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ASSESSMENT OF STRENGTH CHARACTERISTICS OF A HERITAGE STRUCTURE - ALAMPARAI FORT, INDIA

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Abstract

The Alamparai Fort is a heritage site. The fort structure primarily consists of free standing tall brick walls surrounding a large area. The fort faced vagaries of adverse environment and war from 17th Century on the East Coast of Tamilnadu, India, and at present the walls are in dilapidated condition. There is a need for conservation of the structure to its past glory, which requires study on structural stability including assessment of present conditions of major materials used such as bricks and lime mortar. This study involved collection of intact brick samples without any damage but scattered on the floor; in-situ testing of intact bricks on the standing walls using non-destructive tests and carrying out laboratory testing of collected brick samples for assessment of strength characteristics. Comparison of test results with the old (heritage) and modern bricks were made such that suitable intervention could be proposed. The results show that modern bricks with similar or superior quality (color, composition, strength and matching with original bricks) could be used to a greater advantage. Further site investigations are required to assess foundation details, bearing capacity and stability calculations for each section or segment of the fort walls.

***Keywords**: Heritage site; Bricks; In-situ tests; Laboratory tests; Compressive strength; Non-Destructive Test; Rebound hammer test.*

Introduction

The Alamparai Fort is located on the seashore of the Bay of Bengal, at Alamparai village (Fig. 1). The fort is situated about 106km south of Chennai on the East Coast Road (ECR), Tamil Nadu, India. The latitude and longitude are: 12.266°N and 80.010°E respectively. The Fort was built during the seventeenth and eighteenth centuries (Christian Era), which was under the French rule in 1750. There was a port, on the sea-side that contained a dockyard for the merchandise. The important commodities exported from this port were salt, ghee and clothes mostly traded to Pondicherry and Portonova [1]. There was a canal in operation on the west of Alamparai Fort. This canal was constructed during the British regime in 1878, for transportation of merchandise in the absence of other mode of transports. Country boats were used to transport commodities from Marakkanam to Chennai until 1967 [2, 3].

The Alamparai Fort is of rectangular shape in plan as shown in figure 2 with the dimensions of 223m by 163m (length x breadth). The fort structure primarily consists of free standing tall brick walls surrounding a large area. The fort was built of bricks and lime mortar. The bricks of the fort predominantly consist of quartz, andrasite, albite and orthoclase as main

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minerals (feldspar) with minor quantity of iron oxide (hematite). The bricks were of low density and highly porous; raw materials used to manufacture bricks consisted of calcium-poor clay and the bricks were burnt at low temperature below 800°C [3]. Modern bricks are burnt at 1000°C [4]. The stratigraphy investigation on the fort bricks and reported that the bricks were manufactured between 1700 and 1750 AD [1]. Nevertheless, compressive strength values of Alamparai Fort bricks have not been reported till date. The fort walls are in highly dilapidated condition and to restore the fort to the past glory, knowledge of the bricks used, their characteristics and the present conditions are very essential.

Fig. 1. Alamparai Fort at Alamparai Village of Kanchipuram District

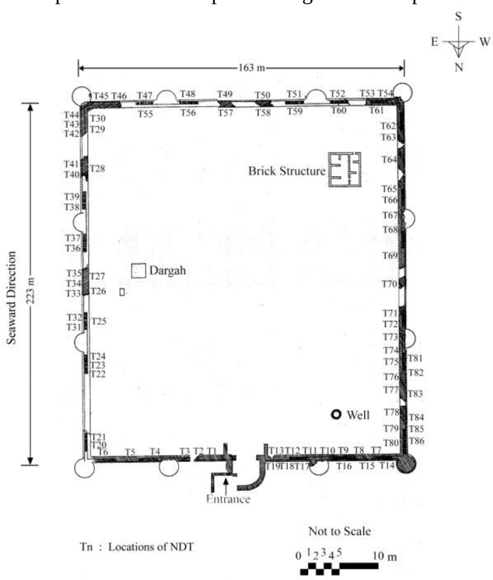

Fig. 2. Alamparai Fort

The brief review of literature shows that preservation of heritage buildings and structures need careful investigation by experienced professionals and demands multidisciplinary approach. Preserving cultural, architectural values and stability are most important, particularly in the context of deteriorating conditions of materials used and loss of strength of structural components. The conservation becomes very tedious as assessment of material characteristics and structural stability are not easy to execute. This is because access is generally restricted and destructive testing methods cannot be sought, in general. Most of conservations were done with available data inferred from surface or peripheral details. The site investigative methods are not well established in India and sophisticated tools and techniques are rare in use and costly. Research on conservation of heritage structures and buildings in India are very few.

They have reported various experimental investigations performed on old and modern bricks, involving both hand-made and machine-made. They recommended that the universal compression test to be the most appropriate method to represent the characteristics of heat resistant material such as brick [5].

Due to the ancient technology of production and materials added in the mortar, the ancient Subramanyaswamy temple still exists in good condition under the sea for 10 centuries and its recent rediscovery [6].

FTIR analysis provides the principal constituents like Calcite, Aragonite, Vaterite, Magnesite, Portlandite, CSH (calcium silicate hydrate) and CASH (calcium alumina silicate hydrate) phases, and organics used could be identified in the aged lime mortars [7].

The main factors damaging the historical building in Rashid are the air pollution, ground water, salts, variation of temperature, rains, and biological factors. The Nano-materials improve the physical and mechanical properties of red bricks in historical building and overcome the ordinary materials [8].

The petrographic study of the wall of enclosure of the Monastery Galata confirms the prevalent presence of the sedimentary rocks from the open pits of Repedea and Scheia Formations. In the composition of carbonate rocks from Iasi area there are mostly oolitic and grainstone limestones. The rocks from the building of the Galata Monastery – Iasi is an useful step and necessary for all the specialists involved or interested in the preservation and restoring of the historical buildings [9].

Natarajan et al., who carried out rehabilitation of St. Lourdes Church at Tiruchirapalli which was built about 280 years later to Danish Fort observe that local materials bricks and lime mortars were used in the restoration work, which enabled bringing back the ancient glory and recommend complete water proofing of roof vaults plaster surfaces and to reduce water related deterioration of heritage structures to enhance functional life these buildings [10].

The Danish Fort, a 400 year old structure structure is located at very severe coastal environment which require constant vigil and scientific approach to assess present and future conditions through non-destructive testing, model studies of structural elements, characterization of major construction materials used such as in-situ bricks, lime sand mortar, further studies and suitable interventions are required towards checking and controlling dampness. Increasing life of such brick structures will help to design and construct modern residential and commercial structures with more design life, thus reducing environmental impact on quarrying of natural resources and cutting trees [11].

A special aspect for actual or future interventions of restoring is the identification of natural resources referred to the extraction of the compatible rock with physical and mechanical characteristics, petrographic, mineralogical and esthetical characteristics specific to the geomaterials used for the initial construction [12].

An important issue is the cleaning of the depositions on the wall surface, laser cleaning method being recommended especially when assisted by simulation in COMSOL for estimation of laser parameters [13].

The formations with pronounced destructions and alteration were taken and macroscopic analysis was performed in situ, following possible endogenic and exogenic causes that affected the status and integrity of the construction in study [14].

The need to regulate and reduce the expansion of urban structure in the context of heritage, and the necessity for Managing natural and cultural heritage sites as an integral part of local and national management plans, in accordance with the laws and regulations [15].

The repair process requires the existing condition of the structure to be identified and its causes of its deterioration. It is also necessary to define how ongoing deteriorative factors should be monitored given the effects of such processes on the rehabilitation of the structure [16].

There is tremendous educational and practical potential to be realized in the area of restoration. An architectural, engineering, management as well as social approach is required for such type of endeavour. Proper education and training for such kind of works is today‟s need. Involvement of more practitioners and technical professionals is required. The potential of this field needs to be realized by integrating and contextualizing the spheres and work of conservation, not only as a self-contained science or technological endeavour but also as a social practice [17].

A comprehensive study of repair and rehabilitation of heritage buildings. The existed problems and its reported solutions are finely reviewed. An effective solution for the reported problem is formulated based on tradeoff between cost, lifetime and adaptability of the solution. Hence this paper delivers its usefulness to those who as an objective of doing repair and rehabilitation in a heritage building [18].

The repairs & rehabilitation of damaged structures it is essential to carryout detailed condition assessment of the building with non destructive and destructive tests so that suitable remedial measures and repair techniques could be employed [19].

This paper reports in-situ site investigations and laboratory tests carried out to assess compressive strength and other characteristics of old and modern bricks. The results have been compared with the strength characteristics of modern bricks. Compressive strength values based on NDTs at the site (engaging rebound hammer) and destructive tests performed on the heritage site bricks in the laboratory are presented herein.

Experimental

Non-Destructive Test (NDT)s at the fort site were conducted on intact bricks employing rebound hammer (make: Consal, Model No. CSS-073). Bricks from the fort site were collected for performing different type of tests in the laboratory. Bricks were collected from north wall, east wall, south wall and west wall respectively at the site. For ease of identifying the bricks collected were grouped as NWB (North Wall Brick), SWB, EWB and WWB. On these samples, water absorption and compressive strength test were conducted at laboratory. These tests were conducted adhering to the Bureau of Indian Standards and according to other researcher's methods as applicable for easy comparison. In each category, a minimum of five specimens were tested and the mean value is presented herein.

In-situ Tests

Compressive strength values have been determined at 86 locations as shown in figure 2 at the Fort site using rebound hammer. The purpose of this test was to establish a correlation between in-situ bricks in the masonry wall and corresponding laboratory average compressive strength values. Figure 3 displays the in-situ testing of bricks using the rebound hammer.

Laboratory Tests

Compressive strength tests

Typical samples of brick collected from the site are shown in figure 4. Two types of compressive strength tests were performed in which 50 percent of the specimens were tested by placing 3mm thick plywood sheets (IS 3495-Part I; 1992) at the top and bottom of each brick as shown in figure 5. The remaining bricks were tested with spreading a thin layer of talcum powder at the top and bottom of each brick as suggested by Bati and Ranocchiai [5]. All the bricks were tested in different directions namely, load applied in stretcher position, σ_{c1}; load applied in shiner position, σ_{c2} and load applied in sailor position, σ_{c3} to compare the compressive strength values. Typical tested bricks are shown in figure 6.

Fig. 3. Performing Rebound hammer (NDTs) at Alamparai Fort walls:
a - north wall, b – south wall, c – east wall, d – west wall

Fig. 4. Bricks from Alamparai Fort site

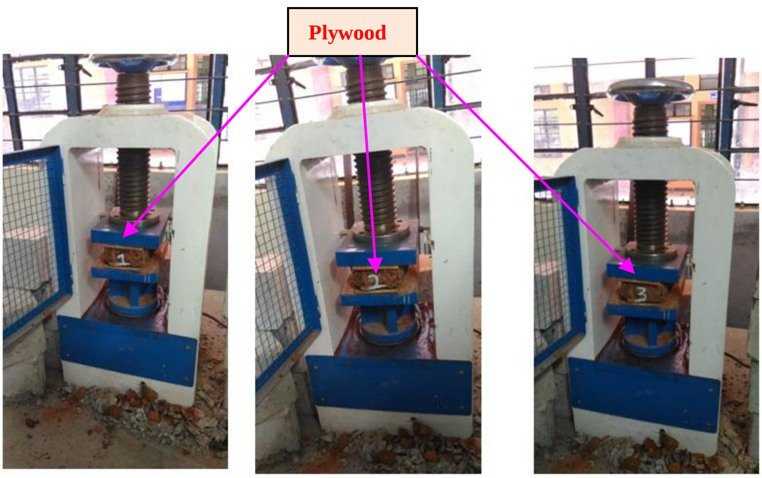

Fig. 5. Testing of Alamparai Fort bricks with plywood

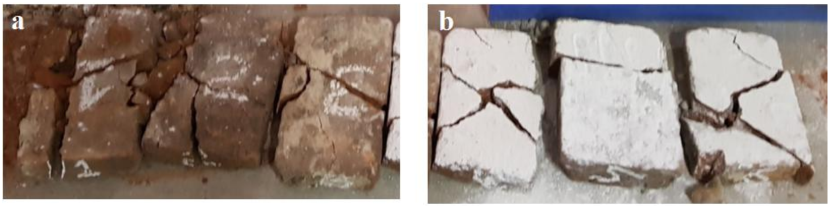

Fig. 6. Alamparai Fort bricks after testing with (a) Plywood (b) Talcum powder

Water absorption tests

The amount of water absorption of bricks was determined as per the specifications of Bureau of Indian Standard specifications (IS 3495-Part II; 1992). The water absorption values as recorded in the laboratory together with compressive strength are shown in Table 1 for brick specimens collected from Alamparai Fort.

Table 1. Mechanical properties of Alamparai Fort bricks, based on laboratory tests

Group	Location at the Fort	Water absorption (%)	Unit weight (kN/m^3)	Compressive strength in different directions (MPa) with plywood			with talcum powder		
				σ_{c1}	σ_{c2}	σ_{c3}	σ_{c1}	σ_{c2}	σ_{c3}
NWB	North wall	12.67	15.01	12.54	15.38	9.36	11.04	13.69	8.24
SWB	South wall	10.88	16.03	16.81	14.38	10.88	14.62	12.94	9.47
EWB	East wall *	13.22	12.54	11.32	10.85	8.42	10.19	9.33	7.16
WWB	West wall	11.55	18.34	17.53	18.22	11.45	14.90	15.49	10.30

σ_{c1}, σ_{c2}, σ_{c3}: Compressive strength in different directions: in stretcher, shiner and sailor positions, respectively.
* East Wall is facing seaward direction

Tests on Modern Bricks

Compressive strength tests and water absorption tests were performed on modern bricks following identical procedures as for the old bricks. The parameters obtained were compared with that of the strength characteristics and water absorption values of ancient bricks. As mentioned previously, compressive strength tests were carried out using 3mm thick plywood sheets and talcum powder separately. Testing of modern bricks is shown in figure 7. The water absorption values as recorded in the laboratory together with compressive strength are shown in Table 2 for brick specimens of modern bricks.

Fig. 7. Compression Testing of Modern Bricks

Table 2. Mechanical properties of modern bricks

Factory ID	Water absorption (%)	Unit weight (kN/m^3)	Compressive strength in different directions (MPa)					
			With plywood			With talcum powder		
			σ_{c1}	σ_{c2}	σ_{c3}	σ_{c1}	σ_{c2}	σ_{c3}
MTB	12.01	19.83	14.52	16.32	11.31	11.62	13.13	9.05
SBW	12.60	18.21	15.54	17.51	12.51	12.43	14.35	10.01
SPV	12.82	18.55	15.61	16.95	12.89	12.49	13.72	10.31

σ_{c1}, σ_{c2}, σ_{c3} : Compressive strength in different directions.

Bricks treated with red oxide solution

The bricks collected from the fort site were immersed in a solution consisting of red oxide and (potable) water mixed in the proportion of 1:4 by weight. The properties of the red oxide used are given in Table 3. The bricks were immersed in the solution for 24 hours and subsequently, the excess solution (if any) was drained out. This process was continued for another 24 hours and after ensuring that there was no trace of excess of red oxide on the surface, the bricks were tested for compressive strength. Figure 8 shows the fort bricks before and after treatment with red oxide solution. The recorded values with red oxide treatment samples are shown in Table 4.

Table 3. Properties of red-oxide

Sl. No	Parameter	Value
1.	Ferric oxide (Fe_2O_3)	90 %
2.	Silicon dioxide (SiO_2)	5 %
3.	Calcium oxide (CaO)	0.5 %
4.	Specific gravity	4.2 - 4.8
5.	Oil absorption	10 to 15 %
6.	Bulk density	2.2 gm/cm^3
7.	pH of 10% aqueous soln.	7.0 - 9.0
8.	Purity as Fe_2O_3	Minimum 90%
9.	Physical appearance	Free flowing dry powder

Table 4. Mechanical properties of Alamparai Fort bricks after treating with red-oxide solution

Group	Location at the Fort	Water Absorption (%)	Unit Weight (kN/m^3)	Compressive strength in different directions (MPa)					
				With plywood			With talcum powder		
				σ_{c1}	σ_{c2}	σ_{c3}	σ_{c1}	σ_{c2}	σ_{c3}
NWB	North wall	10.25	15.01	16.30	19.69	11.98	14.35	17.52	10.71
SWB	South wall	9.62	16.03	21.85	18.69	13.70	19.01	16.82	12.12
EWB	East wall*	11.31	12.54	13.58	13.13	10.19	12.23	11.20	8.59
WWB	West wall	10.11	18.34	21.91	23.68	14.77	19.07	19.83	13.39

σ_{c1}, σ_{c2}, σ_{c3} : Compressive strength in different directions.
* Facing seaward direction

Fig. 8. Alamparai Fort bricks (a) before treatment (b) after treatment

Results and Discussion

In-situ compressive strength values

The rebound hammer results obtained at the site show that the compressive strength was in the range of 12.50MPa and 41.60MPa. The lowest value of compressive strength (12.50 MPa) was recorded at the Eastern side of the fort, which faces the sea. The highest value of compressive strength of 41.60MPa was recorded at the Northern and Western sides of the fort, which are protected from direct sea breeze. The average compressive strength found for North, South, East and West walls respectively were 32.51, 18.96, 15.95 and 32.98MPa (Table 5, column 3). The Eastern wall had faced bombshells during periods of war, hit by high waves during cyclones and tsunami. The Southern wall is affected by close proximity of backwaters.

Table 5. Comparison of laboratory and in-situ Compressive Strength

Group	Location	Compressive Strength Values (MPa) In-situ test	Laboratory test † without red oxide solution	Ratio of In-situ comp. str. / Lab. comp. str.
(1)	*(2)*	*(3)*	*(4)*	*(5) = (3)/ (4)*
NWB	North Wall	32.51	15.38	2.11
SWB	South Wall	18.96	14.38	1.31
EWB	East Wall*	15.95	10.85	1.47
WWB	West Wall	32.98	18.22	1.81

* Facing seaward direction

† Values from Table 1, Column (6)

In general, the rebound hammer is used to determine the quality of concrete, whereas, in this study, an attempt has been made to assess in-situ compressive strength of bricks as a measure of non-destructive testing method. This approach requires extensive study and would be beneficial in the long run of testing of heritage structures made of bricks.

Laboratory compressive strength data

The ancient and modern bricks tested using plywood and talcum powder show that the compressive strength values were higher when tested with plywood and lower with talcum powder (Tables 1 and 2). The variation is of the order of 10-15 percent in the case of ancient bricks and 12 to 18 percent in modern bricks. The possible reason could be that the plywood was exerting binding effect as noted by Bati and Ranocchiai [5].

Modern bricks

The compressive strength values recorded (Table 2) show that the modern bricks possessed higher strength when compared to ancient bricks. The fort bricks were made of locally available materials and burnt at low temperatures at clamps [1], whereas the modern bricks had been burnt in kilns at temperatures of 1000°C or more [4]. However, no appreciable difference was noticed in water absorption between the two types of bricks.

Compressive strength of bricks after soaking in red oxide solution

Comparing ancient bricks soaked in red oxide solution (Table 4) resulted in higher compressive strength values of the order of 20 to 30% with the bricks that were not treated (Table 1) with the same solution. The possible reason for increase in compressive strength was that the pores of the brick were filled in with red-oxide. Nevertheless, more tests need to be performed to confirm this behavior. This method may be an ideal solution for treatment of existing ancient bricks, where required.

Water absorption values

Water absorption had reduced by 1 to 2 percent when the bricks were treated with red oxide solution in comparison to untreated bricks (Table 4). This emphasizes the application of red oxide as an additional measure to reduce water absorption by reducing porosity.

Comparison of in-situ rebound hammer test with laboratory compressive strength test

Table 5 shows in-situ average compressive strength obtained through rebound hammer tests and laboratory values of untreated bricks. The laboratory values are lower than the average values obtained at the site. The NDT test was carried out on existing intact bricks on the walls, whereas the bricks tested at laboratory were recovered from fallen bricks at the site, although good in appearance. The present results can be compared with other researchers particularly with Dizhur *et al.* [20], as they have done countrywide extensive studies in New-Zealand on vintage solid bricks. Notwithstanding many differences, comparison is made for indicative purpose. The porosity range reported by them was in the range of 17.9 to 32.6%, whereas Alamparai fort site bricks tested have shown a range of 10.88 to 13.22%. In similar lines the compressive strength reported by Dizhur *et al.* [20] for brick compressive strength was in the range of 10.1 to 37.9 MPa, whereas Alamparai fort site bricks tested have shown a range of 11.32 to 17.53 MPa. The compressive strength obtained through Non-destructive testing through rebound hammer at Alamparai site was in the range of 15.95 to 32.98 MPa. Dizhur *et al.* [20] reported for vintage bricks in New Zealand, presence of hematite attributing red color to the bricks, quartz present in all the samples tested by them. Presence of calcite indicating low firing temperature, whereas, researchers for Alamparai site [3] have reported that the bricks of the fort predominantly consist of quartz, andrasite, albite and orthoclase as main minerals (feldspar) with minor quantity of iron oxide (hematite), and consisted of calcium-poor clay. Dizhur *et al.* [20] had conducted scratch test at site and NDT rebound hammer test under simulated conditions at laboratory; whereas, in the present work, the rebound hammer test was done directly at the site and the compressive strength values appear to be with reasonable range as reported by them. They have reported scratch test yielding significant categorization of unit compressive strength with wide range. Future research can look into incorporating the scratch test coupling with in-situ rebound hammer test with more reliability of assessment of in-situ bricks without disturbing the masonry.

Conclusions

Heritage structures are symbols of representation of the cultural values of the people at a particular locality or country. Preserving and maintaining heritage structures generate revenue and employment by way of tourism. This emphasizes regular maintenance of heritage structures with professional skills which require site and laboratory investigations.

In general, bricks from heritage structures do not have any information on: (a) burning temperature, (b) composition of the earth material used and (c) mechanical properties. The non-destructive tests carried out at the site need to be extended to other heritage structures to arrive at a suitable correlation between in-situ and laboratory compressive strength values.

The bricks treated with red oxide solution in the laboratory, resulted in higher compressive strength and lower water absorption values. This method may be attempted on other heritage structures without causing any loss to the structural stability and architectural elegance. Nevertheless, more studies should be focused to arrive at useful results.

The numerous tests carried out reveal that significant differences exist in the method adopted to determine the strength characteristics of bricks. Higher values of compressive strength were recorded with plywood and corresponding values were low under identical testing conditions when talcum powder was applied. Interestingly, the same trend was observed when tested with modern bricks as well. Among all the tests performed, the compressive strength test on bricks is very important, as this value is used by structural design engineers to assess structural stability and conditions. Future research can look into incorporating the scratch test coupling with in-situ rebound hammer test with more reliability of assessment of in-situ bricks without disturbing / destroying the masonry.

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