Structural Audit of a Heritage Structure: A Case Study

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Abstract
Alandi temple is Indian famous spiritual location named as "Saint Dnyaneshwar samadhi", which is located on the bank of river Indrayani, a tributary of Bhima River. This temple was constructed in 1570. The constructed temple comprises of different types of basaltic rock, which is the host rock of the area too. The rocks existing in the temple wall are Amygdaloidal basaltic rock, compact basalt, tachylitic rock etc. Presently the walls are been protected by the epoxy material. Still some part of the wall is exposed. The petrographic studies have revealed different mineral composition, their textural relationship has broadly helped to define the strength of the rock.

Keywords: *Petrography, Minerals, Basalt*

I. INTRODUCTION

A visit was planned on 4 March, 2017 to have a reconnaissance survey for the investigation of the rock from Alandi Temple - Shree Dnyaneshwar Maharaj Samadhi Mandir. Alandi (18°40′37.42″N 73°53′47.76″E) is located on the holy banks of the Indrayani River, 20 km north of Pune. The studies of the petrographic rocks was carried out for some specimens of the temple and are assumed to be the representative of the whole temple. The samples collected were from the nearby vicinity of the temple and within the temple region like the Mahadwar, second door entrance of temple, some newly constructed region within temple, outside the temple and the temple from ghat region.

II. METHODOLOGY

Samples were segregated for the petrographic studies which required to prepare a thin section of all these samples. Within these five specimens the Mahadwar specimen was unable to prepare a thin section as the specimen was encountered with rupturing due to hammer attach and the lose material couldn't be enclosed in the thin section. Remaining 4 specimens were sent for thin section preparation. The epoxy used for the preparation of the thin section was araldite which couldn't make any reaction with the existing minerals of the rocks and due to this the section photos were neatly captured. The studies were carried out under polarized Raman microscope.
The minerals show distinctive features under UV light and under polarized light. It was easier for the identification of the minerals as well as the bounding nature of the minerals with in the rock.
The details of every specimen is enlisted below:

1. Cuprite amygdal outside temple area:

Hand Specimen: Fine-grained, greenish black rock comprising dark and white minerals. Contains amygdales, mostly white, though some have black cores. Fine-grained plagioclase laths and irregular clinopyroxene (augite) grains, replaced with calcite. Many of the plagioclase laths have been almost entirely altered. The amygdales are filled with zeolite, growing in spherulitic and radiate patterns. Many have rims of calcite and fine-grained chlorite. Some vein material - granular quartz with sutured contacts

Fig. (1) Hand specimen of Cuprite Amygdal outside the temple area.

Fig. (2): PPL and XPL

2. RTB:

Hand Specimen: Fine-grained, reddish grey rock comprising dark and white minerals. Contains calcic material as cementing in it with glassy nature of minerals. Some discrete plagioclase crystals exhibit irregular oscillatory zoning. Glass inclusions are found in the clino-pyroxene and plagioclase crystals

Fig. (3) Hand specimen of RTB

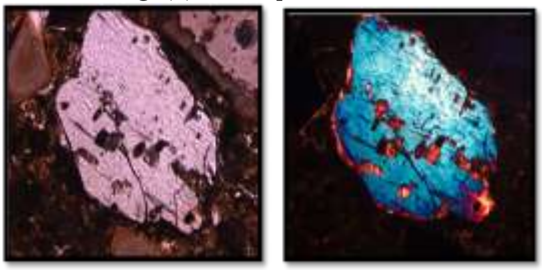


Fig. (4): PPL and XPL

3. Mahadwar:

Hand Specimen: Fine to medium grained, greenish black rock comprising dark and white minerals. Contains amygdales, vesicles and founds to be weathered magnetite mineralization in the specimen. During the preparation of the thin section the sample was loosely holded so was unable to prepare the thin section and hence no data could be acquired during the microscopic studies of this specimen

Fig. (5) Hand specimen of Mahadwar

4. Main Temple:

Hand Specimen: Fine-grained, grey rock comprising dark minerals covered by white cementing material showing pale yellow colour of it. Contains calcic material as cementing in it with glassy nature of minerals. Main Temple Diabase (magnification 40X) is an Intrusive Igneous Rock, which means a magma formed deep in the Earth was emplaced in the crust and cooled slowly. Evidence for slow cooling can be seen in the crossed polars picture, in which Plagioclase grains (white grains with dark striping due to Crystal Twinning) are partly to completely enclosed by Pyroxene grains (all the colored grains: yellow, orange, red, and blue). This is called an ophitic texture, and indicates that the minerals crystallized out of the magma to in a certain order: first plagioclase, then pyroxene.

Fig. (6) Hand specimen of RTB

Fig. (7): PPL and XPL

5. Basalt weather II door foundation:

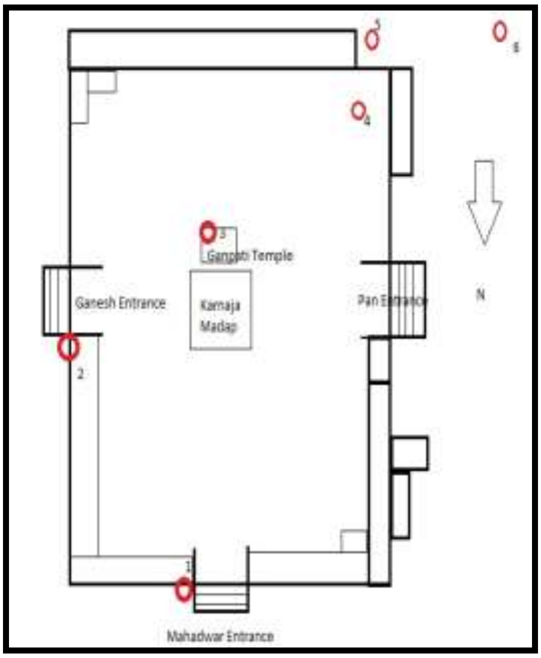
Hand Specimen: Fine-grained, brownish black rock comprising dark and white minerals. Contains amygdales, mostly white, though some have black cores. Thin-section of Basalt weather II door foundation. The black grains visible in the 50x plain light image of Basalt are opaque oxide grains, probably Magnetite. Other parts of the thin section, which are clear in plain light but black with the polarizers crossed, are natural volcanic glass (what's left of the lava, now frozen solid like windowpane glass).

Fig. (8): Hand specimen of Basalt weather II door foundation.

Fig. (9): PPL and XPL

III. OBSERVATIONS

- All the specimens studied under microscope show good relationship for bounding nature of minerals.
- The rocks which are collected are yet in good condition as a building material.
- The weathering effect shown by the rocks in too slow
- Respective mineral composition (microscopic) is enlisted for every specimen except the Mahadwar specimen.
- Mineral association with respect to their textural association is hugely bounded, Cleavages within the minerals are observed but has no relevance to weathering.
- Structures exhibited by the minerals are clear and has good bounding so the rock remains yet in good condition.
- The walls of the temple towards the Pan entrance and towards the shops attached to the temple are being loosen and needs to be treated.



Sample Selected Map

IV. RECOMMENDATIONS

- To understand the exact composition the geochemical studies should be done for these samples.
- The weathering effect shown by the rocks in too slow but there should be treatments provided to the temples from the ghat sections to avoid the erosion of the rocks due to water body from the river channel.
- The walls of the temple at various location are to be treated by Tendons installed to masonry wall.
- The walls towards the Pan Entrance needs to be treated with installation of a rubber tubes in the wall for the installment of the grout.
- The shops covered wall requires to have typical steel connectors for stone masonry as these walls are damaged from the inner side. This can be also supported by crack widening by removing the mortar, loose stones and gallets.

V. CONCLUSIONS

All the below conclusions are made on the basis of the selective samples considered for the analysis of the present work.

- All the specimens studied under microscope show good relationship for the bounding nature of minerals hence the durability of these rocks is good and appears to be best building material.
- The weathering effect shown by the rocks in too slow, so no need to have any treatments for the rocks, but if at all any resistant (like earthquake, friction of blocks etc) on the rock occurs this may increase the ratio of disintegration of the rock.
- Retrofitting of the wall rocks is must and has to be followed by any of the above methods suggested herewith.

VI. RETROFIT METHODS FOR MASONRY STRUCTURES

1. Restoration and Reconstruction of Masonry Walls

Restoration or reconstruction of masonry walls normally involves the failure of one of the two leafs, most commonly the external. In any case it will require the reconstruction of the faulted part and strengthening of the connection using tie-stones (Fig. 10).

Fig. (10): Reconstruction using tie-stones.

After completion of construction the wall should be brushed down and cleaned with water if necessary

Fig. (11): Stone wall construction (elevation).

2. Overlapping Courses Using Tie Stones

The use of tie-stones is essential in the presence of cracks due to unconnected courses. The following procedure is essential:

- The crack is carefully widened and cleaned by brushing and washing using low abrasive tools and water
- Stones are removed along the edges of the crack every 0.50m and they are replaced with tie-stones
- Pointing is removed along the length of the crack at 0.50m on both its sides. Pointing is retained if it is very well preserved
- After the tie-stones are in place, gallets and/or pointing takes place using lime mortar

Fig. (12): Crack restoration with tie-stones.

3. Tying Courses Using Steel TIE-Rods

In addition to the tie-stones that are presented in the previous section there are cases that steel tie-rods can be used to tie courses together using the following procedure.

- The crack is carefully widened from loose stones, mortar and gallets and the opening is cleaned using low abrasive tools and water. The crack is widened at a depth of 0.15m on both sides of the wall (Fig. 13).
- Mortar and gallets are removed from both sides of the crack at 0.75m on each side at a depth of 0.15m. The opening has to be cleaned and then tie-rods (1.50m) are installed on both sides of the wall at intervals of 1.00m in height. The tie-rods must be rustproof.
- The crack must be filled in with stones and gallets and re-pointed with lime mortar in order to complete the wall.

Fig. (13): Crack widening by removing the mortar, loose stones and gallets.

4. Restoration of a Corner

When restoring a corner of a stone masonry wall then the following procedure is recommended (Fig. 14):

Fig. (14): Reinforcing of the corner by galvanized metal element.

- Support of the roof and/or the floor
- Remove loose stones and gallets
- Reinforce the corner with rustproof plates of 1.20m minimum length in each of the two intersecting walls every 1.00m in height. Each plate must be embedded at least 0.60 m in each intersecting wall

5. Wall Connection by Metal Connectors (TIE-Rods)

Steel connectors (tie-rods) can be used to strengthen stone build structures against partial or total collapse and prevent lateral instability of the walls caused by the action of the horizontal structural members. The use of steel connectors is of great importance especially for masonry structures located in seismic zones (Fig.15).

Fig. (15): Typical steel connectors for stone masonry.

Although the observations of seismic damage showed significantly improved seismic behavior of the old buildings which have tied masonry walls, the practice to isolate the floors from the walls has been widely applied a few decades ago. In the normal course of rehabilitation and restoration after an earthquake or after various natural physical damages, the metal connectors are placed directly beneath the floor or at locations where it is necessary (cracking of walls at corners). For this reason, normal tendons can be used. The threaded ends are manufactured to be screwed to the ends of the wall onto a metal anchorage plates (Fig.16).

Fig. (16): Normal tendons (a) metal anchorage plates (b) corrosion resistant paint.

Usually, connections are placed symmetrically on both sides of the wall in horizontal grooves of width about 4-5cm that are created on the plaster connections just below the level of the floor to the wall surface. In such case the walls do not have to be damaged (Fig.17). The rods are held in place with staples placed in holes on the wall, which are opened at the joints. The anchorage plates have thickness of at least 15mm. The length of the plates is slightly larger than the thickness of the wall, while the width is less than 200mm. A slight pretension is applied in the rods with the use of a hand tool and the nuts are screwed on the plate. All metal parts are protected from corrosion with paint and then coated so that the connections are not visible.

Fig. (17): Tendons installed to masonry wall.

6. Use of Grouting for the Repair and Strengthening of Masonry

Grouting is the process of injecting grout in the cavities of the wall and it consists of cement and water. The technique is applicable where the extent of the cracks of the wall does not exceed 1cm. This is an empirical technique even if it is in use for over a century. Grouting is described below:

- Prepare sample tests for various grout mixes depending on the nature of the works. The water is placed in a can and 2/3 of the cement is added. Then any admixtures are added and finally the rest of the cement. The mixture needs four minutes in a mixer with a frequency of at least 1000 rpm. After the mixing it is recommended that the cement based grout passes through a sieve No. 16 to remove any lumps
- The holes are then cleaned from loose material and dust and the edges are smoothed. Most of the times the grout is installed using high pressure. The grout passes through the gaps filling the vacuum and squeezing or pushing the air out of the gaps of the masonry. Knowledge of the internal structure of the wall and the percentage of gaps is an element of concern for choosing the most appropriate grout mix. Grouting is performed using rubber tubes with diameters ranging from 0.3 - 0.6m (Fig.18) depending on the amount of grout
- Since the grout takes the place of air or of any water, care must be taken so that there are at least two holes next to each other. Grouting requires the involvement or supervision of experienced staff that can make decisions as to which grout mix to be used and the location of the holes. The distances between the tubes and the quantity of grout depend on the nature and viscosity of the grout, the pipe diameter, the permeability of the wall, and the intake pressure of the

grout.

Fig. (18): Installation of a rubber tubes in the wall for the installment of the

- The initial pressure is kept constant and 30 MPa until the grout is absorbed by the wall (Fig.23). Then it is increased to 40 MPa and held steady for 5-10 minutes so that the mixture is stabilized and excess water is drained. However high pressure can create problems to low strength masonry and for this reason the pressure to be used should be calibrated. The injection of the grout starts from the lower part of the wall and continues upward in a systematic way. The lower holes are filled first until there is an overflow of grout from holes at the higher level. Then the lower tubes are sealed. The next holes to fill are those that are overflowed by the grout injection at a lower level and the process is continued until all holes are filled (Fig. 19). In the case that grout is inserted in the wall but there is no overflow from a higher level hole then there is a problem which has to be addressed. Ways to do that include the drilling of holes at closer distance or the use of grout with less viscosity. When the process is complete the tubes are removed and the holes are covered with appropriate finish.

Fig. (19): Equipment for the control of the pressure.

Fig. (20): An overflow of grout from holes at a higher level.

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