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Investigations of Historical Structures - A Study of Rational and Irrational Forces

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ABSTRACT: Investigations of historical structures are a tricky matter. Not only for the risks involved but also for various sensitive issues linked with cultural aspects. Systematic analysis and modern investigative techniques are of a great help to ascertain the extent and cause of damages. An intuitive understanding of traditional structures, behavior of local materials and prevailing construction principles are also equally important. In quite a few cases the suitability of particular recommendation may remain debatable. Under such circumstances, knowledge based approach combined with sensitive handling of various stakeholders should ensure that the historical structure is at least protected from further deterioration or ultimate damage. And in such cases structural aspects and safety factors may overrule any other consideration. In this paper two case studies are discussed. Each one has immense heritage value because of historical and artistic reasons.

1 INTRODUCTION

Prior to any intervention in a historic building, diagnosis is of utmost importance. Conservation ethics demand that the investigation process should be non destructive to the physical fabric. Authenticity is of utmost importance and there is no place for conjecture. All of these principles and dictums are derived out of a sincere respect for heritage and history. But more often than not various sensitive issues linked with cultural aspects - myths, sentiments, safety and may be lack of awareness deter proper investigation. Insecurity and unfounded fears of public reprisal often prevent the owners to be entirely transparent. Under such circumstances, an intuitive understanding of traditional structures and behavior of local materials are of a great help to ascertain the extent and cause of damages of a historical structure. In quite a few cases the suitability of a particular retrofitting technique may remain debatable. Under such circumstances, knowledge based approach combined with sensitive handling of various stakeholders should ensure that the historical structure is protected from further deterioration or ultimate damage. And in such cases structural aspects and safety factors may overrule any other consideration. However, the projects become invaluable learning experiences. In this paper two case studies are discussed – one structure belonging to defense – and a famous religious structure. Each one has immense heritage value because of historical and artistic reasons.

2 2 RESTORATION OF LORD KITCHENER'S HOUSE

Restoration of Lord Kitchener's House (Bengal Area Mess) in Majumdar et al.(1996). Kolkata was a challenging task because of structural reasons. A part of this historic building was in severe structural state. Almost 200 years old, Lord Kitechener's house is one of the oldest structures within the Fort. Mainly a single storied structure situated on the rampart of the fort, the structure spans one of the vaulted passageways – a Gate leading out of the Fort. Just adjacent to

the structure is the moat, now virtually a dried up ditch. The basement foundation of the building is a vaulted structure and partially used as army barracks. The upper floor (the raised ground floor) now works as a guesthouse - hence the name Bengal Area Mess. First floor is partially built up - a much later addition - approximately 30 years old.

The veranda has a series of freestanding columns in classical style of Greek architecture (Fig. 1). From the moat side, the structure appears to be two to three storied due to the rows of columns on the outer side of the basement and topmost floor. While rest of the building was in sound condition, the columns abutting the veranda were in precarious state with wide cracks on capitals. As far as the documentation is concerned, a partial elevation drawing and some foundation details were made available to the conservation consultants. However, cooperation was extended for investigating the structure and to find out the cause of distress so that appropriate measures could be suggested. Most of the columns were in distressed state with visible settlement and subsequent cracks. It must be mentioned that prior to investigation process, the authority was pondering about demolition of the structure (at least partially) as a probable alternative.

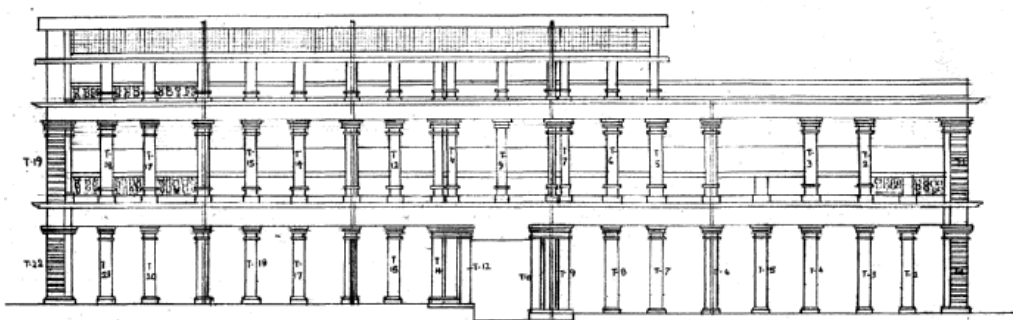

Figure 1 : The veranda from the moat side.

2.1 Investigation

To start with, causes for settlement of the supports and the changes in axial forces induced in the columns had to be established. The restoration measure was based on detailed structural analysis. For load calculations and analysis, the available drawings were taken as reference. The drawings showed the layout of the ground, first and second floors. Sections of the column row and foundations were shown in the drawing. However, it was not clear from the drawings, whether isolated or strip footing had been provided for columns.

A level survey was carried out to record the relative settlements of the columns. A finite element analysis for settlement gave the changes in the column reactions. The original dead load and the final column reactions were calculated (Fig. 2). Two types of footing cross sections were shown in the drawing. From the drawing it appeared that the type of foundation was not uniform - it was isolated in places and continuous in some areas. Load calculations and a stability analysis were carried out to identify the mode of failure. Investigation pointed towards differential settlement of foundation of columns.

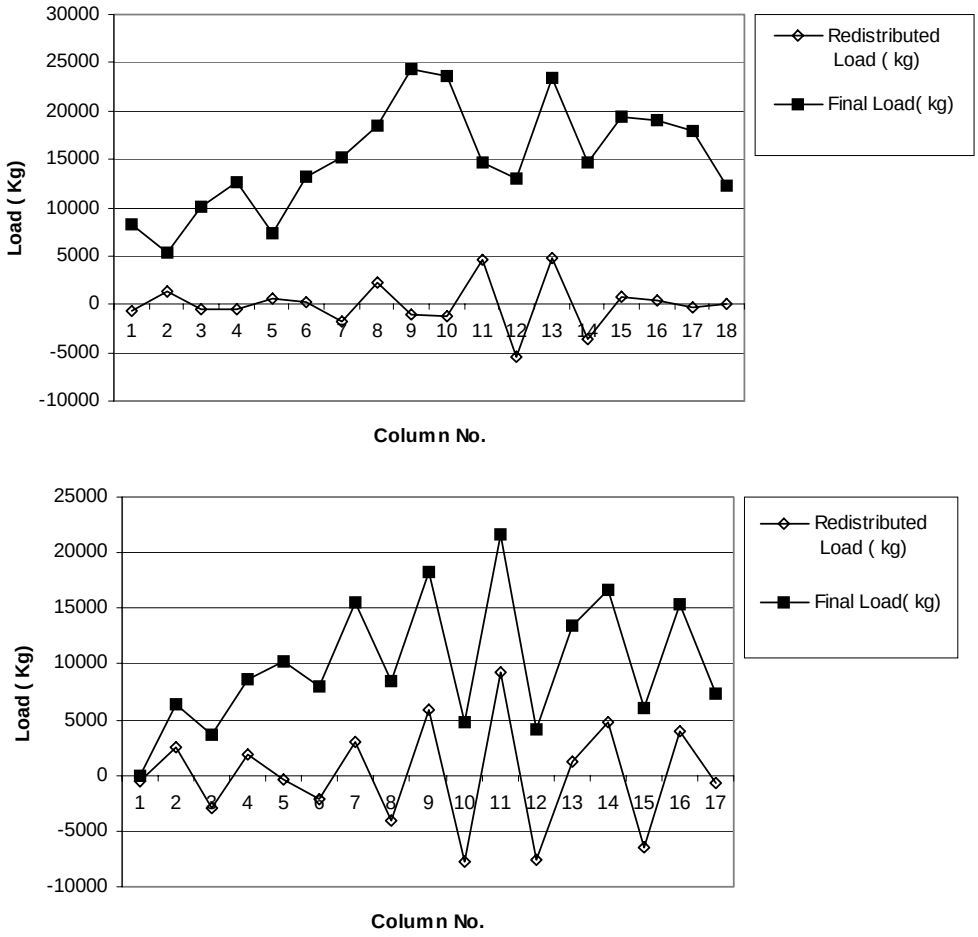

Figure 2 : Expected redistributed loads on columns (ground floor and first floor).

2.2 Diagnosis

Though there was certainty of the diagnosis, causes could not be ascertained properly. Was it due to later additions on the first floor to build more rooms for guest accommodation? Was there a possibility that the later construction did not take care of the bearing capacity of the soil and existing foundation? Or the problem was inherent due to different type of foundation system? Or was it simply the normal decay due to aging process? It was revealed much later; during the restoration process that the materials used for some parts of the original construction (during the colonial time) was of substandard quality. Whatever the reason, it was apparent from the load calculation that the bearing capacity of the soil was unable to sustain such pressure. Further, in the case of saturated clay there will be slow draining of pore water under extra pressure and this will lead to prolonged settling process.

2.3 Remedial measures

In order to relieve the pressure under the footing, it was proposed that the footing area had to be enlarged. Grouting of soil as an alternative approach was rejected owing to high saturation of the soil. First storey column brickwork also exhibited signs of distress in the form of vertical tension cracks, which is common in brittle material. The bricks have also weathered over the years. Strengthening of columns or rebuilding them as per existing design was two possible alternatives. Whereas the first one ensured safety and structural authenticity, the second alternative ensured maintaining the artistic authenticity. Preservation of original fabric and safety were of utmost importance and at any cost demolition of the building was to be avoided. So appearance took a back seat and safety prevailed. And compromise had to be made.

To strengthen the columns and to ward off further deterioration, decision was taken to encase the columns with reinforced concrete jacket. Encasing or jackets extending all the way to the foundation and integrated with the existing footing is expected to provide certain confinement to the brickwork and to stop further cracking and enhance the load carrying capacity of columns (Fig. 3).

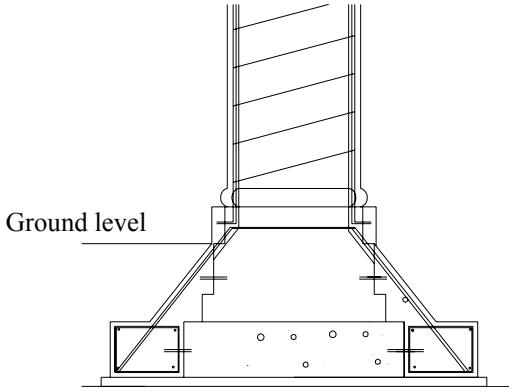

Figure 3 : Section showing jacketing of column and foundation strengthening.

2.4 Design of temporary structure

Strengthening of the column foundations as well as existing columns required careful designing of temporary support system. Arrangement of supporting columns with jacks and provision of extra ties with main walls of the buildings necessitated careful designing of scaffolding and scheduling of the activities. Each and every step was crucial. With great relieve to all the parties concerned, the building regained its strength and survived a probable demolition threat. The jacketed columns with its enlarged and disproportionate dimensions (Fig. 4) undermine the original artistic appeal – a price for the structure's survival for posterity.

Figure 4 : Ground floor columns after restoration.

Contrary to the above-mentioned case study, structural repair of cracks in Dakshineswar Kali Temple, Kolkata posed a different set of challenge where sentiments and aesthetics overruled the logical path of restoration measure.

3 3 RESTORATION OF DAKSHINESWAR TEMPLE, KOLKATA

Aesthetics or appearance becomes crucial in religious buildings. A serious crack in a part of the main temple structure required a through investigation. The temple had to be monitored for a span of time. The diagnosis of the problem is an interesting case in itself (Majumdar et al. 1995).

Located on the eastern side of the River Ganges at Dakshineswar on the outskirts of Kolkata, the Kali temple is of significant importance and is regularly visited by large number of people

from near and far. An accidental discovery of cracks in an internal chamber of the temple, prompted the temple trustees to approach various consultants seeking suggestion for repair of the same. After preliminary investigation by several organizations and experts, a joint meeting was held in the month of September 1994 where it was decided to form a steering committee. The consultants from I.I.T. Kharagpur were entrusted with the responsibility of organizing requisite investigation. In absence of reliable reports for the particular structure, the investigation relied on general knowledge and published documents on local constructions.

A south facing Navaratna Temple, the structure is square in plan measuring 90 m × 90 m based on a raised platform 22 m high. The temple is almost symmetrical in plan with a square sanctum sanctorum surrounded by a covered passageway for ritual parikrama or circuit. The passage way is covered with vaulted roof. The temple is constructed with brick masonry with lime mortar and concrete as per prevalent local construction techniques in those days. Roofing system is a combination of pendant type of dome and vaulted ceiling covered with sloping roof of lime concrete.

On the eastern side of the sanctum sanctorum and accessible through steps leading from the sanctum, is a narrow room - a mezzanine floor with antechambers at both ends. Though no authentic document is available, from all available sources it appeared that the mezzanine floor was a later addition, probably built around 1930's. The room was apparently kept locked for a long time and only recently it was opened when the crack was discovered.

The cracks spanned from one end to the other along ceiling, walls and floor (Fig. 5). Surprisingly no crack was visible on the roof or on the ceiling of the floor below or even on the external walls. From the nature of the cracks it appeared that in all probability the cracks were not a new phenomena. It is surprising why these were not observed or reported earlier, or why there was no mention of these cracks in official documents of temple trustees.

Figure 5 : Crack on the wall of the mezzanine floor.

3.1 3.1 Monitoring of cracks

Cracks were monitored by tell tale glass plates as well as mechanical strain gages. Mechanical strain gages showed changes in the crack width indicating the persistence of the cause (Table 1). However, seasonal fluctuation could not be completely ruled out.

Table 1 : Increment in crack width (mechanical strain gages).

Sl. No.	Date	Crack Width (mm)	Remarks
A. North wall (South ante-chamber)			
North Wall I			
1.	07.12.1994	-	Initial reading
2.	21.01.1994	0.02	
3.	23.04.1995	0.55	
North Wall II			
1.	07.12.1994	-	Initial reading
2.	21.01.1994	0.03	
3.	23.04.1995	0.35	
B. North wall of mezzanine chamber			
Bead I			
1.	07.12.1994	-	Initial reading
2.	21.01.1994	0.02	
3.	23.04.1995	0.09	
Bead II			
1.	07.12.1994	-	Initial reading
2.	21.01.1994	0.03	
3.	23.04.1995	-0.2	Inconsistent
Bead III			
1.	07.12.1994	-	Initial reading
2.	21.01.1994	0.01	
3.	23.04.1995	-	Inconsistent
C. West Wall (South ante-chamber)			
Bead I			
1.	07.12.1994	-	Initial reading
2.	21.01.1994	0.016	
3.	23.04.1995	0.091	

3.2 3.2 Probable reasons for crack initiation

From the Basu and Majumdar (2000) detailed study and rational reasoning it could be concluded with fair amount of confidence that the crack had developed due to the weakening of the structure while installing the mezzanine floor. While part of the wall was chipped out and the mezzanine slab was inserted, component of the weight of the inclined roof, the tangential one, was countered by the friction force at the top of the wall. Once a hinge forms at the top of this wall, this resisting force is no longer available and the inclined component of the weight caused tensile crack on the roof (Basu and Majumdar 2001). However few points were still not clear. Since the crack did not appear on outer walls, it is likely that the outer wall was still holding it out. Eventually, it was surmised that the crack will propagate to the outer face and the wall will tend to collapse.

The crack in the wall indicated change in the load distribution pattern in the wall. A hinge was formed at the bottom of the outer wall. The crack has released some of the initial stresses and has redistributed it to other parts of the structure. As for restoration measures any alternate arrangement of load distribution will induce stresses to other parts. As some parts of the temple structure were over designed, advantage could be taken to redistribute the load to these parts. Care was taken to avoid any kind of stress concentration in these regions. As a remedial measure, pinning was adopted as the most effective solution anchoring the outer wall with the inner walls (Figs. 6 and 7). Two pairs of anchor bars inserted on both walls intercepting the cracks and later grouted with cement slurry were given as proposal (Fig. 8). All the necessary details were worked out along with specification and working schedule. At all stages, it was taken care to involve all the stakeholders, with necessary explanation of the remedial measures and pros and cons of the various alternatives. Consequences of each step were deliberated and sugges-

tions were sought. Because of the sensitive nature of the structure, sentiments attached were given due consideration. However some of the steps were unavoidable if the safety of the structure had to be ensured.

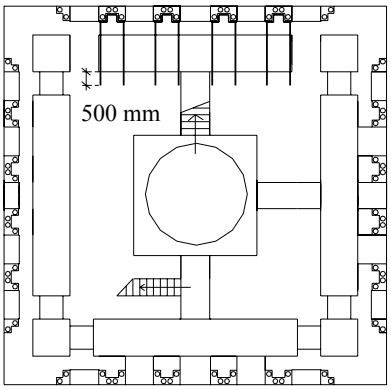

Figure 6 : Section showing the layout of the pinning arrangement at upper level.

3.3 3.3 Execution

Recommended procedure of pinning the damaged portion to the main wall was to take care of the fault. The implementation stage revealed the overriding power of irrational forces in play. The teamwork with all the stakeholders is an interesting learning experience.

The work started with grouting as per specification. It was just before the drilling process that reservations were expressed by the temple authority regarding probable damage to the structure inflicted during the drilling across the wall section. A compromise was worked by pinning it along the walls within a groove section rather than through the wall section, even though consultants had reservations about the reliability of this method. The owners did not accept even this arrangement and at the last stage the entire process was carried out in a different manner with the pins spanning at a safe distance from the walls. As the structural efficacy of this method is to some extent questionable, consultants had to disassociate themselves from the project. The authority went ahead with the process and completed the pinning in a modified manner. The restoration measure is now complete and quite a few years have passed by. It is necessary to monitor the crack to ensure long-term safety of the structure. But that onus now rests with the trustee members. Officially the building is not a listed one and the local authority do not have clear dictum about its conservation status.

The structure enjoys respect of pilgrims from all over. Hopefully the fabric has resolved its load distribution problem. The thousands of pilgrims and visitors, who regularly visit the temple, remain oblivious of the underlying stresses and tensions in play.

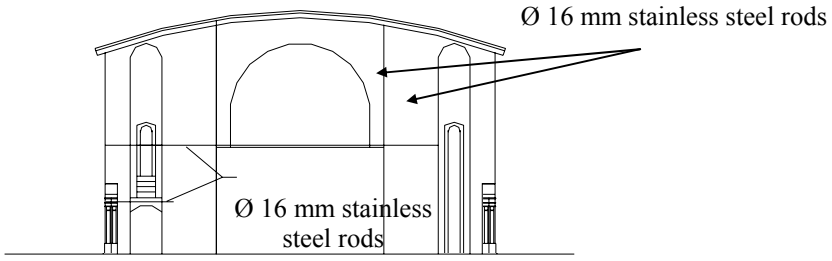

Figure 7 : Section through the sanctum sanctorum showing position of stainless steel rods.

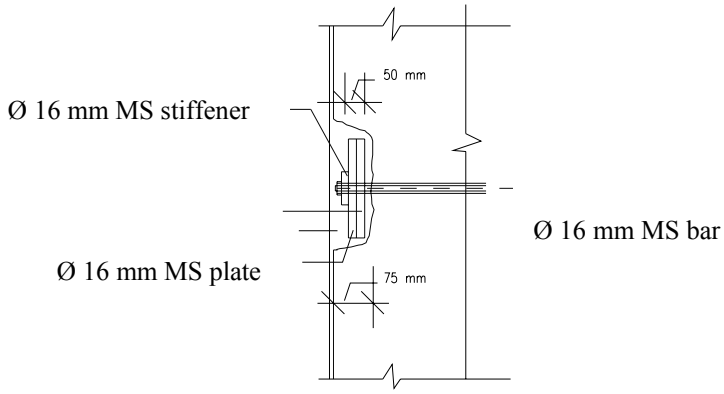

Figure 8 : Details of anchor bar.

4 CONCLUSIONS

The implementation stage in the above-mentioned case studies revealed the overriding power of irrational forces in play. The teamwork with all the stakeholders is an interesting learning experience. Knowledge based approach combined with sensitive handling of various stakeholders are equally important. Grading and enlisting are crucial under such circumstances. At any cost, one should ensure that the historical structure is protected from further deterioration or ultimate damage. And in such cases structural aspects and safety factors may overrule any other consideration.

REFERENCES

Basu, S. and Majumdar, S. 2000. Heritage Structures of Bengal: Form, Decay and Restoration Measures. *Vastuvidya 2000. International Seminar on Traditional Indian Architecture*, Department of Architecture & Regional Planning: I.I.T. Kharagpur, India.

Basu, S. and Majumdar, S. 2001. Mathematical Model for Deterioration in the light of Heritage Structures of Bengal, *Proceedings of the 1st International Workshop on Aging and Restoration of Structures*, Department of Civil Engineering: I.I.T. Kharagpur, India.

Majumdar, S., Basu, S. and Bhattacharyya, S.K. 1995. Repair and Restoration of Dakshineswar Temple, Kolkata . *Unpublished project report*: I.I.T.Kharagpur, India.

Majumdar, S., Basu, S., Bhattacharyya, S.K. and Dhang, N. 1996. Repair and Restoration of Bengal Area Mess, Fort William, Kolkata . *Unpublished project report*: I.I.T. Kharagpur, India.