A report on

Structural Condition of Chander Kunj Army Towers (CKAT) at Silver Sand Island, Vytilla, Kochi

(IITM Report-4)

Submitted by

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Chennai – 600 036, India
November 5, 2023

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1 Introduction

Figure 1 shows a view of the Chander Kunj Army Towers (CKAT) of the Army Welfare Housing Organisation (AWHO) in Silver Sand Island in Vytilla, Kochi, Kerala. The construction completion and occupancy certificates for these buildings (i.e., Towers A, B, and C) were given in February and March 2018, respectively. These buildings consist of 264 apartment units – owned by people who served and serving the Indian Military and cover an area of about 36,111 square metres. This report focusses on the distress of only Towers B and C.

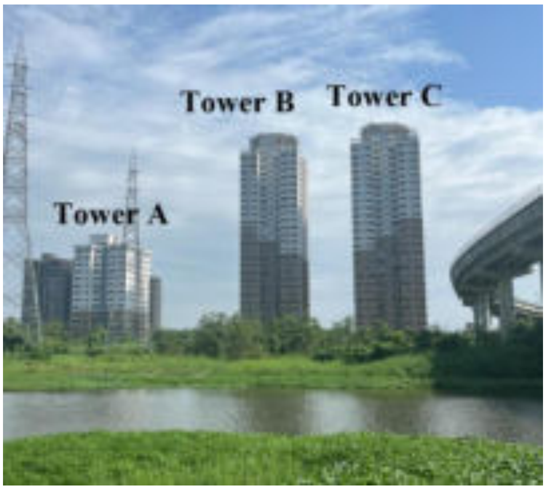

Figure 1 General view of the Chander Kunj Army Towers, Vytilla

Unfortunately, within about one year after construction, many corrosion-induced cracks were observed in the reinforced concrete (RC) elements of Towers B and C, especially in the basement. This continued to happen, and more RC elements started exhibiting severe corrosion-induced cracking and spalling throughout Towers B and C. Later, it became a practice to inadequately patch-repair the cracks and spalled regions in Towers B and C. However, as expected (due to the halo effect), such inadequate patch repairs were failing within a few months; exhibited by additional corrosion-induced cracking/spalling of the adjacent regions – indicating a greater distress level. During the last few years, the steel reinforcement continued to corrode. Now, after about five years of construction, the corrosion and structural conditions of Towers B and C have aggravated significantly and indicate that continuing to occupy them could be risky and a threat to the lives of the occupants. The remainder of this report discusses the involvement of IIT Madras in chronological order and the various findings through visual inspections, laboratory and field tests, and the following reports:

- MACE Report; dated September 15, 2020; by Mar Athanasius College of Engineering (MACE) in Kothamangalam
- BV Report-1; dated December 3, 2020; by Bureau Veritas India Pvt. Ltd. (BVIL)
- IITM Report-1; dated December 14, 2020; by IIT Madras & MACE
- IITM Report-2; dated February 5, 2021; by IIT Madras
- BV Report-2; dated May 15, 2021; by Bureau Veritas India Pvt. Ltd.
- Evaluation report of the BV Report-2; by Ciby George, Anil Raj and S.S. Prasad
- IITM Report-3; dated September 26, 2021; by IIT Madras
- BV Report-3; dated April-May, 2023; by Bureau Veritas India Pvt. Ltd.
- Evaluation report of BV Report-3; dated September 2023; by Sarala M.S. and Anil Raj
- Structural Assessment report; dated March 31, 2022; by GEC Barton Hill, Thiruvananthapuram

2 Studies undertaken by IIT Madras

As requested by the CKAT residents, Prof. Elson John of MACE, Kothamangalam and Mr. Naveen Krishnan (Research Scholar, IIT Madras) visited CKAT on September 3, 2020. During the visit, several corrosion-induced cracks and reappearance of cracks along the periphery of the patch-repaired regions were observed. I was involved in further discussions on these observations. On September 15, 2020, Prof. Elson submitted a report (MACE Report) citing the major observations made during the site visit. See Appendix A for the MACE Report.

On December 3, 2020, BVIL Kochi submitted a test report to AWHO (hereinafter called 'BV Report-1'). The test regions, test types, and data analysis in the BV Report-1 were found to be incomplete and/or inadequate to make inferences for developing recommendations for durable repair of the entire building. Later, IIT Madras collected concrete samples from the building and determined the chloride content. Then, a report (herein called 'IITM Report-1') dated December 14, 2020, incorporating the visual observation by IITM and MACE, chloride test results from IIT Madras labs and the inconsistencies in the BV Report-1 was submitted to the Resident Welfare Association (RWA). See Appendix B for IITM Report-1.

On January 19, 2021, as requested by the RWA authorities, I (along with Prof. Elson John of MACE, Kothamangalam and Mr. Abhilash Joy of StruFoCon Engineers Pvt. Ltd., Kochi) conducted a walk-through inspection of Towers B and C of CKAT in the presence of a few owners and IITM Report-2 with the key observations was submitted (dated February 5, 2021). See Appendix C for the IITM Report-2.

Later, BVIL conducted additional tests and submitted their second report (BV Report-2; dated May 15, 2021). As requested by RWA, the BV Report-2 was evaluated by IIT Madras and it was found that the repair strategies suggested in the BV Report-2 were insufficient to achieve a corrosion-free service life of another 20+ years with minimal maintenance and without requiring any major repairs. In the evaluation report submitted by IIT Madras (IITM Report-3; dated September 26, 2021), it was recommended to provide a revised report with additional chloride and carbonation tests conducted on intermediate floors so that adequate scientific measures to arrest further deterioration of the building can be undertaken at the earliest. See Appendix D for the IITM Report-3.

On September 24 and October 3, 2023, I (along with Mr. Abhilash Joy of StruFoCon Engineers Pvt. Ltd., Kochi) again visited Towers B and C and observed that the level of corrosion has significantly aggravated. Now, the towers exhibit much more inadequately repaired regions and much more widespread and severe cracking & spalling in most of the RC elements in the buildings, as compared to what we saw in January 2021. Numerous falling hazards along the corridors, staircases, and periphery of the buildings exhibiting very high levels of distresses are visually evident in these buildings. This report (IITM Report-4) summarizes the key findings and inferences from the above-mentioned reports and the visual observations made during the visits on September 24th and October 3rd. In my opinion, these are sufficient to make decisions to ensure the long-term safety of the occupants, which is of utmost importance.

3 Key findings and inferences

Following are the key findings and inferences obtained from the reports based on the visual inspections, field tests, and/or laboratory tests conducted by my team (including my students and staff at IIT Madras, Prof. Elson John of MACE, and Mr. Abhilash Joy of StruFoCon) and the other reports forwarded to me by a few CKAT residents.

3.1 Basements were identified as one of the most critical parts of the buildings. Severe leakage of water through the peripheral retaining walls occurs due to high water table, especially during the rainy season. Despite multiple repairs by grouting on the negative side of the retaining wall, leakages were found to reappear in the same locations (See Figure 2). Dampness, peeled-off paint, spalled concrete and exposed corroded rebars on the roof slabs in the basement were visible (See Figure 3). Seepage and stagnation of water in the basement caused by inadequate waterproofing at the construction joints and improper slope for rainwater drainage were also observed.

3.2 Columns, shear walls, and beams in the basement were found to be severely corroded causing extensive cracking and spalling of concrete (see Figure 4 and Figure 5). Most of the corbels have also suffered significant damage and it was found that multiple patch repairs were done, see Figure 6. In several long-span and deep beams, metal pipes (red-painted; for fire-fighting system) pass through the bottom portions of beams, the consequences of which must be checked by a structural consultant (see Figure 7).

3.3 Columns, shear walls, and beams in the intermediate floors of the building have significantly deteriorated due to steel corrosion, see Figure 8, Figure 9 and Figure 10. Multiple patch repairs at various locations on the elements were also observed during the multiple visual inspections since 2020.

3.4 De-bonding of heavy granite panels/wall claddings on the shear walls near the lifts/elevators was observed in all the floors. This is a severe falling hazard and a serious safety concern. This poses high risk to the users, as all the occupants would wait and/or pass below these granite panels. As shown in Figure 13 & Figure 14, it is surprising to see that numerous of these heavy granite panels are affixed with duct-tape, which is not adequate to safely carry their weight and hold them in place, if fully de-bonded. Figure 11Severely corroded rebars, loose concrete and inadequate filling of mortar between the cladding and the walls were seen upon removal of the claddings (See Figure 11). It was found that the damaged regions in the shear walls were inappropriately patch repaired at multiple locations near the elevators (See Figure 12).

3.5 Tenting, popping-up and cracking of floor tiles (see Figure 15) because of corrosion of the underlying concrete slabs were observed at several locations. Upon removal of floor tiles at random locations, it was seen that many steel reinforcement have severely corroded with significant cross-sectional area loss, see Figure 16.

3.6 Tenting, popping-up and cracking of floor tiles in the landing of staircases was observed at various locations in multiple floors (see Figure 17). Also, extensive cracking and spalling of concrete were visible on the waist slab, landing beam & slab of staircases in most of the floors (see Figure 18). Further, cracks were observed in the periphery of the patch-repaired regions of the waist slabs, indicating corrosion induced by the halo effect.

3.7 Repeated unscientific patch repairs to cover up the distress due to corrosion of rebars were observed at various locations on the numerous RC elements. The cracks were found to be repaired by placing filler materials/mortar without taking adequate measures to address the root cause and prevent halo effect. These patch-repairs are not durable and are failing within a few months (see Figure 19). Propagation of earlier cracks, formation of new cracks and repeated repairs associated with these indicate ongoing active corrosion and inadequate repair procedures. Patch-repairs without electrochemical treatments or undercutting cannot control corrosion due to the residual chloride effect and halo effect. The residual chloride effect is due to possible chlorides in the substrate concrete and inadequately cleaned rebars. surface/presence of rust and the halo effect is due to the pH difference between the repair and substrate concretes. Such repairs are not appropriate for ensuring long-term safety of the occupants.

3.8 Insufficient cover depth of RC elements was reported by BVIL in the report dated May 15, 2021. The cover concrete specified as per sketch ST-WD-REB.117C-018 is 35 mm for columns, 30 mm for beams and 30 mm for slabs. However, as per Clauses 8.2.2.1 and 26.4.2 of IS 456:2000, the minimum nominal cover to be provided in “severe” exposure conditions is 45 mm.

3.9 All the samples tested by IIT Madras and some tested by BVIL show that the chloride content is more than the permissible limit of 0.6 kg/m^3 of concrete, as specified in IS 456:2000. The source of chlorides seems to be the chloride-contaminated mixing water, curing water, aggregates, and/or admixtures during construction. This indicates that corrosion of the elements is due to the significant amounts of chlorides present in the concrete and not necessarily due to the air-borne chlorides.

3.10 In the structural stability assessment report submitted by BVIL dated April 2023, 77% and 53% of UPV test results in Tower B and C, respectively, indicate doubtful concrete quality (pulse velocity below 3.75 km/sec). ‘Doubtful’ is the worst category as per IS 516 (Part 5/Sec 1):2020. Moreover, 85% of locations in the Tower C lift wells were found ineligible for testing due to debonding of concrete.

3.11 The study conducted by GEC Barton Hill in Thiruvananthapuram found that there is no record of quality control measures adopted during the construction of the towers. The lack of good quality control during the construction might have resulted in the continued use of poor-quality materials and premature corrosion of the building.

3.12 Structural analysis of the towers performed by GEC Barton Hill and reviewed by BVIL showed that the capacity of columns and shear walls does not meet the demand under lateral load and all the elements with a demand-to-capacity ratio greater than one require retrofitting.

NOTE: Softcopies of photographs and videos collected during the various visual inspections and testing of the buildings are also submitted along with this report.

4 Conclusions

4.1 Towers B and C are exhibiting severe corrosion due to presence of chlorides in concrete. The source of chlorides can be mixing water, curing water, and/or sand used for construction.

4.2 Presently adopted routine patch-repairing procedures without adequate electrochemical treatments are insufficient to address the root cause and extend the service life of the buildings for 50+ years, which is the current expectations of the owners.

4.3 The present corrosion condition has arisen not only due to inadequate construction and material testing practices; but also due to the delays in implementing durable repair measures as soon as the corrosion of steel was observed within a year of construction.

4.4 Considering the nature and current condition of the buildings, additional condition assessment would be highly challenging, time consuming, and would involve significant disturbance to the occupants. Also, such exercises are not required at this stage, because such exercises may not bring in new information that is critical, not included in this report or not extractable from various reports available.

4.5 Continued occupation of these buildings is a serious threat to the lives of the residents and hence, highly risky.

4.6 Current structural/corrosion conditions are so severe that implementing repairs that would ensure long-term safety of the users would be very challenging.

5 Recommendations

Considering the information gathered since September 2020 and the safety of the users including the residents, visitors, and/or workers, the following are **strongly recommended**.

(a) **Immediate removal of all the partially de-bonded vertical granite panels above the elevator doors and all loose concrete from the staircase elements.** These are severe falling hazards and a serious threat to the lives of the users, even during the proposed evacuation.

(b) **Immediate evacuation of all the residents from Towers B and C.**

(c) **Immediate removal of all the remaining partially de-bonded vertical granite panels around the elevators.**

If you have any queries or need assistance in this matter, please feel free to contact me at pillai@civil.iitm.ac.in or +91 90032 28158.

Regards,

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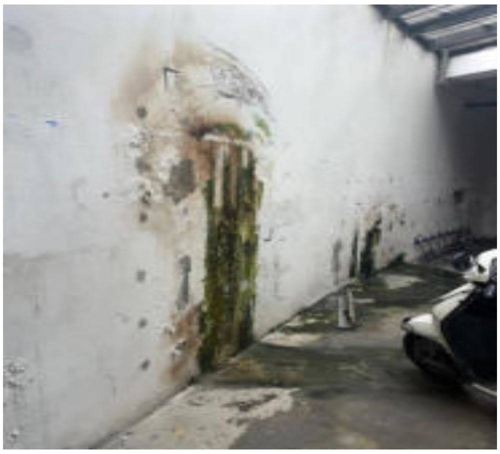


(a) Flaked paint, corrosion stains and algae growth on retaining walls and water leakage

(b) Flaked paint, corrosion stains and algae growth on retaining walls and water leakage

(c) Flaked paint and corrosion stains on retaining walls

(d) Flaked paint and corrosion stains on retaining walls and water leakage

(e) Water dripping from beam and dampness on beam during rain

(f) Water leakage during rain

Figure 2 Water leakage and consequent corrosion visible in the basement

(a) Cracked, spalled and exposed corroded rebars at various locations

(b) Cracked and delaminated concrete

(c) Peeled-off paint, cracked and delaminated concrete

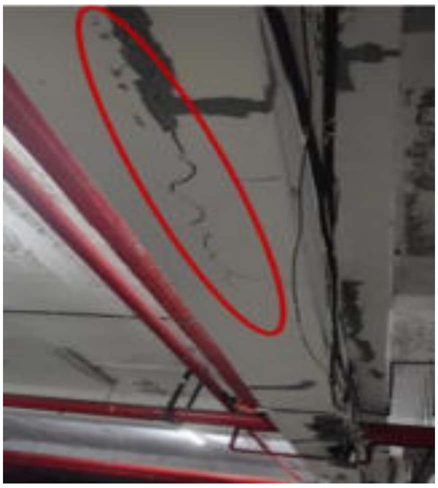
(d) Flaked paint, dampness, corrosion stains and cracks

(e) Spalled concrete and exposed corroded rebars

Figure 3 Visual distresses on the roof slabs in the basement

(a) Cracks in the beam-column joint and side face of a beam

(b) Cosmetic repair of cracks



(c) Cracks reappeared in patch-repaired region in beam

(d) Spalled concrete and cement paste applied over rebar to cover up corrosion of rebar

(e) Spalled concrete in beam and patch repairs

Figure 4 Visual distresses and patch repairs done in the basement

(a) Cosmetic repair of spalled region

(b) Wide crack

(f)

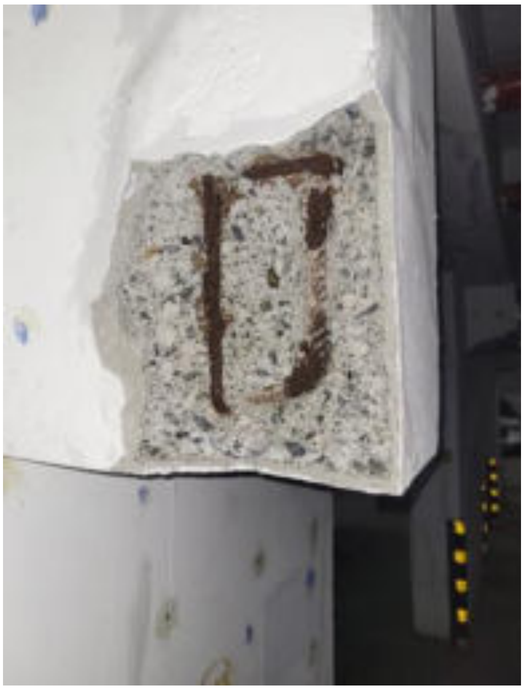
(c) Cosmetic repair of cracks and spalled region

Figure 5 Wide cracks and patch repairs done in shear walls in the basement

(g) Cosmetic repair of spalled region and cracks

(h) Cosmetic repair of spalled region and cracks

(i) Cosmetic repair of spalled region in corbel and cracks in shear wall and beam



(j) Spalled concrete and exposed corroded rebars

Figure 6 Patch repairs and exposed corroded rebars in corbels in the basement

Figure 7 Fire-fighting system pipes passing through the beams

(a) Spalled and corroded rebars

(b) Spalled and exposed corroded rebars

(c) Cosmetic repair of spalled region

Figure 8 Visual distresses and patch repairs in columns located in various floors

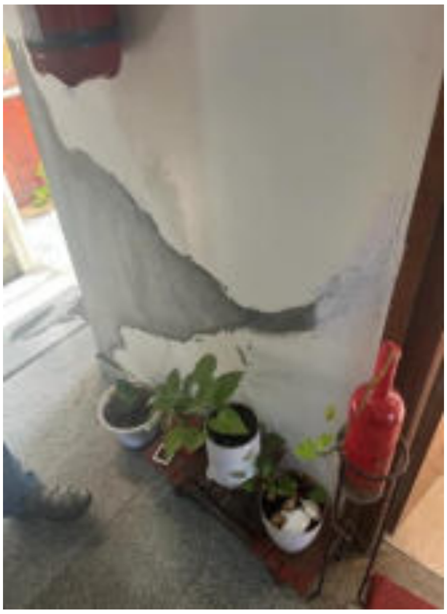
(a) Cracked, delaminated and spalled concrete

(b) Cracked, spalled concrete with cosmetic repair

(c) Cracked and delaminated concrete

(d) Wide longitudinal crack in concrete

(e) Spalled and severely corroded rebars



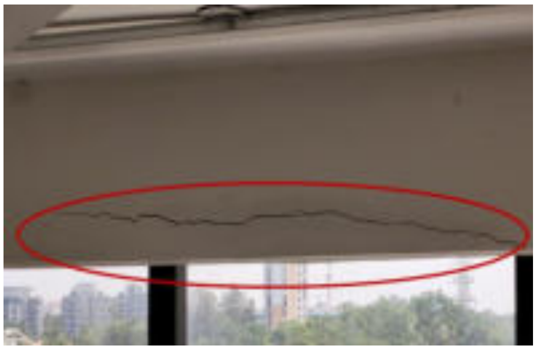
(f) Cosmetic repair of spalled region

Figure 9 Visual distresses and patch-repairs in shear walls located in various floors

(a) Multiple longitudinal cracks in the side face and soffit of a beam

(b) Wide longitudinal crack in the soffit of a beam

(c) Multiple longitudinal cracks in the side face and soffit of a beam



(d) Wide longitudinal crack in the side face of a beam

(e) Spalled and severely corroded rebars

(f) Cosmetic repair of spalled region

Figure 10 Visual distresses and patch repair in beams located in various floors

(a) Disintegrated concrete and severely corroded rebars

(b) Disintegrated concrete and severely corroded rebars visible after removal of de-bonded cladding

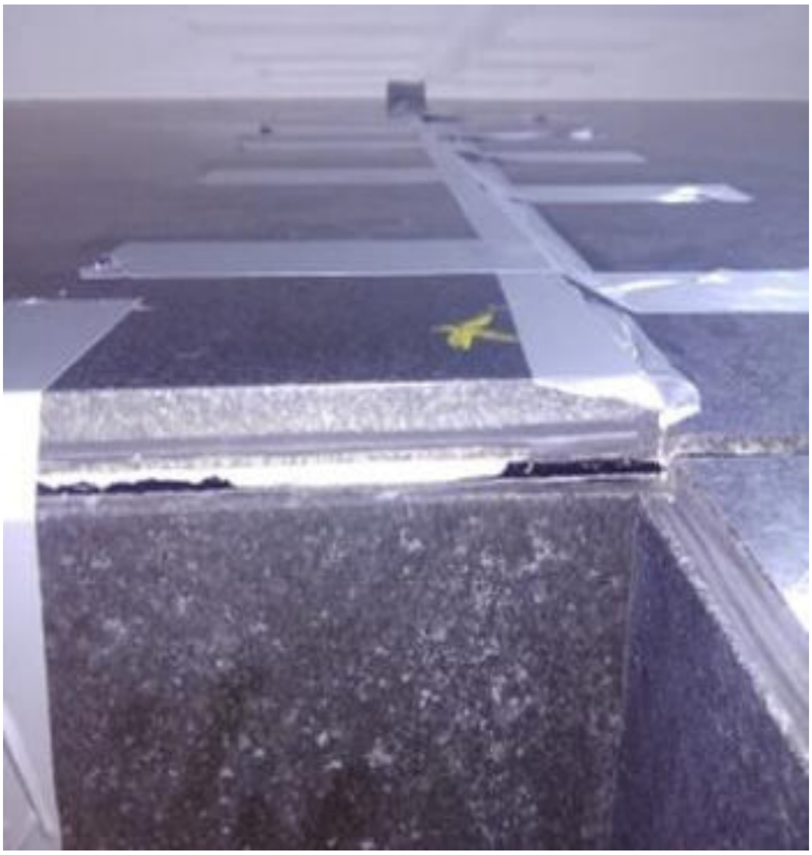
(c) Severely corroded rebars with significant cross-section loss

Figure 11 Distresses in shear walls near the elevators

(a) Cosmetic repair of spalled region of the shear wall near elevator

(b) Cosmetic repair of spalled region

Figure 12 Inappropriate patch repair of damaged region in shear walls near the elevators (this should not have been done this way)



(c) De-bonded granite cladding hanging dangerously above lift door (looking upward)

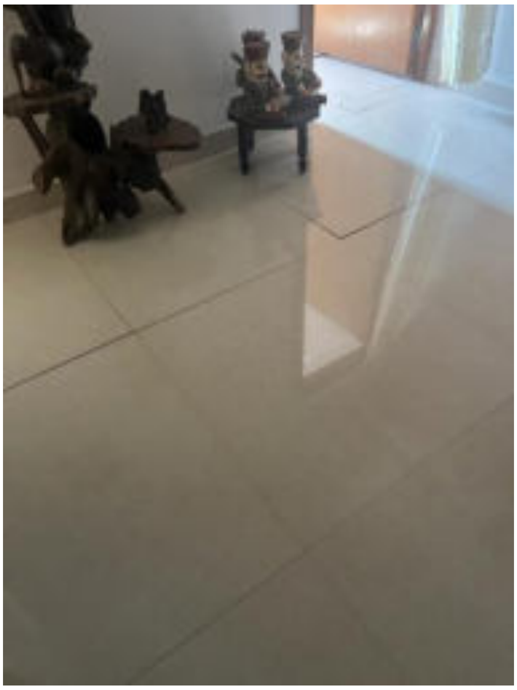
(d) De-bonded granite cladding inadequately held using tape

Figure 13 De-bonded claddings of shear walls near the elevators temporarily fixed using duct-tape (severe falling hazard)

(a) De-bonded cladding inadequately held using tape

(b) De-bonded cladding inadequately held using tape around the entire elevator area in the basement

Figure 14 De-bonded claddings of shear walls near the elevators temporarily fixed using duct-tape (severe falling hazard)



(a) Tenting and popping-up of tiles

(b) Upheaval of tiles

(c) Popping-up of tiles

Figure 15 Tenting and popping-up of floor tiles in various floors

(a) Severely corroded rebars

(b) Disintegrated concrete and severely corroded rebars

(c) Spalled concrete and exposed corroded rebars

(d) Disintegrated concrete and corroded rebars with significant cross-section loss

(e) Disintegrated concrete and severely corroded rebars

Figure 16 Deteriorated concrete and heavily corroded rebars visible upon removal of tiles

(a) Upheaval and tenting of tiles

(b) Disintegrated concrete and corrosion stains

Figure 17 Tenting and popping-up and cracking of floor tiles in the mid-landing of staircases and ground floor stairs

(a) Wide crack in waist slab

(b) Spalled concrete and exposed corroded rebars

(c) Spalled concrete and exposed corroded rebars

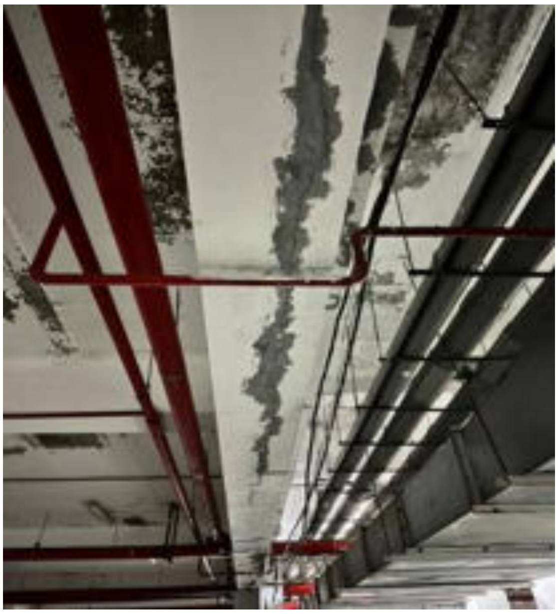
(d) Cracks and cosmetic repair of spalled region

(e) Extensive cracking

(f) Extensive cracking and delamination

(g) Cracks at various locations

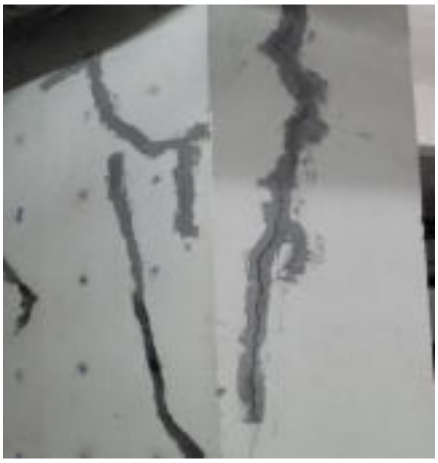
Figure 18 Extensive cracking and spalling of concrete in staircases



(a) Cracks reappeared in patch-repaired beam

(b) Cracks reappeared in patch-repaired shear wall

(c) Cracks reappeared in patch-repaired beam



(d) Cracks reappeared in patch-repaired shear wall

(e) Cracks reappeared in patch-repaired beam

Figure 19 Reoccurrence of cracks in already patch-repaired locations

APPENDIX A

Report by MA College, Kothamangalam

REPORT ON VISUAL INSPECTION OF CHANDERKUNJU ARMY TOWER AT SILVER SAND ISLAND, COCHIN

Project

CHANDERKUNJU ARMY TOWER

SEPTEMBER 2020

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Letter No: MACE-EJ-2020-01

15 September, 2020

To

Col. Chandra Mohanan Unnithan

Silver Sand Island

Vytilla, Kochi.

Subject: Report on Site visit to Chander Kunj Army Towers at Silver Sand Island, Vytilla, Kochi

Dear Col. Chandra Mohanan Unnithan,

As requested by you, Er. Naveen Krishnan (Research Scholar, IIT Madras) and I visited the Chander Kunj Army Towers in Silver Sand Island, Vytilla, Kochi on September 3, 2020 (Thursday). Guided by Capt. Paul and Col. Sibi, we had a walk-through visual inspection of the various parts of the tower buildings. The observations made are as follows:

Visual observations

Figures 1 to 13 provide representative photographs showing the condition of the various elements of the building. Some of these and other observations made during the visual observations are listed below.

1. Reinforced concrete columns, beams, sunshades, slabs and walls have significant cracks. Most of the cracks are due to the corrosion of embedded steel.
2. Vertical cracks on the columns were observed in many places, which seem severe and need critical IMMEDIATE attention for arresting corrosion, providing adequate reinforcement, and ensuring safety of the structure and inhabitants.
3. Re-occurrence of cracks in the already patch-repaired portions were observed.
4. The cracks are repaired by just placing filler materials even without opening the cracked portion and performing necessary treatments or precautions (in many cases).
5. It was informed that there was severe water leakage from the retaining wall at the basement level. During the visit, repair works of these retaining wall were in progress.

The leakage seems to be mainly through the construction joints. There were 15-20 cm wide regions with damaged plastering. The waterproofing compound and plastering materials were being re-applied. For the drainage of the water during the repair works, weep holes (small drainpipes) were being installed. The local water proofing is done on the exposed surface of the retaining wall of the basement, which seems insufficient to solve the problem permanently.

6. Water is leaking from the water tanks.
7. The photos taken before the repair of the damaged portions shows that, in many places the reinforcement are corroded severely/completely. It seems only the local repair with mortar is done without addressing the root cause and replacing the severely corroded rebars or adding new rebars.
8. Some of the cladding granite in the lift portion are delaminated from the wall. This is a severe falling hazard.
9. While walking through the building, foul smells were felt. Hence the details of the drainage and plumbing are also need to be checked.

Figure 1. Repairing of the leaking portions in the basement

Figure 2. Improper cutting of the beams for fire pipes

Figure 3. Dampness in the walls and water tank walls

Figure 4. Cracks on the beams due to corrosion

Figure 5. Improper repair of cracks in columns with filler material

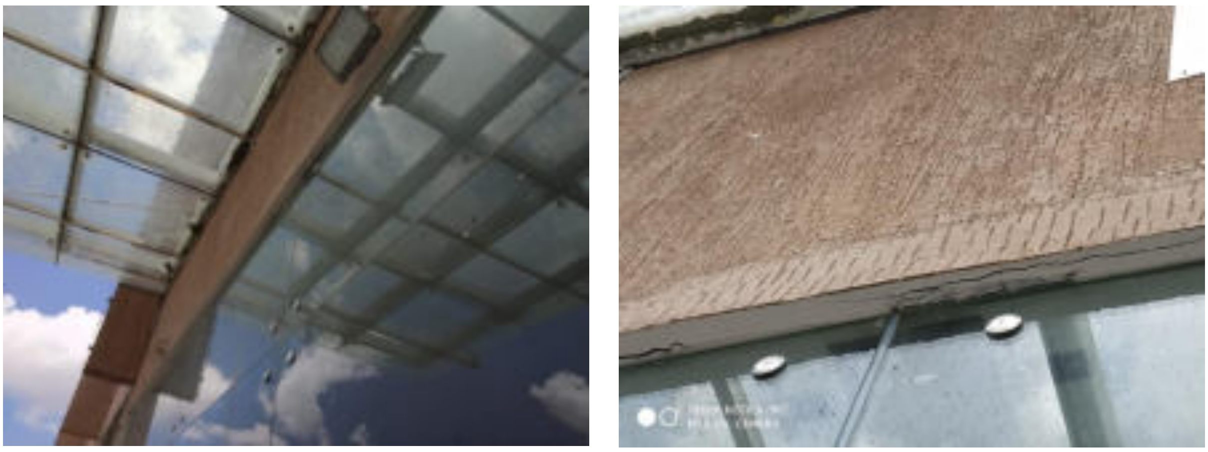


Figure 6. Reoccurrence of cracks in the already repaired beams

Figure 7. Rapaired beams on the balcony of almost every floor and many shades

Figure 8. Cracks in structural elements

Figure 9. Occurance of cracks in the visinity of already repaired portion

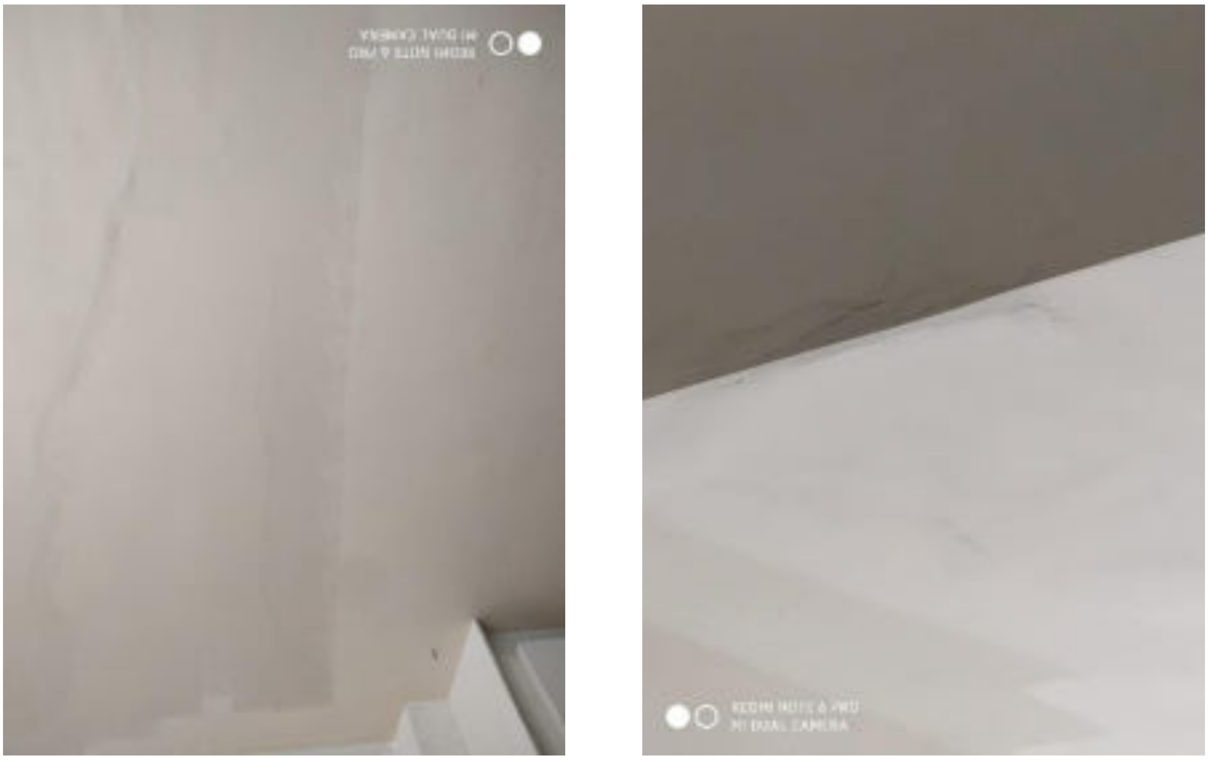


Figure 10. Reoccurance of cracks in the repaired portions

Figure 11. Cracks in columns due to corrosion of reinforcement

Figure 12. Cracks in shade

Figure 13. Water is gettng staginated in the floor

Recommendations

Following information is required to identify the root cause and suggest feasible and durable repair/strengthening procedures.

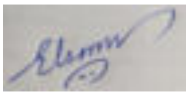
1. Chloride concentration and profile in the concrete used in the East and West side of the buildings
2. Carbonation depth in concrete cover on West and East side of the buildings
3. Half-cell potential of steel on the regions adjacent to the severely corroding regions on various structural elements
4. Compressive strength of concrete (if concrete coring is not allowed, use an impact hammer to obtain the possible compressive strength; then, if needed, more realistic estimations can be made by testing cored concrete cylinders)
5. Uniformity of cover depth of reinforcement in beams and columns
6. Original test reports on soil at site
7. Original test reports on water used
8. Original test reports on steel reinforcement used
9. Specifications and original test reports on the concrete used
10. Specifications and original test reports on the plastering material used
11. Detailed structural drawings of the structures.
12. MEP drawings of the Buildings.

Conclusions

In short, the corrosion and corrosion-induced structural distress in the structure are in severe stage considering that the building was constructed just about 5 years ago. Moreover, in many places the cracks are re-appearing in the same region or occurring in the nearby portion (halo effect) immediately after the patch-repair. This shows the present procedure of crack-filling, patch-repair etc. is not sufficient to address the root cause and give a long life for the structure. As the structure is exposed to coastal atmosphere, immediate steps should be taken to preserve the structure in its present condition to avoid a disaster.

Please feel free to contact me if you need further guidance/consulting.

Regards,



Dr. Elson John

APPENDIX B

Report-1 by IIT Madras

A Review on the Report by Bureau Veritas on

Investigation of distress in basement floor and terrace level overhead tanks of Army Welfare Housing Organisation "Chanderkunj Army Towers" at Silver Sand Island, Vytilla, Kochi, Kerala (November 2020)

&

The results of the chloride tests conducted at IIT Madras

Prepared by

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Elson John
Professor
Department of Civil Engineering
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Kothamangalam, Kerala

Submitted to

Brigadier Sunil Kumar

ARMY WELFARE HOUSING ORGANIZATION (AWHO)
New Delhi

December 14, 2020

Review of the report by Bureau Veritas (dated Dec 3, 2020) for Chander Kunj Apartments, Silver Sand Island, Vytilla, Kochi

&

Results of the chloride tests conducted at IIT Madras

References:

(i) email from Brig. Sunil Kumar, President RWA addressed to Prof. Manu Santhanam dated September 23, 2020
(ii) my email to Brig. Sunil Kumar, President RWA, CKAOT dated December 6, 2020; and
(iii) email from you dated December 5, 2020 with the BV Report (dated Dec 3, 2020)
(iv) email from you dated December 13, 2020.

We have reviewed the report on the Chander Kunj Apartments by Bureau Veritas (BV). Based on earlier submitted photographs, videos, and inputs from the site visits by Prof. Elson John and Mr. Naveen Krishnan, it was found that the beams and columns are also severely corroded/cracked/spalled and patch repairs were also failing at fast rate. This raised concerns about the chloride conditions of the concrete used. Later, all the tests done by IIT Madras and some tests done by BV indicate more than allowable amounts of chlorides (as per Table 7 of IS 456) in the concrete used in the about 5-year old structure. This indicates the presence of admixed chlorides in the concrete; either through mixing water, curing water, aggregates, and/or admixtures used.

The report from BV is based on the tests on basement floor, stilt floor, retaining wall and overhead water tank; and does not provide sufficient data on the corrosion and chloride conditions of the beams and columns of the buildings. Without the test results and inferences on the severely corroded/patch-repaired and distressed members, **the BV Report is incomplete and inadequate to make necessary inferences and recommendations** to achieve durable repair/rehabilitation work for the three buildings.

Table 1 provides my responses/suggestions against all the inferences in the BV Report. Also, the recommendations made in the BV Report are inadequate to achieve a service life of multiple decades with minimal maintenance and without major/repeated repairs. **Please arrange to conduct more tests and data analysis as suggested in Table 1 and revise the Sections D, E, F, and G of the BV Report.** Also, the collected data should be assessed in a quantitative manner, wherever possible. The submitted BV report do not comment on the corrosion and chloride conditions of the members that exhibited and are exhibiting corrosion/cracking. The revised report must reflect these. Note that Item 6 in Table 1 shows that the chloride contents (from the tests conducted at IIT Madras) in the concrete samples supplied is higher than the allowable chloride content of 0.6 kg/m^3 (as per IS 456).

As mentioned in my previous communications, these three towers need IMMEDIATE attention. Hence, I request you to avoid further delays due to bureaucratic and other reasons; because such delays will lead the building to a more unsafe situation for the residents. Hence, **we strongly suggest to prioritize, obtain the revised report in two weeks, and complete the suitable repairs before the upcoming monsoon season**. If a revised BV Report cannot be obtained in two weeks or a reasonable time, then it is suggested to engage other agencies and expedite the corrosion/chloride condition assessment of the representative/critical elements of the buildings and proceed.

We both are available for an online meetings with the various stakeholders for any technical discussions. Prof. Elson John is available for site visits also.

Table 1: Specific comments on inferences in BV Report

#	Inferences as given in the BV report	Response from IIT Madras
1	From the observations of extracted concrete core samples, it is evident that the extracted Samples are uniform, homogeneous, and free from voids / honeycombs. From the concrete core test results, it is inferred that the strength of concrete in the tested basement floor RC retaining walls were found to be satisfactory.	Inference is reasonable
2	From the results of Non-destructive ultrasonic pulse velocity & rebound hammer tests, it inferred that the quality of concrete in the tested RC members were found to be **satisfactory**	About 50% of the test results presented are in 'Doubtful' category. Hence, BV's inference that the quality of concrete is 'satisfactory' is not reasonable.
3	From the results of Cover meter studies, it is inferred that the cover concrete provided to the rebar were **adequate** in most of the tested RC members except at isolated locations where cover concrete was observed to be less.	As per BV report, the range of cover depth measured are: Columns - 45 to 60 mm Retaining walls – 25 to 65 mm Beams – 25 to 35 mm Slabs – 25 to 40 mm These values must be compared with the structural specifications/drawings before making an inference that it is 'adequate'. Hence, the BV's inference that cover depth is 'adequate' is not reasonable. ***R3a***: *Please include a comparative table with information on specified cover depth and observed cover depth.*
4	From the results of Half-Cell Potential Measurement test, it is inferred that the probability of corrosion fall in the category of **"High probability of no corrosion to Uncertainty of corrosion"** (i.e., **Initial stage to Moderate** stage) in the tested RC members.	No data from the corroded/patch-repaired beams and columns are provided. ***R4a***: *Provide photos of measurements* ***being taken*** *at all the 16 locations; at least for representative locations.* ***R4b***: *Provide data from beams and columns that are/were experiencing corrosion/cracks etc. Also, include photographs and grid size of measurement points. Consider Appendix X1 in the ASTM C876-15 while making inferences.*

<table>
<tr>
<td>5</td>
<td>From the results of Carbonation test, it is inferred that the carbonation is limited to surface concrete only in the tested RC members.</td>
<td>5 to 10 mm carbonation depth in 5 years is reported. Based on Tutti's model, corrosion due to carbonation can initiate at about 30 and 100 years at locations with carbonation depths of 10 and 5 mm, respectively.

<u>R5a</u>: No further carbonation test is recommended.</td>
</tr>
<tr>
<td>6</td>
<td>From the results of chemical tests on concrete samples collected from RC members it is Inferred that the Chloride content in most of the tested samples is found to be with in the Permissible limit except for the concrete sample of column & slab of Basement floor at Tower —B , where the chloride content exceeds the permissible limit & Sulphate content is found to be with in the permissible limit. Further, the pH value of the tested concrete is found to be satisfactory.</td>
<td>The chloride data in BV report are given in the Table 6a.

Table 6a Data reproduced from BV report
<table>
<tr><th>Location</th><th>Chloride content reported (kg/cm3)</th></tr>
<tr><td rowspan="4">Retaining wall - Basement floor</td><td>0.045</td></tr>
<tr><td>0.04</td></tr>
<tr><td>0.028</td></tr>
<tr><td>0.096</td></tr>
<tr><td rowspan="2">Tower-B basement floor</td><td>1.12</td></tr>
<tr><td>1.12</td></tr>
<tr><td rowspan="2">Tower-C basement floor</td><td>0.34</td></tr>
<tr><td>0.26</td></tr>
<tr><td rowspan="2">Parking area</td><td>0.37</td></tr>
<tr><td>0.04</td></tr>
<tr><td>Tower A - stilt floor</td><td>0.4</td></tr>
<tr><td rowspan="3">Water tank</td><td>0.045</td></tr>
<tr><td>0.045</td></tr>
<tr><td>0.079</td></tr>
</table>
IIT Madras conducted experiments on samples collected from the exterior elements of the building. See Table 6b.

Table 6b Photo of the samples collected and acid soluble chloride content (kg/m^3 of concrete)
<table>
<tr><th>Photo of the sample collected</th><th>Acid soluble chloride content (kg/m^3 of concrete)</th></tr>
<tr><td>
</td><td>2.46</td></tr>
<tr><td></td><td>4.94</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td></td>
<td>Some of the obtained chloride contents are above the allowable chloride concentration as per Table 7 in IS 456 (see below).

Table 7 Limits of Chloride Content of Concrete
(Clause 8.2.5.2)
<table>
<tr><th>Sl No.</th><th>Type or Use of Concrete</th><th>Maximum Total Acid Soluble Chloride Content Expressed as kg/m³ of Concrete</th></tr>
<tr><td>(1)</td><td>(2)</td><td>(3)</td></tr>
<tr><td>i)</td><td>Concrete containing metal and steam cured at elevated temperature and pre-stressed concrete</td><td>0.4</td></tr>
<tr><td>ii)</td><td>Reinforced concrete or plain concrete containing embedded metal</td><td>0.6</td></tr>
<tr><td>iii)</td><td>Concrete not containing embedded metal or any material requiring protection from chloride</td><td>3.0</td></tr>
</table>

The discrepancy in the results from BV and IITM raises some confusions. Also, the samples collected from basement and water tank elements alone are not representative of the entire building. Chloride contents in corroded/corroding beams and columns are essential to make useful inferences towards making good recommendations.

<u>R6a</u>: Perform chloride tests at 20 locations on the beams and columns that are/were corroding. Photos of sample locations are also needed.

<u>R6b</u>: Provide the calculations used for expressing the results in kg/m³ of concrete.

<u>R6c</u>: Provide the chloride concentration of the water in the surrounding river.</td>
</tr>
<tr>
<td>7</td>
<td>Seepage of water in basement roof slab & retaining wall is essentially due to very high-water table in the vicinity of the area</td>
<td>Inference is reasonable.</td>
</tr>
<tr>
<td>8</td>
<td>Leakage & damp patches in peripheral retaining walls in basement floor are essentially due to in-effective waterproof treatment at the junctions of the wall, the construction joint regions of the wall leading to ingress of water into the basement through retaining walls. (Further, it is reported that, during rains leakage from retaining wall is severe)</td>
<td>Inference is reasonable</td>
</tr>
</table>

9	Stagnation of water over roof slab is essentially due to improper slope provided towards disposal of rainwater.	Inference is reasonable
10	Dampness/damp patches in basement ceiling slab is essentially due to continuous leakage of water from the roof slab.	Inference is reasonable
11	Peeling of paint may be due to dripping of water from ceiling slab at few locations.	Inference is reasonable
12	Cracks in RC members of overhead water tanks may be due to corrosion of rebars. Corrosion of rebars is essentially due to carbonation of cover concrete & ingress of moisture into RC members	Inference is not reasonable. Carbonation depth reported is 5 mm. Also, pH reported in water tank elements are 12.15, 12.17, and 12.30. These do not support the reasoning that corrosion is due to carbonation and moisture. ***R12a***: *Provide information on the locations of corroding rebars and chemical analysis of adjacent concrete.*

If you have any queries or need clarifications, please feel free to contact us.

Regards,

Radhakrishna G Pillai   Elson John

APPENDIX C

Report-2 by IIT Madras

Department of Civil Engineering
Indian Institute of Technology Madras (IITM)
Chennai – 600 036

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Associate Professor
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February 5, 2021

To
Brigadier Sunil Kumar
President, Residents Welfare Association (RWA)
Chander Kunj Army Towers (CKAT)
Vytila, Kochi

Subject: Report on visual inspection of CKAT, Vytila on Jan 19, 2021 and prior inputs

Dear Brigadier Sunil Kumar,

As requested by the authorities at CKAT, I visited the CKAT on January 19, 2021 (between about 11 and 1 pm). I was accompanied by Prof. Elson John and Er. Abhilash. Following is a brief on the key observations made during the visit.

In the presence of the RWA authorities, walk-through inspections of Towers B and C were conducted. Severe corrosion-induced cracking of structural elements, associated patch repairs (repeated patch repairs at same locations, as informed by tenants), signs of leakages etc. were observed. As a particular case and to confirm the corrosion condition, the cracked/delaminated location of one of the long beams in the basement was autopsied (i.e., delaminated cover concrete was removed using a hammer and chisel). This region was found to be an already repaired region and significant steel rust/corrosion products were observed (see Figure 1).

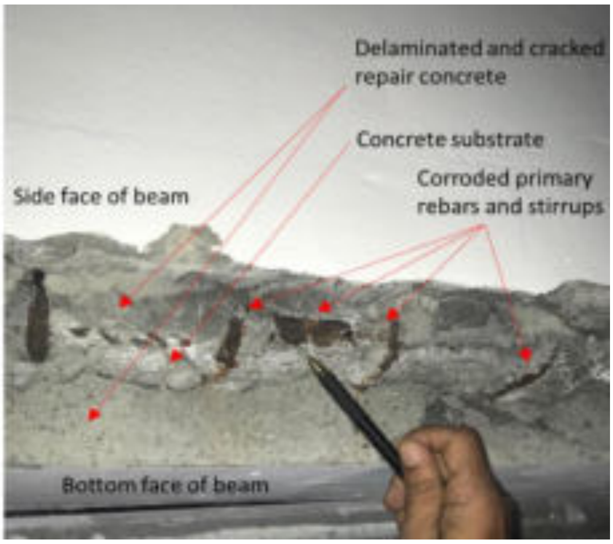

Figure 1 Ongoing corrosion in the repaired beam in the basement

This cracking and delamination might have occurred because the prior repair could not arrest the corrosion of the primary reinforcement and stirrups. This is due to the possible presence of sufficient chlorides in the concrete in contact with the steel. As informed and observed, it seemed that the repair was done by covering the substrate concrete and steel using repair concrete (without any undercutting and electrochemical treatments). The lack of coarse aggregates in this repair concrete indicated that this was possibly microconcrete. Such patch repairs with microconcrete and without undercutting and electrochemical treatments cannot control corrosion due to (i) the residual chloride effect and (ii) the halo effect. The residual chloride effect is due to the possible chlorides in the substrate concrete and the inadequately cleaned steel surface/rust present and the halo effect is due to the difference in the chemistry between the repair and substrate concretes. The microconcrete was about 2-inch thick, which seemed more than required cover thickness for such members. Also, non-metallic mesh for confinement was observed at the side faces (it seemed that mesh was not present at the bottom face), questioning the effectiveness of mesh in confining the concrete.

Also, several exterior columns, beams, and other elements in the basement and other floors were found to have numerous patch repairs, as already reported in earlier report by Prof. Elson John (dated September 15, 2020). A few photographs from the same is provided in Figure 2 and the full report is enclosed, for your quick reference. During my visit on January 19, 2021, these locations were easily identifiable because of the plaster and paint with slightly different texture and colour, respectively. Also, I was also informed of the propagation of earlier cracks and formation of new cracks at various locations and associated repeated repairs - indicating ongoing active corrosion and implementation of inadequate repair procedures. It was also informed to us that multiple repair works have been going on at the same locations (say, repeated repairs).

Figure 2. Leaking of basement wall (performance of recent repair must be checked during the upcoming monsoon)

Figure 3. Fire pipes passing through the beams (the consequences must be checked by a structural consultant)

Figure 4. Patch repair of cracks in columns

Figure 5. Cracks on patch repaired columns (indicate inadequate repair practice)

(a) (b)

Figure 6. Rapaired beams, columns, sunshades, etc. at many floors (see the changes in texture and colour) exhibiting additional cracks - indicating inadequate repair practice

Based on these and the results from the prior laboratory tests conducted by IITM and other inputs, the possible root cause of this premature corrosion seems to be the presence of chlorides in the concrete used. In this context, I am also attaching a copy of the earlier report by me and Prof Elson (dated December 14, 2020) with the evaluation of BV Report and the test results from IITM labs, for your quick reference. The source of chlorides could be the mixing and/or curing water and/or fine aggregates. To confirm the level of contamination at various parts of the building and advice on a suitable repair strategy, further sample collection and field/laboratory tests are required.

The total fee for the site visit and this report is Rs. 25,000 plus GST and payable to "Registrar, IIT Madras". Please find enclosed the invoice. If you need further information, please feel free to contact me.

Sincerely,

Radhakrishna G. Pillai

Dr. Radhakrishna G. Pillai
Associate Professor
Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY MADRAS
Chennai, TN 600036, INDIA

Enclosures:

1) Report (dated September 15, 2020) on visual inspection by Prof Elson John and Mr. Naveen Krishnan
2) Report dated Dec. 14, 2020 with the evaluation of BV Report
3) Invoice

APPENDIX D

Report-3 by IIT Madras

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Dr. Radhakrishna G. Pillai
Associate Professor

September 26, 2021

To,
Col. C. M. Unnithan
263, Dinesh Vihar
AWHO Complex
Thazampur P.O.
Chennai – 600 130

Subject: Responses on the report by Bureau Veritas (dated April 2021) – Chander Kunj Apartments, Silver Sand Island, Vytilla, Kochi

Dear Col. Unnithan,

I have reviewed the first BV Report (dated December 2020) and highlighted the drawbacks. It seems that BV has taken it seriously and performed some additional tests and incorporated the findings in the Report 2 (dated April 2021). However, Report 2 still lacks (1) the presentation of data on the tests conducted on basement and stilt floors and (2) tests on intermediate floors of the buildings. Table 1 provides my responses/suggestions against some of the key inferences in the BV Report 2. The inferences provided clearly indicate that the root causes of corrosion could be either admixed chlorides and/or carbonation. It is recommended to conduct additional chloride and carbonation tests on every other intermediate floors and provide a revised report with the data and tests from intermediate floors as well. These tests can be done on core samples (50 mm dia. x 25 mm depth) collected from within the cover concrete region – hence, no structural issue. These tests can be done and a revised report can be submitted within a period of one month. Additional chloride/carbonation data and results will help optimize the repair strategy to achieve durable repair with minimal cost implications.

Also, the repair strategy suggested in Report 2 is not sufficient to provide a repair-free life of another 20+ years. Experience says that such repair strategies would lead to *halo effect* and *residual chloride effect* (as mentioned in my journal paper; already shared with you). To provide a durable repair, an electrochemical repair strategy (say, cathodic protection) seems essential in the case of this building contaminated with chlorides; and probably carbonation too. Also, life cycle cost of such electrochemical repair strategies will be much less than the repair strategies suggested in BV Report 2. Serious review is required on the repair strategies.

Table 1: Specific comments on the key inferences in BV Report (dated April 2021)

#	Inferences copied from BV Report 2	My response
1.	From the results of Non-destructive ultrasonic pulse velocity & rebound hammer tests, it inferred that the quality of concrete in the tested RC members in Towers B and C are **Doubtful to good concrete**, and the RC members in Tower A were found to be **Good concrete**	Integrity of concrete is "doubtful to good". Indicates there is no significant honeycombing or voids in the concrete. It is reasonable to assume that the integrity of concrete in the upper floors of Towers B and C can also be in "doubtful to good" category.
2.	From the results of Rebound Hammer test, it is inferred that the quality /surface hardness of tested RC Slab of identified floors of Tower A, B and C is found to be **satisfactory**.	The calculated strength values range from about 24 to 30 N/mm^2 and are categorized as '*satisfactory*'. This inference needs to be justified. ***R2a***: *Include a comparative table with information on the design grade of the concrete and the calculated compressive strength obtained using the rebound hammer test. Provide this table and justify the inference on why this is satisfactory.*
3.	From the results of the Half-Cell Potential Measurement Test, it is inferred that the probability of corrosion falls in the category of "**Moderate to Advance**" stage of corrosion in the tested RC members of identified floors of Towers B & C	The report uses the term "identified floors". However, I could not find the Floor Numbers corresponding to the tests. Please respond with the page numbers where this information is given in Report 2. If not given, then provide this. Also, page 22 refers to Table 3 and 3A for half-cell potential (HCP) readings. However, I could not find any table in this 32-page BV Report 2. The BV Report 2 seems not reviewed adequately. Without providing the data on floor numbers and HCP data, I cannot judge if this inference is reasonable. ***R3a:*** *Provide the table with half-cell potential data.*
4.	From the results of carbonation test, it is inferred that the carbonation front **has reached up to reinforcement level** from the surface in most of the tested RC members of identified floors of Tower B & C. **"…considering the age of the concrete,** the depth of carbonation in the affected members is more than expected…"	Need more data to make a judgment on the inference provided in the Report 2. ***R4a:*** *Provide information on the time lapse between fracturing of concrete and the phenolphthalein tests?* ***R4b***: *Provide the carbonation depth data from each point tested and photos of the phenolphthalein tests already conducted.* ***R4c***: *Core a concrete sample (50 mm dia. x 25 mm depth) from each floor and perform carbonation tests. Provide carbonation depth data and photos of phenolphthalein tests.*

5.	From the results of chloride content test, it is inferred that the level of chloride content in all the tested samples of RC members of identified floors of Tower B & C are beyond the permissible limit of 0.6 kg/m^3	The results shown in Section C.4 (Page 23) of the B V report do not provide information on the floor level and whether the samples are collected from interior or exterior members. This information is necessary to decide whether to have a generalized repair strategy or a customized repair strategy for various types of structural elements in each floor. ***R5a***: *Provide a table with chloride test data from each sample. Also, mention which standard chloride test procedure has been adopted?* ***R5b:*** *Provide the chloride concentration of the water in the surrounding river.*
6.	**Less cover provided for RC members.** The cover concrete specified as per sketch ST-WD-REB.117C-018 are as follows: Column – 35 mm, Beam – 30 mm Slab – 30 mm	The results from the cover depth measurements are not mentioned anywhere in the new report. Inference is not reasonable ***R6a:*** *Provide a table with data on specified cover depth and measured cover depth.*

I had given similar suggestions in my previous review of BV Report 1. However, BV Report 2 did not address all the comments adequately. Please ensure that the next report from BV provides the data requested in R2a, R3a, R4a, R4b, R4c, R5a, R5b, and R6a and addresses the comments adequately. Without adequate response to these, I cannot provide additional judgments and provide a customized repair strategy.

I am available to provide any guidance to BV for the additional testing and developing cost-effective and durable repair strategy, if needed. Please feel free to contact me if you have any queries or need clarifications.

Regards

Radhakrishna G Pillai