Structural Preservation of Monument

A Case Study Of Lord Jagannath Temple at Puri, Orissa

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Historical Background of Jagannath Temple

Lord Jagannath temple at Puri (Figure 1) was constructed in the first quarter of the 12th century. The monument is standing on a high platform connected with the ground level by flight of 22 steps (belived to be part of it's foundation). The height of temple is over 66 mt. It is only 2 Km away from the sea.

Fig: 1 View of temple complex

Structural Problems of The Main Temple and Need for Intervention

The construction of Lord Jagannath Temple has been done in ashlar stone masonry with blocks of Khandolite (a local sand stone) laid in courses. For the construction, no mortar has been used. Instead the stones have been jointed with help of wrought iron U-shaped cramps or dowels and have been supported one over another resulting fascinating wall and corbelled roof, in the shape of frustum of pyramid. The geometrical arrangements of the stones perfectly match with the proven thesis of arches, where all the elements are primarily subjected to compressive forces. The wall thickness of the main temple is about 5.5 metre and the main temple has three floors, i.e. three corbelled roofs inside, which are being supported by huge wrought iron beams (about 25 cm. x 25 cm. solid section), spanning over 9 metre of length. The wall face externally has been plastered with 45 cm. thick coat of lime plaster, applied in nine distinct layers, while the inside wall has a thin coat of plaster up to a height of 3 metre.

The maximum damage to the temple was caused by the rusting of these clamps. Apart from this the stone expanded due to seepage, generating pressure and causing chunks to fall.

The outer faces which was covered with lime plaster (about 45cm) had failed to control saline induced deterioration and leakage besides putting extra pressure on the fabric of the temple and hiding the beautiful carvings.

It was found that the condition of the inner walls and corbels required attention. Similarly, on the southern side of the temple major structural weakness were detected in the form of multiple cracks, missing architectural pieces, etc.

Intervention Schemes

The following recommendations were made by the expert committee which was subsequently implemented through a joint venture of engineers from ASI and the State PWD (Public Works Department).

I. Replacement of missing corbels as per the original.

II. Replacement of rusted wrought iron cramps by stainless steel cramps.

III. Sealing of the stone joints by a joint sealant comprising stone dust, cement, polymer (acrylic type) and non-shrink additives.

IV. Grouting the inner core with polymer modified, flexible, non-shrink, cement grouts.

V. Anchoring the loose cantilevers and corbel stones with help of 1.5m to 2.5m long, threaded stainless steel anchors, grouted with low viscous epoxy resins.

VI. Providing a stainless steel anchors, grouted with low viscous epoxy resins.

VII. Providing a stainless steel space frame, as a secondary defence to support the ground floor corbelled roof.

VIII. Lateral confinement of the entrance corner walls of each floor by stainless steel flats.

IX. Improvement to the existing ventilation system by drilling appropriate diameter holes through the ceiling of the first and second floor and provision of suitable ventilation duct in the top floor.

X. Provision of temporary support to the ceiling of the first and second floor in the form of tubular scaffolding system to monitor corbel movements and any associated deformation in those floors.

XI. Desalination of the external fascia stones by paper pulp technique.

XII. Application of suitable chemical preservative to the fascia stones (in place of methyl metha acrylate) and suitable biocide treatments.

Consolidation Of Temple Wall And Corbels

The walls and corbels of the main temple had shown gross deformations with weakening of interconnections of structural elements, thereby endangering the very stability of these structures. This is primarily due to the ingress of rain water through the weathered joints into the thick dry stone walls thereby leading to the rusting of iron dowels / cramps. It has been proved with success that injection of polymeric grout into the pore structure of the masonry diminish the splitting forces and at the same time increases the adhesion between the stones. Therefore, for structural stability and proper load distribution of the space frame and to prevent the water ingress into the core of the structure, it was felt necessary to take adequate conservation measures by sealing the joints, surface cracks and grouting the walls with a material which besides meeting the general requirement, would also be compatible with the structural behaviour of the Ashlar masonry structures. Considering the condition of the temple structure, its structural design and inherent weakness, results of the analytical study regarding the stability of the temple against the earth quake forces and requirement for uniform load distribution from proposed stainless steel space frame, it was essential that the injection grouts should meet the following main criteria :

1. should not be excessively brittle
2. should be elastic having resilience and permit minor movements without fracturing or cracking
3. should firmly adhere to the stone surface
4. should be able to set without curing, without any deformation.

The first three characteristics are also essential for any mortar mix used for sealing of open joints or cracks and the last characteristic being of additional advantage. Since the ordinary Portland cement mortars suffer from shrinkage cracks and are excessively stiffer and strong, their use for sealing of joint as grout material appears to have certain limitations. For historical buildings, the grout materials should be compatible with the structural behaviour and for this purpose, the properties of cement mortars need to be modified for the present ashlar masonary structures.

Typical test samples were prepared from the same ordinary Portland cement with polymer loadings of 5% and 10%. The materials used for the different grout mix formulations are :

1. Ordinary Portland cement
2. Modified Acrylic Resin Emulsion of Methyl Methacrylate with copolymer of 2-ethyl hexa acrylate and butyl acrylate. It has 40% of solid resin content.
3. A solid component material of expanding and plasticizing nature to help in low water / cement ratio, positive expansion for non shrink infilling and jointing.
4. Admixtures based on selected lingosulphonates which is adsorbed on to the cement particles and acts as a dispersing agent and breaks down agglomerates of cement particles and enables the water in the mix to perform more efficiently.

To evaluate the effect of polymer loadings in different proportion and other additives on the setting time and mechanical properties of Polymer Modified Cement (PMC) mortars, the following formulations were used in the experimental study. In all the tests, cement sand were added in the ratio of 1:3 by weight.

I. Cement

II. Cement : Polymer :: 4:0.5

III. Cement : Polymer :: 4:1

IV. Cement : Polymer : Expanding grout additive : 4:1:0.02

V. Cement : Polymer : Expanding grout additive : Plasticiser Cum Retarder :: 4:1:0.02:0.02

Since the polymer emulsion has 40 percent solid content, the polymer added in the above formulations II & III corresponds to 5 percent and 10 percent loadings respectively. Experimental studies for setting time, compressive strength, flexural strength and bond strength were carried out for the above mix formulations and it was observed that polymer loadings with addition of plasticizers and retarders help to secure adequate adhesion with the stone surface. The elastic behaviour of PMC grout will induce the required flexibility in to the system. Results of polymer loading in different proportions along with other additives on the strength characteristics of PMC grouts were thus experimentally verified and applied accordingly. Additional temporary stresses generated by forces or constrains on masonry, produced during the grouting process were controlled by selection of proper grouting parameters.

Seismic Safety Assessment of the Temple

The temple falls in seismic zone III according to the available quantitative seismicity maps. Instances of occurrence of earthquakes of magnitude around 5 on Richter scale have been recorded at about 100 to 150 kms South-east of Puri. The analytical study has been carried out by the Civil Engineering Department of Indian Institute of Technology, Kharagpur to check the stability of the block structure of the main temple against earth quake forces. The results of the analysis indicate that the temple structure will safely withstand forces developed due to seismic excitation up to a Richter scale of 5.0. Since the loosely joined stone blocks as in case of massive structures built in ashlar masonry are less vulnerable to earthquake induced vibrations than the solid structures, it was essential to see that the grout materials using injection techniques will not solidify the structure fully and alter its structural behaviour completely. For this purpose, the use of PMC grouts was considered favourable.

Treatment of The Distress Outer Fascia

The outer and inner fascia of the temple core are made from Khandalite stones. Khondalite rocks being of metamorphic sedimentary origin, with evidence of post magnetic action, are essentially heterogeneous with several types of inclusions. Subjected to the exposure of salt laden air, moisture, air borne sand particles etc. both in isolating and combination, the surface of the temple structure and the sculptural features have shown extensive distress. The anxiety was two fold: structural strength and damage to scriptural features. There was evidence or large scale leaching from the surface layer and ingress of moistures of deep inside the walls, not only along the un-mortared joints but also within the main (individual) rock bodies. The process has been further accelerated due to high humidity and temperature. This had significantly increased the porosity of the stones, thereby hastening the process of deterioration. Evidently, the formation of the water soluble salts has taken place. These soluble salts had subsequently leached out from the interior of the stone structures enhancing their porosity several folds. All this appears to explain a typical poker faced features on the surface of the stone. Evidently there is loss of strength of the rocks progressively with aging. As the stone of the choice (khandolite) is not very homogeneous, samples collected from different locations exhibited different stages of distress. It is highly relevant and appropriate to emphasize here that this non-uniformity demanded difference in treatment mode for different stones even when the basic chemical system was the same. Moreover it should also be recognized that this process of progressive deterioration got accelerated with time.

The objectives of the chemical treatment to the outer surface was therefore planned such that :

- Tubular scaffolding were made for treatment of outer faces as shown in (Figure 2).

Fig: 2 Renovation of outer face

- The treatment should be compatible with the basic stone in respect to chemical bond as also thermal expansion / contraction and moisture movement.
- The sealant or consolidant should not develop a tight and impervious surface skin preventing access of moisture. This tends to develop pressure behind the treatment causing other kinds of damage caused by trapped moisture drawn to the surface by temperature gradient. The sealant should discourage ingress of fluid but encourage transmission of vapour.
- A merely physically coexistent system should fail to be durable and act as consolidant.
- Silicones, urethanes, acrylates have been tried for limited sealing of sandstone surfaces but the efficacy depends on the fluid vehicle, the emulsifier and the molecular size of the sealant.
- Equally important are the characteristics of wettability and response to UV radiation.
- The treatment should permit trapped salt to escape.
- The fluid vehicle should be water or water miscible.

It may be noted that various organic or organo-inorganic polymers and polymeric precursors, which are finding increasing use as consolidants are alkoxy / saline silicates, epoxy resins, microcrystalline waxes, poly acrylate / methacrylates, silicone resins, polyurethanes. Still there is a need to find tailored materials for better end results. In order to search out a chemical system that would be compatible with the eroded and degraded khondalite stones a set of test parameters were identified to compare response of treated rock samples with that of untreated samples.

- Chemical uptake to stabilize a surface zone, upto a depth not less that 5-10mm depending on the state of deterioration was measured.
- Capailary absorption studies to indicate susceptibility of water penetration were carried out.
- Electron microscopy to study the surface morphology and texture of the treated samples was carried out.
- Porosimetric studies to measure pore size distribution profile of polymer treated sample were carried out.

The treatment to the kalash shown in (Figure 3) and temple after complete renovation shown in (Figure 4).

Fig 3: Treatment being given at kalash

Fig 4: Temple after renovation

Conclusions

In case of historical buildings and monuments made of masonry, it is important to have sound assessment and diagnosis of structural behaviour prior to any permanent intervention. It is also impossible to predict the behaviour prior to any permanent intervention. Since masonary is a non-elastic, anisotropic and non-homogeneous material, it is generally impossible to predict the behaviour of masonary buildings from the mechanical properties of the constituent materials as the input parameters in the calculation procedures which are based on the assumptions of the theory of elasticity. It is especially so in case of ashlar masonry buildings having thick dry stone walls where the core has relatively loose prior to any permanent intervention. Since masonary is a non-elastic, anisotropic and non-homogeneous material, it is generally impossible to predict the behavior of masonry buildings from the mechanical properties of the constituent materials. It is especially so in case of ashlar masonary buildings having thick dry stone walls where the core has relatively loose stone blocks and the outer veneering structural members are held together by iron cramps / dowels. These dowels in due course of time have rusted into powder forms leaving voids in between stone blocks where they once were. These type of structural problems are mainly tackled by structural consolidation with help of grouting as was done for the Puri temple. When dealing with the repair by grouting of masonry structures, the improvement of their carrying capacity has certainly to be considered as one of the most important aims of the intervention. Nevertheless the long term performance and durability of repairs has also to be taken into account; repairing should also ensure an increase of the service life of the structure. The effectiveness of the grout from the point of view of bond strength, improvement of the mechanical strength of decayed masonry and durability of injected grout to thermal cycles should be experimentally verified before application. The main problem associated with grouting is determination of pressure distribution as well as the analysis of stress applied to the mass of masonry during injection. These are in general difficult to be solved theoretically. The difficulty stands on the inability of geometrical presentation of voids system, the particularity of the system of voids itself, as a flow duct, the great variability of flow conditions and further more on the number of parameters involved (kind and composition of grout, kind and geometry of masonry etc.). The control of applied stress is made through practical limit state checks in accordance with the type and geometry of masonry in the point of pressure application. In case of Puri temple restoration work, two checks namely, check of blowing stones out of the masonry face and check of horizontal swelling of masonry were made to control the grouting process.

Period of repair : 1992-1993

Owner : Sri Jagannath Temple Administration, Puri

Repaired by : Archeological Survey of India and PWD Govt. of Orissa

Expert Committee: ASI, PWD, SERC, CBRI, IITK, RRL Bhubaneshwar