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ERADICATION OF VEGETAL GROWTH AND SYSTEMATIC SCIENTIFIC CONSERVATION APPROACH OF BALLALESHWAR TEMPLE, TRIMBAKESHWAR (INDIA)

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Abstract

This research emphasizes the impact of vegetation on historical monument of Ballaleshwar Temple, Trimbakeshwar, India and its systematic eradication and restoration strategies followed for the site. The lime mortar samples extracted deep within the rock were subjected to mineralogical and instrumental investigation using XRF, XRD, FTIR spectroscopy and Scanning Electron Microscopy (SEM). The aggregates in the mortars were subjected to extensive petrological analysis to prepare matching repair mix for restoration. It appears that aggregates obtained through Basaltic rock disintegration were mixed in the mortar preparation for the temple. Major structural conservation measures were initiated in the form of stone elements removal and its subsequent restoration with lime mortar mix.

Keywords: *Lime mortar; Vegetation; Conservation; Replication; Lime/silica; Peepal tree*

Introduction

Vegetation plays a vital role in life cycle of living organism whereas the growth of vegetation on historic structure, buildings and monuments can cause serious damage. Historic buildings and monuments are liable to be affected by a wide variety of ‘vegetation growth’ ranging from roots of mature trees that form part of design or natural landscape to micro-organisms that can grow on the external and internal surfaces of building materials [1]. The presence of biological growth on buildings often provides a useful indicator of excess moisture, and investigation about nature and extent of growth can highlight defects in the structural fabric. In some situations, plants growing against or on masonry may be of botanical or historic significance. If identified, such plants should be retained and their growth checked by appropriate methods at regular intervals. In tropical climate condition, the growth of vegetation over the historic structures causes quite serious problems as compared to a non-tropical climatic condition. Small plants may not cause serious damage to the masonry, but all the woody rooted vegetation damages the structure, hence should compulsory be removed [2, 3].

Plants can be classified according to the period of their life cycle. a) Annuals are plants that live for a year or less based on latin ‘annus’ meaning year. b) A plant that takes two years to grow from the seed to fruition, bloom and die or a plant that lasts for two years is a biennial.

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c) Perennials are those last longer for more than 2 years. Ex. Peepal, Banyan, apple, maple etc. The plants can be classified as annual, biannual or perennials depending on its life cycle and damage the ancient structures at varied rate.

The plants on ancient structures may also be classified into vascular/non-vascular on the basis of their cell structure. The non – vascular plants (smaller plants) are small, simple plants without a vascular system (Xylem and phloem. Eg. Algae, moss, lichen, liverworts, hornworts etc.), whereas the vascular plants (higher plants) are numerous plants, including the seed plants and ferns, having well developed vascular tissues consisting of phloem to transport sucrose and other organic nutrients and xylem to transport water and minerals. They are also called as tracheophyte.

Environmental factors that affect the growth of plants in the soil as well as on the monuments are light, temperature, water (humidity) and nutrition. Light is necessary for all plants because they use this energy to photosynthesize. The quality, duration and intensity of the light are essential for vegetation growth on the monuments. The low light area is not favorable for vegetation growth. Temperature plays an important role in the productivity and growth of plant on the monuments. At higher temperatures, the micro-vegetation growth is comparatively less than to warm and humid climatic regions. Water is a primary component of photosynthesis. The humid region favors more vegetation growth. For plant nutrition, the availability and type of nutrients present in the substrate plays a responsible role in the vegetation growth. The two types of nutrients categories are organic and inorganic in nature. The organic nutrients may be impurities and microorganisms present on the substrate. The minerals present on the substrate may be intake as inorganic nutrients.

Established vegetation can cause irreparable damage to historic monuments, through root system, displacement of wall fabric and abrasion against monuments due to wind action. In some cases, the extent of the damage caused by unchecked growth may eventually present safety problems for visitors and adjacent dwellers. The higher plants can cause substantial damage to masonry as their roots penetrate into the joints and cracks of the masonry (Fig. 1).

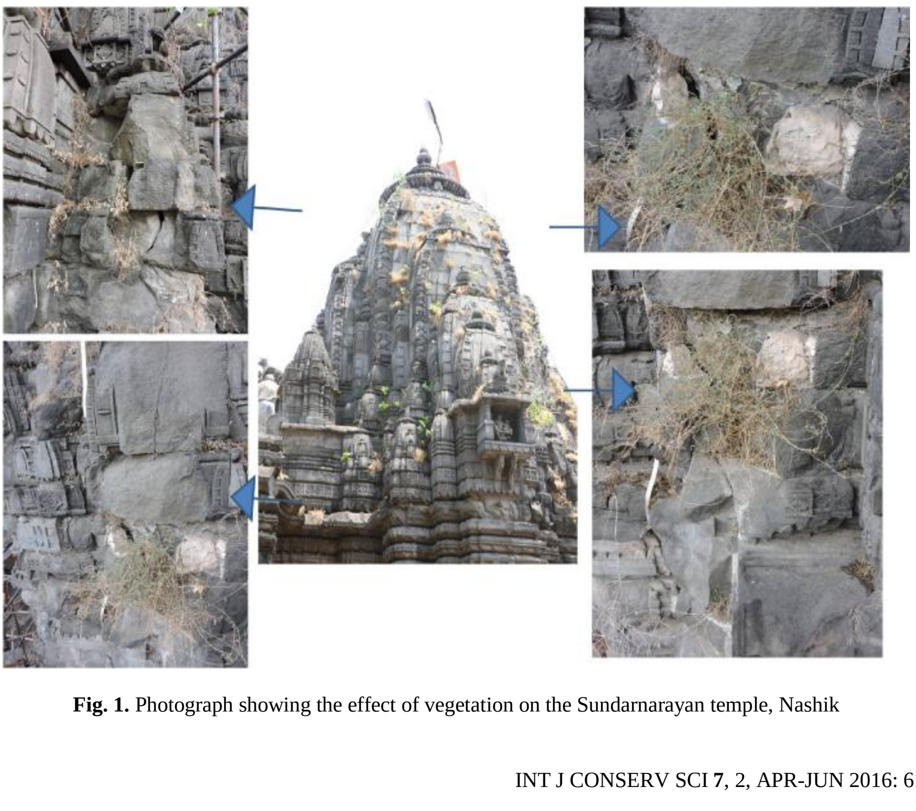

Fig. 1. Photograph showing the effect of vegetation on the Sundarnarayan temple, Nashik

Such root growth can dislodge part of the masonry allowing water penetration and leading to extensive structural problems, if ignored [4, 5]. The types, identification, properties and effects of vegetation growth are tabularized in table 1.

Table 1. The detailed properties, identification, location and effects of vegetation growth on monuments&buildings

Vegetation Growth	Colour	Appearance	Example	Locations	Effect on masonry
Trees & Scrubs	Green	Leefy & some have woody roots		Growth is often seen at higher level, such as gutter, or where there is defective masonry	Woody root growth can penetrate into the walls and dislocate the stones that leads structural damagae
Ivy & Creeps	Evergreen	Woody stemmed trailing perennides & self clinging climbers		Commonly found in large buildings & monuments	Areal roots and woody growth can penetrate the joints and create damages.
Lichens	White, grey, orange red	Variable surface crusts or leaf		Stone, wood and soil portion of the monuments	Acid secretion that leads deterioration, In rare occasions blistering & pitting occurs.
Mosses	Green/Red	Leafy with a primitive root loosely attached to the surface of the structure		Found on stone, soil, it requires damp environment	Deposition of mosses may restrict moisture evaporation & rainwater disposal system.
Fungi	Yellow, orange, red, brown	Filmy, spots that resembles general soiling		Most common on organic substrate often associated with algae	Some species causes pitting of marble & lime stone structure.
Algae	Usually green / red orange	Mats, films, patches with borders		Seen on wood, stone, soil, glass, plastic etc. Generally requires high moisture area.	Heavy growth causes slippery on paving stones. Secretion of acids leads deterioration
Slim moulds	White	Spores, slim moulds		Mostly seen on walls, they consume bacteria, needs excess moisture	Generally benign but leaves patches
Cyanobacteria	Blue-green, grey or green	Mats, films, surface coating colonies (bio films)		Seen on wood, stone, soil etc, it grows in the area away from sun light	Generally benign unless heavy growth, they cause slippery of pavements

Trimbakeshwar is one of the pilgrimage places in India, situated at about 30km from the holy city of Nashik. The origin of Godavari River is also located nearby Trimbak. Trimbakeshwar shiva temple dating to 8^{th} Century A.D is one of the twelve Jyothirlingas attracting lot of devotees. Ballaleshwar is one of the small, beautiful and ancient temples located in Trimbak of similar period. The temple is made up of basaltic stone blocks. As this region, especially Trimbakeshwar receives high rainfall volume, the tropical climate is ideal for vegetation growth over the monuments and buildings. This paper emphasizes the eradication of vegetation growth and systematic conservation approach of Ballaleshwar temple, Trimbakeshwar, Maharashtra, India. Figure 2 shows the general view of Ballaleshwar temple. A successful attempt was made to eradicate the vegetation growth of the Balleshwar temple and restore the temple with compatible lime mortar.

Fig. 2. General View of Ballaleshwar temple, Trimabakeshwar

Systematic scientific conservation approach

Before the commencement of work, the condition of the monument, stone masonry, and vegetation growth was recorded with written description, drawings as well as photo documentation. This was mainly done to analyze the current condition of the monument fabric, highlighting structural defects and identifying the causes [6]. The major problems noticed in the monument were vegetation growth, both smaller plants and larger plants. Growth of woody deep rooted peepal *(Ficus religiosa)* tree (Fig. 3) was observed on the upper wall of the monument which was a big threat to the structure. The roots penetrated deep into the stone blocks creating cracks, voids in the structure. As a peepal tree *(Ficus religiosa)* has the natural tendency to re-grow rigorously when they are cut, the tree cannot be cut. Hence, it was decided to destroy the tree by chemical method. According to the conservation strategy, the higher plants must never be removed alive from the structures. In accordance, attempt was made to slowly kill the tree at first in three month time. For this, a suitable herbicide solution was sprayed over the tree to get it dry. Subsequent, the main root systems of the tree were identified and suitable herbicide was injected into the root systems at regular intervals. The tree was left to dry completely for three months. After three months, the dead stems on the surface of the wall were removed by hand under care and precaution. As the woody roots were thick and penetrated deep into the masonry, it was decided to dismantle the portion to remove the woody roots completely. As the stonework needs to be dismantled in order to reach to roots deep within the masonry fabric, the original position of stones was recorded piece by piece and marked with water based paint and the numbers noted in the photographs/drawings to help in accurate resetting.

Fig. 3. Peepal tree growing on the temple

The conservation of historical structures is guided by the principles of minimum intervention, clarity and reversibility. It is essential to maximize retention of organic fabric and to ensure that no information about the architectural history of the structure is lost [7]. The repairs must be limited to structure stabilization and should be carried out using materials and methods as close as possible to the original. The samples of lime mortar were therefore collected and detailed scientific investigations were carried in order to find the mineralogical and chemical composition of lime mortar for replication/ to make identical lime mortar for restoration work.

As the tree was located on the upper side wall of the monument, the required scaffoldings were erected to execute the work. Figures 4 and 5 show photos done during the dismantling of stone fabrics and removal of the root system. The stone fabrics were carefully dismantled and the decayed woody root system (Fig. 6) was completely removed carefully from the masonry. The root system was allowed to dry completely before removing it from the stone masonry.

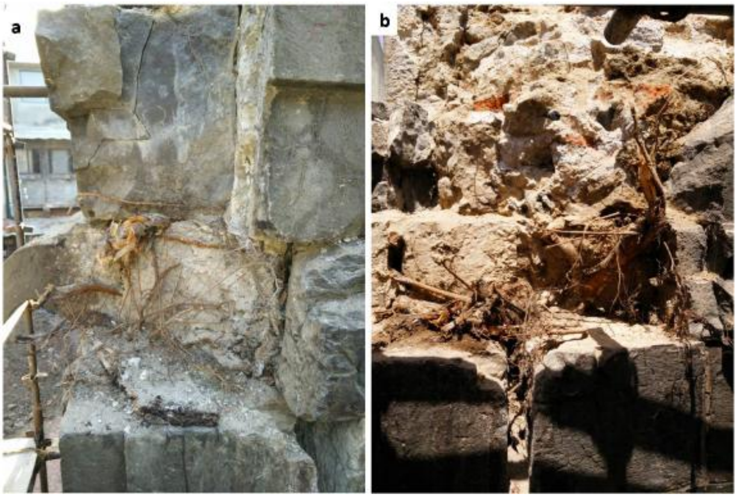

Fig. 4. Photographs showing the condition of temple during dismantling of stone fabrics and removal of the root system

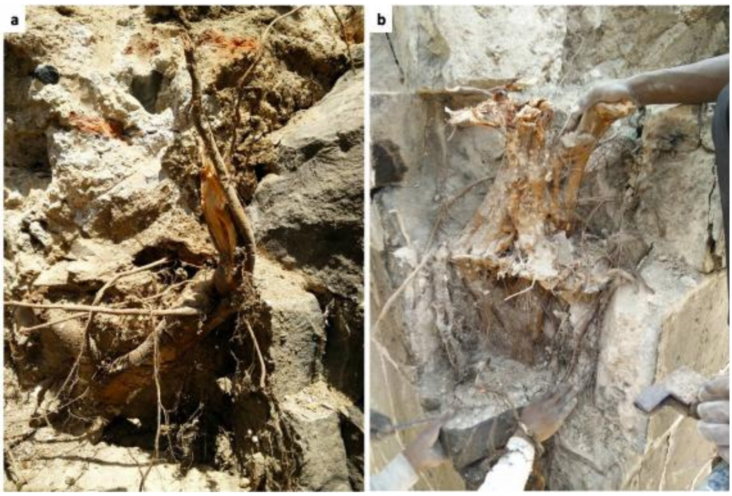

Fig. 5. Photographs showing Woody root system removal from stone fabrics

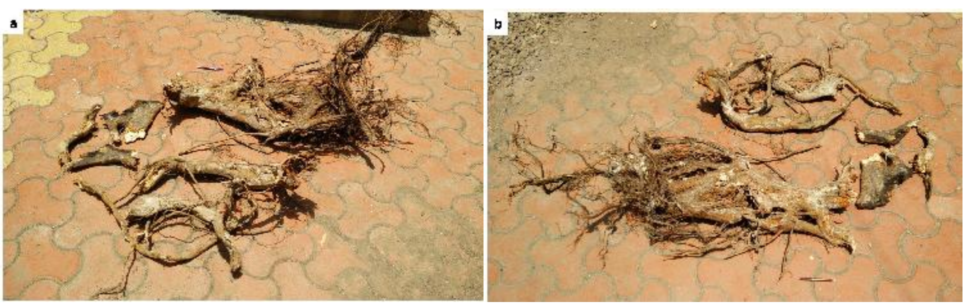

Fig. 6. Photographs showing the decayed woody root system removed from the temple

Scientific analyses of lime mortar

In order to prepare matching lime mortar for the restoration works, the lime mortar collected from Ballaleshwar temple was subjected to various scientific investigations using X-ray flouresence spectroscopy, XRD, SEM, FTIR and sedimentalogical analysis. The detailed analytical results are presented below.

Chemical composition of lime mortar

The chemical composition of mortars were determined by X-ray fluorescence spectroscopy (Phillips PW 1410, Holland) as per standard procedure by mounting the compressed pellet in the sample holder of XRF set up. The wide range of major oxide concentrations obtained through X-ray fluorescence include calcium, silica, magnesium and aluminium (the principal components of the mortar) and sodium, iron, potassium as the minor elements (Table 2). From the chemical analysis data, it is observed that calcium alone forms the major components of the mortar with concentration varying between 45 to 46 weights %. Another major component is the silica making around 25 % weight of the mortar. The percentage of magnesium oxide observed in the sample is in the range of 2 to 3 % pointing to the use of carboniferous lime stone as raw material for the mortar. Aluminium oxides have also been detected in the range of 7 – 8 %. The chemical analysis result (Table 2**)** shows the value of minerals oxides in all the samples. This indicates near uniformity in the chemical composition of the mortar samples. The CaO/SiO_2 ratios have an important impact on the mechanical strength of the mortar and also point towards the development of technological skill of that period. For better strength and durability we generally opt to maintain lime/silica ratio to about 0.33 in the modern period. The lime/silica ratio of Ballaleshwar mortar varies from 1.39 to 1.41 shows a near uniformity in the composition.

Table 2. Chemical composition of Lime mortar of Ballaeshwar temple (weight %)

Sample	Na_2O %	MgO %	Al_2O_3 %	SiO_2 %	P_2O_5 %	K_2O %	CaO %	TiO_2 %	MnO %	Fe_2O_3 %	LOI %
A1	0.08	2.37	7.69	24.25	0.23	0.17	34.64	0.59	0.10	4.22	25.66
A2	0.08	2.31	7.84	24.77	0.17	0.15	34.84	0.59	0.12	4.30	24.82
A3	0.07	2.34	7.81	24.35	0.29	0.15	34.82	0.59	0.11	4.31	25.16
A4	0.08	2.35	7.75	24.82	0.21	0.16	34.56	0.58	0.12	4.28	25.09

*LOI – Loss on ignition.

XRD analysis of lime mortar

The mineralogical composition of the mortar was determined by X-ray diffraction spectrophotometer (Phillips 2404, Holland) having graphite monochromator and Cu Kα radiation. The sample was scanned at 2θ ranging from 5 to 80°. In the present research, the proportions of binder and aggregate were examined based on XRD pattern. The interpretation is based on the assumption that the aggregate proportion corresponds to the quartz and feldspars sum, and the binder to the calcite percentage. This assumption was derived from the earlier petrographic study, which demonstrated a basaltic origin of the aggregate and showed the presence of calcite only as binder. In general, the quotient aggregate/binder determined in the mortars is higher than one. The chemical analysis data of Ballaeshwar mortar samples shows higher aggregate/binder proportion in all samples in consistence to the XRD analysis. Figure 7 shows XRD result of the lime mortar samples of Ballaleshwar temple which are mainly composed of carbonates and quartz. The results also corroborates with the results obtained from SEM.

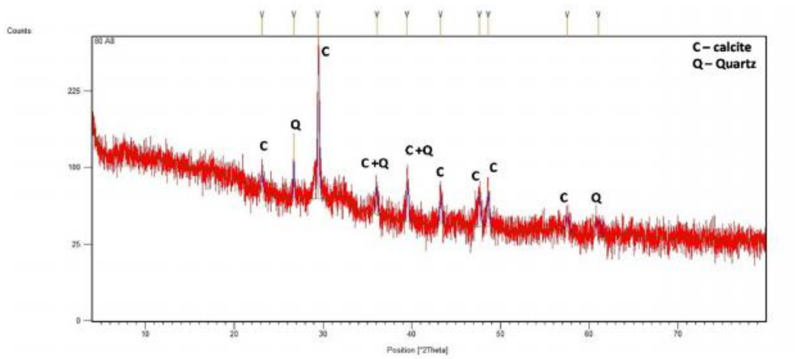

Fig.7. XRD spectrum of Lime mortar sample of Ballaeshwar temple

Petrological analyses

For petrological analysis, the sample of plaster was digested in 10% dilute hydrochloric acid. Digested plaster was filtered and aggregate sieved after drying. Figure 8 shows the types of aggregates found mixed in the mortar sample. From the examination of aggregates, it is observed that the sample is more or less homogeneous, uniform textured, light colours, essentially composed of sub rounded to subangular grains of silt to fine sand sized sediments, mostly composed of calcium carbonate and very fewer of silica.

Fig. 8. Showing the types aggregates mixed with the lime mortar of Ballaeshwar temple

The feldspar is lower in numbers and is recognized easily by its tubular, sub vitreous structure with two set cleavage while silica grains were identified by their sub vitreous massive forms.

Further, the aggregates in the mortars were investigated based on their shape and size. In this sample, majority of the sediment showed sub rounded and sub angular shapes in the proportion of 34% and 48%, respectively. While very few i.e. 2% and 16% grains showed angular and rounded shaped grains of sediment which clearly indicate the sediment are low to moderately low transported from their provinces. In the present sample, most of the grains showed earthy and massive form and are composed of calcium carbonate material. According to the shape analysis, it is found that the grains of aggregates were essentially composed of calcium carbonate, clay and remaining fine sand to silt grade materials. In accessory proportion, coarse and medium grade sediments are present. On the basis of the material, less maturity of the aggregates were observed. The presence of above mentioned aggregates was also confirmed by XRD, SEM-EDX and FTIR analysis of Ballaleshwar mortar samples.

FTIR analysis of lime mortar

The samples of mortars were examined under infrared spectroscopy (IR) at Archaeological survey of India conservation laboratory, Aurangabad. The analytical investigation was mainly carried to gather quality information about the major components present in the mortar. The infrared spectroscopy of the mortars was recorded using an Agilent (Cary 600 series) FTIR spectrophotometer equipped with nitrogen cooled MCT detector. For FTIR measurement a small amount of sample was removed with a sharp tip micro scalpel and placed on a freshly prepared KBr pallet. The FTIR spectra were recorded in the region of 4000-550cm^{-1} under a spectral resolution of 2cm^{-1} for the powdered mortar samples (Fig. 9). The characteristic peak of calcite was noticed at 1400 and 711cm^{-1}. The vibrational bands around 1430 – 1475cm^{-1} were assigned to the characteristic in plane bending and symmetric carbonate out of plane bending vibrations of calcite. The characteristic bands of silicates or alumino silicates were observed at the spectral region of 1000-900cm^{-1} in the mortar. A peak occurred around 2350cm^{-1} corresponds to the free carbon dioxide present in the air. The presence of calcite and alumina silicates is corroborated with the results of XRF, XRD and SEM analyses.

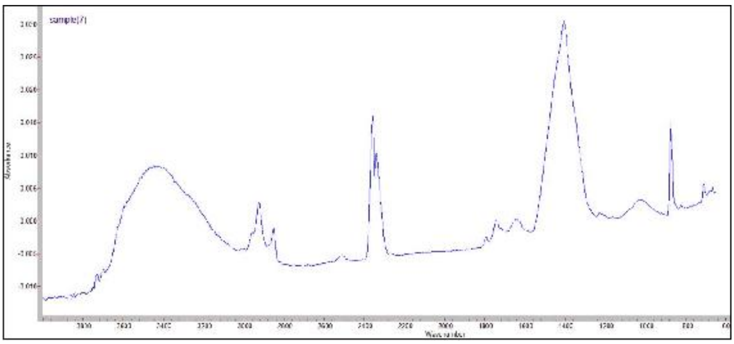

Fig. 9. FT-IR Spectrum of Lime mortar of Ballaeshwar temple

SEM analysis

The information about the mortars materials namely binder, aggregates and reaction compounds that allowed the observation of their forms, sizes, textures and distribution in the mortars was derived from SEM photomicrograph. Figure 10 taken at a magnification of 1000X and 2000X respectively showed the most important micro structural features of the studied samples.

It was possible to determine the fact that the aggregates mainly consist of quartz, calcite and feldspars. Large areas of the surface and pores were filled with calcite crystals formed possibly by a carbonate dissolution/recrystallization process of the binder. The presence of rhomboidal calcite, Quartz with rod like morphological structures were noticed in the SEM photomicrographs. These are in good agreement with XRD or FTIR Spectroscopic observations of the mortar. In figure 10 few partly resorbed detrital K – feldspar grains were also observed in the SEM analysis.

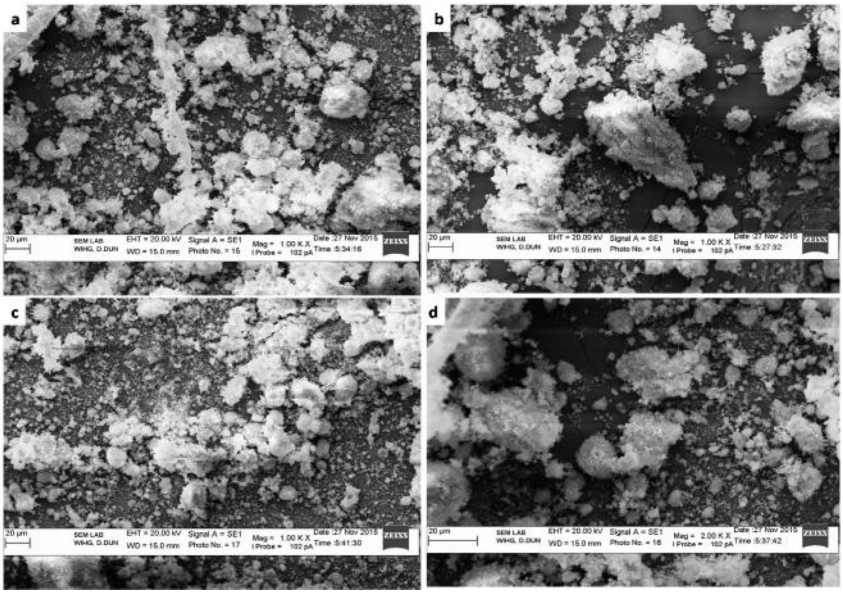

Fig. 10. SEM images of lime mortar samples of Ballaeshwar temple at the magnifications of 1000X and 2000X

Preparation of identical lime mortar

Lime, because of its ecofriendly nature, good breathability, improved workability, autogenously healing, improved bond strength, resistance to rain penetration, greater final strength and recyclability, plays a vital role as a binder in the durability of ancient structures [8]. The number of published studies on limebased materials, mostly mortars, used in historical buildings from prehistory to practically our days, is large, and has steadily increased over the last two decades [9 – 17]. As we had tried to replicate the original mortar, the lime was slaked at site in a slaking pit. As per the results observed from the analytical results, the lime to silica ratio used in the mortar, the lime mortar was prepared by the mixture of 1 part of lime putty; 3 parts of sand and grit mixed as coarse stuff and stored at least overnight. Brick dust was added that might be used in some circumstances to promote a chemical set as pozollanic additive [18 – 19]. Over 65% of lime mortar is made up of aggregates, and they acted as fillers in mortar. The aggregates were selected, containing range of materials with different particle sizes from sand to grit and gravels. As the lime/silica ratio of the lime mortar obtained from the old lime mortar did not give higher strength, the lime/silica ratio used to prepare the replication lime mortar was kept as 0.33. The replicated lime mortar was used to reset the old stone masonry after the complete removal of woody roots of peepal tree.

Conservation of Masonry

The stone members were set as per the original positions guided with the annotations and from the drawings/photographs. As the new lime mortar needs to cure slowly, adequate covering of the reset area was done with the help of netting cloth. The mortar was also covered with wet cloth for slow setting. It minimized the rapid drying caused by wind and washing out by rain. The aftercare measures also increased the performance of the mortar.

Other micro-vegetation growth like moss, lichens, etc were removed by using the mixture of 1% Liq. Ammonia and non ionic detergent solution. Then the surface of the masonry was washed with sufficient quantity of fresh water and left out for complete drying. The dried surface was sprayed with 1% sodium pentachlorophenate as biocide to arrest the further growth of micro-vegetation. Finally, to make the surface hydrophobic, Wacker BS – 290 (a Silane - Siloxane based preservative) in mineral turpentine oil solvent, with a ratio of 1:13 was applied as preservative coat. Now, the monument is in good state of preservation. Figure 11 shows the condition of the monument before and after scientific conservation, respectively.

Fig. 11. Photographs showing the condition of the monument before (a) and after scientific conservation (b)

Conclusions

It is a successful attempt to complete removal of peepal tree and other vegetation from the ancient monument and to prepare identical replica lime mortar for structural restoration. The peepal tree and other vegetation were completely eradicated from the monument as per the systematic conservation approach. The major constituents of the mortar, calcite and quartz, were confirmed with the results of our analytical investigations. From the petrological examination of aggregates, it was observed that the sample is more or less homogenous, uniform textured, light colored, essentially composed of sub rounded to subangular grains of silty to fine sand sized sediments. The replication mortar was prepared by mixing lime and silica in a 1:3 ratio and the structure was restored successfully with the newly prepared mortar. Wacker BS – 290 (a Silane - Siloxane based preservative) in the solvent of mineral turpentine oil with the ratio of 1:13 was applied as preservative coat to make the surface hydrophobic. Now, the monument is in good state of preservation.

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