REPORT ON INSPECTION, ASSESSMENT AND NONDESTRUCTIVE TESTING OF RESTORED BUILDINGS OF IIM AHMEDABAD: LIBRARY AND DORMITORY NO. 15
By IIT Roorkee September 2021

1. INTRODUCTION

Indian Institute of Management Ahmedabad (IIMA) approached Indian Institute of Technology Roorkee (IITR) for carrying out technical evaluation of the two buildings at IIMA campus which were repaired and restored in the recent past. The IIM Ahmedabad old campus houses academic blocks, faculty offices, student dormitories and a library. The construction of various buildings in the old campus was undertaken in the 1960s and since then the buildings have aged and now in the recent past different age related symptoms of deterioration started manifesting. Distresses started emerging not only in the external components but also in the internal built fabric. Efforts to preserve and restore the buildings under reference received nationwide attention and the repair and restoration works were initiated in the year 2015 by the agencies from Mumbai and Ahmedabad. While the proposed restoration of Library Building and Dormitory 15 has already been completed, the same for faculty is underway currently. A detailed restoration of building components, services and spaces was designed by a consultant based on field investigations. Seismic analysis of the buildings was undertaken by IIT Madras.

A team from IIT Roorkee lead by Prof. Umesh Kumar Sharma, Professor, Civil Engineering, undertook site investigations at IIM Ahmedabad in the first week of August 2021. This was followed by analysis of fresh field test results as well as evaluation of past investigations and restoration works undertaken in Library and Dormitory 15 Buildings. Prof. Yogendra Singh, Professor, Earthquake Engineering Department, I.I.T. Roorkee was also part of the IITR team for evaluating the seismic analysis performed earlier before the restoration of the two buildings.

The dormitory D15 was among the first set of dormitories that was constructed at IIMA campus during 1964-69. Being one of the oldest dorms, it was reported to show a higher level of architectural and structural distress compared to other dormitories. Another structure i.e., the Library building constructed between 1968-75 also required immediate repair interventions. The Dormitory D15 is a boy's dorm that consists of Ground + 2 floors with a mezzanine floor between ground and first floor in the toilet block. The Library on the other hand consists of Ground + 4 floors and is divided into two wings by a central circulation area which has two staircases (with a common landing) on either side. The buildings are load bearing reinforced brick masonry structures. While Library building has all masonry components as reinforced brick masonry, the Dorm 15 building's masonry has reinforcement only in arches, locations of embedded RWP lines and oculus openings. Both buildings have RCC slabs as storey floors and roof slabs.

2. SCOPE OF WORK

The conservation and maintenance manual submitted by the consultant for restoration of Library and Dormitory 15 Buildings had recommended undertaking periodic inspection, non-destructive testing and scientific analysis post restoration of these buildings. Towards that end, IIM Ahmedabad requested IIT Roorkee to do the needful for the two restored buildings under reference. The scope of the consultancy work assigned to IIT Roorkee includes:

- Technical inspection of the two restored buildings i.e., Dormitory D15 and Library, to examine the performance of the buildings after their restoration and thereby take note of distresses, if any.
- To undertake relevant non-destructive tests for ascertaining the soundness of structural members post-restoration.
- To peruse the investigations carried out by the original architectural and structural consultants engaged for the restoration of the two buildings under reference.
- To submit report on the adequacy of past structural restoration and the soundness of structural members.
- In case any deficiencies are noted in the previous structural investigations or any fresh distress or deterioration is noted then recommendation shall be made by IIT Roorkee for remedial actions. However, recommendations for the future investigations, if any, shall be part of the future scope of work.

3. OBSERVATIONS ON PREVIOUS INVESTIGATIONS AND RESTORATION WORKS

A detailed condition assessment of dormitory D15 and library buildings was carried out and condition mapping drawings were prepared by the earlier consultants before execution of restoration works. Site investigations and Non-destructive tests were also carried out to analyse the properties of the building elements, soil bearing capacity, state of building materials such as cement mortar, concrete, bricks and reinforcement, condition of structural members, etc. After the condition of the buildings was analysed, a restoration and conservation plan for restoration and up gradation of these buildings was prepared and executed.

The data and details of past studies received from IIM Ahmedabad for dormitory D15 and library buildings in the form of condition assessment reports, drawings and restoration details were thoroughly studied by the team from IIT Roorkee and the observations are briefly summarised below:

1. The past investigations utilised visual, non-destructive tests and chemical methods to ascertain the condition of the buildings. The distresses were categorised into architectural and structural defects, and solutions to treat both these kind of distresses were provided by the consultants.
2. Distresses were listed floor wise for both the buildings and were observed in different forms. Most commonly noted distresses were the presence of efflorescence, growth of moss and algae on the brick surface, rising damp, water seepage, disintegration of

bricks and mortar joints, cracks, disintegrated water proofing works, corrosion related cracking/spalling in both masonry and RCC members in dormitory D15 and library buildings.

3. The condition of foundations/footings in most cases was reported to be satisfactory. No global settlement was noticed anywhere. However, tall parapet walls were found to be deflected.
4. The nature and properties of structural materials namely, bricks, mortar and RCC were established in the previous investigations. Sectional details and location of bars in masonry were established.
5. Architectural distresses have been addressed effectively by the consultants and the associated agencies. The Rising Damp was addressed in 1m from GL on periphery wall. The plinth protection in full building periphery was reported to have been done along with anti-termite treatment. The removal of Moss Growth and Ficus Growth was done wherever needed. The Brick Replacement and brick pointing was done wherever needed. The Efflorescence & other Deposit Cleaning from Brickwork & Concrete were also undertaken at the distressed locations. Various water proofing works on the terrace were reported to be done.
6. Restoration and conservation works were seen to be undertaken keeping the heritage value of the buildings in mind. Various original spaces were restored to the extent possible along with their face lifting and refurbishment.
7. Structural distresses in masonry walls and arches in the form of cracks were treated by stitching the cracks using the Helifix bars. However, the source of cracks i.e., corrosion in most of the cases was left untreated.
8. High levels of chloride content and carbonation in the masonry is a clear indication of corrosion occurrence in the reinforced steel bars in the masonry. Increased diameters of horizontal and vertical reinforcements suggest considerable amount of corrosion has occurred in the steel bars that had led to development of sufficiently wide cracks in the masonry.
9. Carbonation and provision of inadequate cover thickness were reported to be the reasons of corrosion related distresses in RCC slabs. Spalled and deteriorated RCC slabs and other RCC elements were reported to be repaired and restored.
10. In Library Building, many distressed flat arches over the openings were reported to be reconstructed. RCC slabs in terrace of East Block and a portion at first floor was reported to be constructed afresh. The parapet walls on the Library Building were reconstructed and retrofitted with buttresses.
11. In addition, interior conservation works like re-introduction of common rooms in dormitory D15's ground floor, redesigning interiors, upgradation of mechanical, electrical and plumbing services were also undertaken in both the restored buildings in the past.

4. IN-SITU INVESTIGATIONS UNDERTAKEN IN PRESENT STUDY

A detailed condition assessment of the structural components of the restored buildings was conducted by a team from IIT Roorkee, which included visual inspection, distress mapping, in-situ non-destructive tests (NDT) and chemical investigations.

4.1 Visual Inspection and Distress Mapping

During the visual inspection, the externally observable surfaces of elements were inspected with the naked eye and note was made of the general condition of the structure in terms of any symptoms of distress in the form of cracks, deflections, surface degradation of masonry, efflorescence, seepage, corrosion related distresses in RCC etc. Detailed distress mapping was prepared.

4.2 Non-Destructive tests

Non-destructive tests were performed on few structural components of the buildings which were found to be distressed and at few locations where repair was carried out recently. The following NDT were carried out: (i) The ultrasonic pulse velocity (UPV) test was conducted to ascertain the condition and integrity of reinforced concrete members, (ii) Carbonation depth test, and ground penetrating radar (GPR) tests were performed to locate the bars in masonry joints and to know corrosion vulnerability in reinforced masonry, (iii) Concrete resistivity test was carried out to ascertain corrosion vulnerability of RC members. Representative test locations were selected on the various structural components of the buildings based on results of the distress mapping. Results of these tests were analysed in detail.

5. CONCLUSIONS FROM INSPECTION AND DISTRESS MAPPING

A thorough visual inspection of the library building and dormitory D15 building was carried out prior to the commencement of Non-destructive testing. A detailed description of the distresses observed in the two buildings during visual inspection was prepared. Following is the summary of distresses observed in Library and Dormitory D15 Buildings even after the restoration of these buildings:

1. The main structural distress observed in the Library Building was in the form of serious cracking of masonry piers in the West façade (near entrance) in lower two storeys. It was noted that these distressed portions were propped and preparation for some kind of grouting was underway. These cracks are observed to be due to corrosion of reinforcing bars in these masonry piers. They have appeared even after the restoration of Library Building due to the fact that corrosion of underlying bars in masonry was not addressed earlier.
2. The main structural distresses noted in the restored Dorm 15 Building were major cracking of masonry semi-circular arches near their joint with the supporting RC beams and seepage through walls and slabs adjacent to wet areas.

3. Minor cracks were also noted in the façade masonry of Library and Dorm 15 Buildings at various other locations. Some typical locations are walls, semi-circular arches, flat arches/lintels and piers.
4. Fresh symptoms of spalling of bricks, disintegration of mortar joints, effloresce, seepage, biological growth etc. were noted on the façades of both Library and Dorm 15 Buildings.
5. The cracking was observed not only in the external façade but also on members inside the buildings. Cracks were seen on the soffits of RCC floor slabs, which generally were minor except few cases where corrosion induced cracking and spalling was clearly evident.
6. Many locations in RCC staircase of Library Building and in few similar cases in Dorm 15 Building showed corrosion induced cracking, which were significant near the joints of railing with RCC.
7. RCC beams supporting semi-circular arches in Dorm 15 Building and in few cases in Library Building had corrosion induced cracking.
8. Above mentioned distressed locations were mostly those locations where fresh distresses had occurred after the repair and restoration of the Buildings under reference. The repaired and restored elements in both Library and Dorm 15 Buildings were generally found to be alright indicating that the past repairs were mostly satisfactory. However, the locations, especially in reinforced masonry elements, where the surface cracking had occurred due to corrosion of underlying reinforcing bars, were not addressed by the previous agencies and these locations have now started showing symptoms of distresses.

6. CONCLUSIONS FROM NON-DESTRUCTIVE TESTING

Based on in-situ NDT investigations carried out at the site, following conclusions can be drawn:

1. It is well known that the major factors responsible for reinforcement corrosion are chloride contamination and the atmospheric carbon dioxide, both of which alter the chemistry within the concrete or mortar microstructure and in the presence of moisture the process of corrosion gets accelerated. Therefore, in-situ tests to determine the depth of penetration of carbon dioxide and laboratory tests to determine the amount of chlorides present in the masonry mortar were conducted to ascertain the cause for the corrosion of reinforcement in reinforced masonry elements. As per the test results for chlorides, the chlorides were found to be within the acceptable range indicating that chlorides are not the cause of corrosion.
2. The carbonation tests in the mortar joints of masonry show that mortar was found to be carbonated till the reinforcement in the external walls. This shows that carbonation of mortar is the cause of corrosion in the masonry that led to cracking in masonry walls, piers and arches. The pH values also showed relative acidic environment in the mortar joints.
3. The durability performance of repaired reinforced concrete slabs indicated by concrete electrical resistivity results was found to be satisfactory in resisting flow of corrosion current, showing that repair of concrete was satisfactory.

4. Ultrasonic pulse velocity (UPV) (Indirect probing) values were used to form opinion about the quality and integrity of concrete in various RCC elements of the buildings, especially repaired locations. The results show that majority of UPV values in the show reasonably sound concrete. However, in the upper two storeys of the library building, few UPV values indicate either surface micro-cracking or delamination due to corrosion.

7. STRUCTURAL SAFETY OF BUILDINGS

Based on the past investigations and the investigations undertaken in this study, following observations are made on the structural safety of both the buildings:

7.1 Library Building

The library building consists of thick brick masonry walls with reinforcement provided in ties and mullions. In addition, reinforcement has also been provided between courses of masonry at different levels. There are a few reinforced brick masonry piers also provided in the library building. Reinforcement has also been provided in the arches. Corrosion of this reinforcement embedded inside masonry has been noted as the main cause of structural distress and deficiency in this building.

The results of previous structural analysis show that even after taking into account full contribution of reinforcement provided in the ties and mullions, not all the walls of the library building are safe under MCE and one wall is unsafe even under DBE. The current condition of the reinforcement is in fact suspect at least in external walls and elements in view of corrosion indicating that full contribution of reinforcing bars cannot be considered in the analysis.

7.1.1 Way Forward

Although Ahmedabad is located in Seismic Zone III, as per the current Indian code IS 1893-2016. However, a lot of damage was observed in Ahmedabad during 2001 Bhuj earthquake. Hence a site specific seismic hazard analysis is recommended for the site of the building. This site specific analysis should take into consideration the seismo-tectonic sources which can affect the site and the local soil conditions to estimate the soil amplification.

As corrosion of reinforcement embedded inside the masonry walls is the main source of distress in the building and this is also the major source of structural deficiency, a detailed structural analysis should be undertaken considering corroded bars to estimate the existing capacity of the walls. To control the corrosion, it may be required to replace the corroded reinforcement by new/stainless steel reinforcement, based on its feasibility. In such a case, the calculations need to be performed to estimate the required reinforcement for structural safety against gravity and earthquake forces.

As no information is available about the mechanical properties of the existing masonry, which has undergone significant aging and deterioration, it is important to

perform in-situ material characterization to estimate the properties of masonry crucial for estimating the structural capacity of the building.

The in-plane flexure/shear force demand and capacity in the walls should be re-assessed. In case the shear capacity is lower than the demand in some of the walls, suitable strengthening measures should be provided to enhance the capacity. These measures may be in form of addition of RC walls or use of a strong overlay over the existing walls.

However, it is to be noted that replacement/addition of reinforcement embedded in the masonry walls is a very difficult and a cumbersome task. Strengthening of existing building is also a challenging task and requires skill to design and implement.

7.2 Dormitory Building

The dormitory buildings are also masonry buildings, which suffered damage during the 2001 Bhuj earthquake. While their walls are seen to be unreinforced masonry walls, the arches, oculus openings and portions around RWP lines are in reinforced brick masonry. The RVS performed in the past evaluation has indicated several deficiencies and lack of good features, which could ensure good performance during earthquakes. These have large openings, there are no seismic bands and there are several stiffness and strength irregularity.

In the previous evaluation, nonlinear static analysis was performed for analysis of dormitory buildings. This analysis considers only a single mode of vibration and is reasonable to use only if the considered mode has more than 75% mass participation. In the dormitory buildings, the maximum modal mass participation is in the range of 30-40%. In this situation the results are not reliable.

The dormitory buildings have been found to be deficient in RVS as well as detailed analysis. The previous investigation, suggested to provide some shear walls in the ground storey to resist the earthquake forces.

The building also consists of a double storey height space. The masonry walls in this space are particularly vulnerable to earthquake actions, and it has been suggested to reduce the height of these walls to reduce the unsupported height of the taller walls.

7.2.1 Way Forward

As the masonry in the dormitory buildings has undergone ageing and deterioration, the in-situ properties of masonry need to be evaluated. The structural safety of the building needs to be re-assessed using the estimated in-situ properties. The evaluation carried out during past investigation indicates that the building is unsafe for estimated gravity and earthquake actions.

Considering the deterioration of masonry and structural deficiencies of the building, it will require both repair and strengthening. The repair will consist of replacing and

grouting of deteriorated masonry. The strengthening will require some interventions to enhance the structural capacity of the building. These interventions may consist of adding new structural members, like shear walls and/or strengthening of existing walls using structural overlays. The low wall density and double storey height walls identified in the past evaluation, indicate that the building will need some interventions in its structural configuration also.

8. SUMMARY AND RECOMMENDATIONS

Within the scope of the work assigned to I.I.T. Roorkee and based on the investigations undertaken, following overall conclusions and recommendations are made:

1. Investigations undertaken in this study show that the two masonry buildings of I.I.M. Ahmedabad under reference have undergone ageing and deterioration due to environmental exposure over an extended period of time. All symptoms of distresses reported in this study and those pointed out in the previous investigations before the recent restoration works are related to deterioration of exposed masonry and RCC members. The deterioration has been significant in the absence of protective layer of plaster as the buildings were planned and designed in such a way.
2. Though most distresses were addressed during the recent repair and restoration exercise, many fresh distresses have surfaced post restoration. The reason for reoccurrence of distresses is attributed to the inability in properly addressing the corrosion of reinforcing bars in reinforced brick elements namely walls, arches and piers in Library Building; arches and oculus openings in Dorm 15 building. It may be mentioned here that while the corrosion repair of reinforced concrete is possible and methods are well established, the corrosion repair of reinforced masonry is difficult and no clear effective methodology is known.
3. Based on the investigations, it can be reasonably assumed that the reinforcing bars in external and exposed reinforced brick masonry elements, especially the bars towards the outer wythe in these members are completely corroded having negligible structural contribution. This puts a big question mark on the structural capacity of these masonry elements and the buildings at large.
4. The preceding section of this report on structural safety of the buildings has clearly pointed out the shortcomings of previous structural analysis report. Even the previous report has also shown structural deficiencies in the Buildings, which have not been addressed conclusively. Therefore, it is recommended to undertake a fresh detailed structural analysis of the buildings for all the applicable load cases utilizing the actual in-situ properties of masonry and RCC and by considering the reinforcement to be completed corroded especially in the outer layers of external exposed masonry walls and elements. It is expected that the buildings shall require repair and retrofitting interventions to make them safe against various relevant load cases. Such an intervention, without altering the architecture of the building, will be a difficult and challenging proposition.
5. Till the above investigations and structural analysis (which were not in the current scope of this study) are undertaken, all the serious structural distresses noted in this report should be addressed immediately according to the below mentioned procedures:

a. The cracked reinforced masonry elements namely (i) piers on the west side façade and cracked arches of the Library Building and (ii) cracked arches in Dorm 15 Building should be repaired using fine grained cementitious grouts. The recommendations of ASTM C 476 shall be followed in this regard. The grouts should be just medium strength cementitious grouts (compressive strength in the range of 20 to 30 MPa) only and high strength epoxy or other forms of high strength grouts shall not be used. The grouts should have good flow ability and non-shrinking properties ensured by suitable admixtures. The cracks shall be then stitched using the technique employed earlier during the restoration of these buildings (using helical stainless steel reinforcing bars).
b. The other distresses namely spalling of bricks, disintegration of mortar joints, effloresce, seepage, algae growth etc. on the façade elements shall be repaired and restored using the procedures used earlier. The procedures used earlier by the previous consultant to address these distresses have been found to be satisfactory.