	0.0	0.0	0.0	0.4	0.6	950.8	1045.7	285.4	58.7	T	T	7.3
1992	0.0	0.0	0.0	0.0	0.0	129.8	603.6	863.2	339.6	38.9	0.0	0.0
1993	0.0	0.0	0.0	0.0	T	373.5	810.6	396.0	904.6	130.1	T	0.3
1994	17.8	T	0.0	2.0	5.8	553.1	953.6	504.9	386.5	79.7	0.5	0.0
1995	1.5	T	T	0.0	T	82.2	661.5	419.4	527.5	61.2	T	0.0
1996	0.7	0.0	0.0	0.0	T	219.3	996.9	377.2	283.8	237.0	0.8	T
1997	1.7	0.0	0.0	0.0	0.0	515.2	504.1	743.3	324.3	0.0	61.1	21.8
1998	0.0	0.0	0.0	0.0	0.3	540.7	520.9	587.7	540.4	376.6	22.7	T

T: Rainfall less than 0.1 mm

Monthly Mean Relative Humidity 1998, percent

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0830 hrs IST	80	66	70	71	70	79	87	88	87	82	69	59
1730 hrs IST	56	49	53	62	65	76	83	82	81	72	59	47

Source: Government of India, India Meteorological Department, Mumbai.

APPENDIX II: CASE STUDIES

1. Cleaning of a portion of the Empire building

Project brief and details

Stone cleaning was undertaken as part of the restoration programme for a portion of the Empire building. The challenge here was the safe removal of the paint layers without damaging the limestone, a tight schedule and ensuring continuation of the activities in the rest of the building.

Condition and the soiling of the facade before cleaning

Black Kurla and white Porbundar limestone were painted with several coats of oil paint over a cement primer. Vegetative growth covered most of the surface of the facade. The facade was unkempt and worn out. The cornices were broken at several places and a lot of plaster was missing, *Fig 39.*

Choice of cleaning technique

The hard Kurla basalt was cleaned using the conventional sand blasting technique. The soft Porbundar limestone was delicately cleaned using the special suction blast technique. Suction blast was tested with success under laboratory conditions and was found to be the precise technique for cleaning this particular stone. Chemical cleaning was also tried but was found to be inadequate for the effective removal of layers of paint.

Figure 39 Before and after cleaning

Stone cleaning in context of heritage buildings in Mumbai

The procedure of cleaning the Kurla basalt was:
(i) masking the area to be blasted using suitable covers
(ii) blasting sand on limestone with suction blast machine at 2 Kg/cm
2 at a suitable angle so as to avoid damage to the stone.
(iii) Conventional sand blasting on Kurla stone at 5 Kg/cm
2 at a suitable angle
(iv) close inspection of the surface for any remnants
(v) cleaning the surface free of fine dust with water
(vi) cleaning the surrounding area.

Suction blast with a higher grade of sand (quartz sand) was selected. A custom made gun was designed to facilitate adequate and precise flow of sand and air. The result on limestone was exactly as desired. The technique also worked well on Kurla basalt but due to the hard nature of stone conventional sand blasting was preferred as it was faster.
The restoration of the cornice and finishing of the ornamental limestone followed the cleaning process. Impact of cleaning on the immediate context was considerable making a positive contribution to urban conservation. Partial cleaning of buildings is generally not recommended but this project serves as a pilot project for stone cleaning of building facades.

2. Cleaning of Bombay House

Project brief and details

Bombay House located on Homi Mody street in the Fort area of Mumbai, was designed by architect George Wittet and constructed in 1924. It is a four storey colonial structure built of dressed Malad stone with rustications on the ground floor, *Fig 40.*

The scope of the project included the cleaning of the external building surfaces, approximately 52840 metric unit along with surface repair and the renewal of the finishes. The job was started in October 1997 and completed in April 1998.

Soiling and the condition of the substrate

Cleaning the stone facade had been attempted at least once before in the past. The building is one of the best maintained heritage buildings and the owners have taken timely attention for the upkeep of the building, particularly the interiors. The heavy loading of pollutants in the atmosphere has been responsible for the soiling of the building. The soiling included grime, tar coating, oil paint, graffiti, stubborn adhesives, and growth of vegetation that was required to be removed. The southern and western sides of the building were distinctly soiled due to the prevalent wind direction and driving rain. Patches of damp areas were visible at various locations on these sides. On the ground floor the western and the southern sides were covered by glue used for sticking posters.

The cleaning process

Mist cleaning was adopted for the general surface, areas of stubborn soiling were removed using controlled sand blasting . The process for mist cleaning included:

(i) air- dusting under pressure (1kg/cm / nozzle)
(ii) misting with water under pressure using low pressure and volume from specially designed nozzles
(iii) application of appropriate chemicals in suitable dilution interspersed by brushing with phosphor bronze brushes and water rinsing
(iv) application of non-ionic soap solution
(v) misting- rinsing with water and air drying
(vi) application of mild fungicide and weedicide on the cleaned area and drying
(vii) application of transparent, antistatic, pore lining, UV resistant, hydrophobic coating in two layers
(viii) air drying.

Figure 40 A portion of the building just before cleaning. The same portion after cleaning.

The process of controlled sand blasting included:
(i) masking the surrounding areas using suitable covers
(ii) sand blasting the surface at a pressure of about 5 kg/cm 2 at a suitable angle.
(iii) second round of sand blasting after inspection of the surface to remove remnants of soiling.
(iv) washing with water to remove sand on the surface.
(v) application of mild weedicide/ fungicide and a protective coating
(vi) cleaning of the surrounding areas.

A strict supervision of the cleaning processes was carried out to ensure satisfactory results.

Post cleaning condition

Any exposed stone surface will, due to the interaction with the environment, begin to soil. Also the defects on the masonry surface will become more apparent. An inspection in March 1999, revealed that some soiling has occurred in the areas where the masonry is damp or in contact with water. Also some stains (probably iron) were observed on the surface of the stone.

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The Mumbai Metropolitan Region- Heritage Conservation Society was established on 14th November,1996 by the Mumbai Metropolitan Region Development Authority (MMRDA)
To focus attention on various environmental and heritage concerns in the Mumbai Metropolitan Region (MMR).
The Society is registered under the Societies Registration Act, 1860 and under the

The objectives of the Society are:

- Promoting preservation, conservation, protection, development and improvement of natural, built and related cultural heritage within MMR;
- Developing heritage conservation-related data base for MMR;
- Training, education and awareness in heritage conservation;
- Providing financial assistance to conservation;
- Promoting networking of various agencies in MMR including local historical societies; and
- Acting as advisors, consultants, appraisers and assessors with respect to all aspects of heritage

The Society is an autonomous body. Its affairs are managed by a Board of Governors, which is headed by the Metropolitan Commissioner, MMRDA. It consists of representatives of eminent institutions like: INTACH, Asiatic Society, concerned Government Departments, Local Authorities, NGOs and individual experts in the heritage conservation field.

MMR HERITAGE CONSERVATION SOCIETY

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