REPORT

EVALUATION STUDY OF REPORTS

SUBMITTED BY

BUREAU VERITAS INDIA PVT LIMMITED

ON

STRUCTURAL STABILITY ASSESSMENT OF EXISTING CHANDERKUNJ ARMY RESIDENTIAL TOWER-B & C OF ARMY WELFARE HOUSING ORGANIZATION (AWHO) AT SILVER SAND ISLAND, VYTTILA, KOCHI, KERALA

(IND.B.7.2022.300DR-R3)

APRIL-MAY 2023

EVALUATION STUDY CARRIED OUT BY

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SEPTEMBER 2023

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EVALUATION OF BVIL REPORT MAY 2023

TOWER – B & C, CHANDERKUNJ ARMY TOWERS, SSI, KOCHI

EVALUATION OF NON-DESTRUCTIVE TEST RESULTS

1. Based on the requirement projected by the owners of Chander Kunj Army Towers, an evaluation study was undertaken to evaluate the structural analysis report submitted by Bureau Veritas India Pvt Ltd (BVIL) dated Apr-May 2023. This evaluation report covers the **Non-Destructive Tests, their results and analysis, covering both towers B & C** and is being submitted for the information and dissemination to all interested parties.

2. The objective of the study is twofold. Firstly, it aims at evaluating the general procedure followed by BVIL in the testing process, and the validity of the results and analysis produced in the report in the context of both Indian and international codes, as referenced by BVIL in the report. Secondly, it seeks to determine whether the outcomes of Non-destructive Testing (NDT) methods align with the observed distress patterns within the tower, with the intention of identifying any disparities in the findings.

3. As the various national and international Codes have specified, while Non-Destructive testing methods are valuable for assessing the quality and appropriateness of hardened concrete for its intended purpose, it is crucial to approach their results with an awareness of their inherent limitations. Consequently, considering the constraints associated with each concrete NDT method, industry codes emphasize the importance of a cautious selection of test methods and the necessity of reinforcing the outcomes of one method with complementary tests. In short, these test results must be analysed following the guidelines specified in the codes in a wholesome manner and any attempt to refer to isolated test results and deduce conclusions would render such conclusions unscientific and invalid.

Ultrasonic Pulse Velocity Test Results And Their Interpretations

4. Ultrasound pulse velocity method is a convenient technique for investigating in-situ concrete. The underlying principle of assessing the quality of concrete is that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality, lower velocities are obtained. If there is a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength is attenuated and it passes around the discontinuity, thereby making the path length longer. Consecutively lower velocities are obtained.

5. It is important to bear in mind that the analysis should be carried out as a wholesome process taking into consideration the various instructions given in the codes. Any attempt to pick and choose the results to achieve any pre-conceived opinion would render the analysis completely invalid. The quality of concrete in terms of uniformity incidence or absence of internal flaws, cracks and segregation, etc, (indicative of the level of workmanship employed) can be assessed using the guidelines given in tables as below.

6. Whenever the UPV values are lesser by more than 10% of average value of the member or part of structure, the location shall be considered as having internal flaws or segregation caused by poor workmanship or there could be micro cracks.

7. The quality of concrete in terms of velocity criteria has been amended in 2019 as part of the first revision of **IS 516 (Part 5/Sec 1): 2018 Hardened Concrete – Methods of Test. Part 5 Non-Destructive Testing of Concrete Section 1 Ultrasonic Pulse Velocity Testing**.

Table 1 Velocity Criterion for Concrete Quality Grading

(*Clause* 2.5.2)

Sl No. (1)	Average Value of Pulse Velocity by Cross Probing km/s (2)	Concrete Quality Grading (3)
i)	Above 4.40	Excellent
ii)	3.75 to 4.40	Good
iii)	3.00 to 3.75	Doubtful[1]
iv)	Below 3.00	Poor

[1] In case of 'Doubtful' quality it may be necessary to carry out further tests.

Table 1a. Before amendment.

Table 1 Velocity Criteria for Concrete Quality Grading

(*Clause* 2.5.2)

Sl No. (1)	Average Value of Pulse Velocity by Cross Probing km/s (2)	Concrete Quality Grading (3)
i) For concrete (≤ M 25):		
a)	Below 3.5	Doubtful[1]
b)	3.5 – 4.5	Good
c)	Above 4.5	Excellent
ii) For concrete (> M 25):		
a)	Below 3.75	Doubtful[1]
b)	3.75 – 4.50	Good
c)	Above 4.50	Excellent

[1] In case of 'Doubtful quality', it shall be necessary to carry out additional tests.

Table 1b. After first revision in 2019.

8. **Inference as per BVIL Report on Tower B Para 8.1 Page No. 125**. From the results of Ultrasonic pulse velocity test, BVIL has inferred that the quality of concrete in the tested RC members of Tower-B fall under the category of "**Doubtful to Good concrete**". However, from the above table, it may be observed that there is no category of "**Doubtful to Good concrete**", the categories are, 'Doubtful', 'Good' and 'Excellent'. Therefore, the inference can be validated only by stating the appropriate category and in the present state, the inference may have to be considered invalid. The implication of this error would be understood more clearly from the subsequent paragraphs.

Findings of Evaluation of Test Results

9. Individual UPV test results on members tested have been provided in the form of schematic representations from page Nos 167 to 216 (total of 49 pages). A total of **523** average UPV values have been derived from the individual test results, from page Nos 139 to 165. The average values have **presumably** been derived from the individual tests. This is because the

individual UPV test results in the report for Tower B consists of readings **for both B and C Towers** (as summarized in the table below) **instead of just Tower B**.

Page No	Description	Page No	Description	Page No	Description
28/77	Parking/Tower B	40 to 55/77	Basement/Tower?	74 to 77/77	29th floor
29/77	Cannot be read				
30/77	Tower C	56/77	Stilt/Tower?	Note. Tower C UPV test results have been provided in 5 pages within the report for Tower B in the schematic representation.	
31/77	Tower C	57/77	Tower B		
32/77	Tower C	58/77	Tower B		
33/77	Parking/Tower B	59/77	Tower B		
34/77	Parking/Tower B	60/77	Ground floor/Tower?		
35/77	Parking/Tower B	61/77	Ground floor/Tower?		
36/77	Tower C	62/77	Ground floor/Tower?		
37/77	Tower C	63 to 72/77	27th floor		
38/77	Tower B				
39/77	Basement	73/77	29th floor		

Table 2. Summary of schematic test results.

10. In the case of the 5 Nos of Lift wells, 41 (42%) out of 98 average values could not be obtained as the concrete was debonded and 40 values are less than 3.0 Km/sec. Hence, a total of 81 readings out of 98 indicate that the concrete is in poor condition (as the concrete was debonded), which amounts to a **staggering 83%** of the readings.

11. It would help in better appreciation if it is noted that prior to First Amendment of 2019, average value of pulse velocity less than **3.0 km/s have been categorized as "Poor" concrete** (refer Table 1a above as in Para 4). Post revision, all UPV values falling below 3.75 km/sec for concrete mix of M25 and greater, have been classified under "**Doubtful**" category. Therefore, it must be borne in mind that "Doubtful" category is the worst category and it must be treated as such in the final assessment of the situation. The summary of test results is as under:

Sl No	Description of UPV tests	Nos	Remarks
Complete Test Results			
1	No of average values tabulated in the report	523	
2	Values which could not be recorded due to debonding of concrete	41	Lifts 1 to 5 from 1st to 20th floor which is in line with the visual distress map attached.
3	Total recorded average values	482	(523-41=482)
4	No of average values above 4.5 km/sec	0	**Excellent** quality of concrete
5	No of average values above 3.75 km/sec but below 4.5 km/sec	111 (23%)	**Good** quality concrete

6	No of average values below 3.75 km/sec including 3.0 km/sec	371 (77%)	**Doubtful** quality. 86 (18%) test values fall below 3.0 Km/sec, which prior to the revision in 2019, was categorized as **poor concrete**.
Lift Well Only			
1	No of average values tabulated in the report	98	Including 41 cases where debonding of concrete had taken place
2	No of average values after deducting for debonded concrete	57	
3	No of average values above 4.5 km/sec	0	**Excellent** quality of concrete
4	No of average values above 3.75 but below 4.5	17 (30%)	**Good** quality concrete
5	No of average values below 3.75 km/sec including 3.0 km/sec	40+41 debonded (83%)	**Doubtful** quality. All tested values fall below 3.0 Km/sec, which prior to the revision in 2019, was categorized as **poor concrete**.

Table 3. Analysis of UPV test results.

12. **Para 2.5.3 of IS 516 (Part 5/Sec 1): 2018** Code, lays down clear guidelines that whenever the **UPV values are lesser by more than 10% of average value** of the member or part of structure, the location shall be considered as having internal flaws or segregation caused by poor workmanship or there could be micro cracks. No such attempt has been made in the report to analyze any such aspects of the investigated member in particular or the construction quality in general. A random member with UPV values has been selected for demonstrating the said point.

13. Particulars of the member for analysis:

Sl No	Particulars	Details
1	RC member location as per report	3b/Ab-Bb (Shear wall in Tower C)
2	Total No of UPV readings	120
3	No of readings not recorded	01
4	Average value of UPV of 119 readings	3.206 Km/sec (Doubtful category)
5	UPV value below which readings indicate internal flaws – 2.885 Km/sec	2.885 Km/sec (refer Para 11 above)
Note: The portion of the member marked in red is a region within the member which could be having internal flaws or micro-cracks		

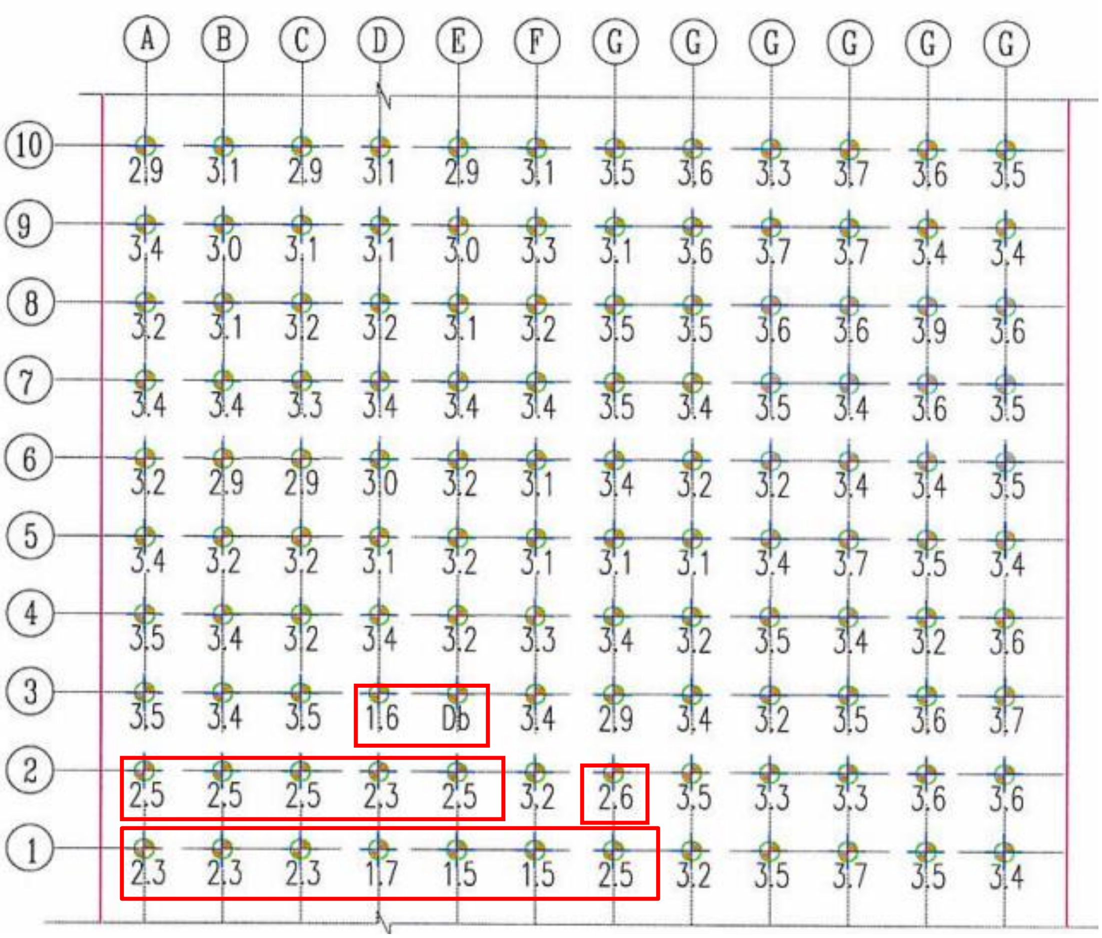

Fig 1. Individual UPV test results on shear wall in Tower-C as per details in table above.

14. This brings out another important aspect, that is, the selection of the sample location in the concrete member. From Fig. 1, it may be observed that the area having internal flaws would vary depending on the selection of the test location based on visual inspection. If there is any deliberate attempt to avoid any particular distressed location based on visual inspection, the validity of the result would be adversely affected. In the present BVIL report, there is no mention about the methodology of sample selection, hence the validity of the test results cannot be established.

15. Under Section 5 of Probing Tests in the BVIL Report, **Para 5.2** pertaining to UPV results have been reproduced floor wise. The members have been indicated as falling into category of "**Doubtful to Good**", whereas in the IS Code being referred to, there is **no such category**. The three broad categories post revision in 2019 of the IS Code are: **Excellent, Good and Doubtful** (see Para 6 above). **The correct categorization should be 23% Good and 77% Doubtful.**

16. **<u>Comments on the Inference of UPV tests by BVIL</u>**.

(a) Drawing conclusions about the quality of concrete by categorizing test results as '**Doubtful to Good**' without providing a clear explanation of the actual results within each category is misleading. This is especially critical when a significant portion of the results are below 3.0 km/sec or has even debonded. There is **lack of clarity and transparency in reporting these findings**. The report in its present form is **invalid** because of following reasons:

(i) Overall (for Tower B), **only 23%** of test results indicate **"Good"** concrete, whereas **77%** of the values indicate that the quality of concrete is "**Doubtful**" whereas by combining as "**Doubtful to Good**", it is showing a misleading result.

(ii) The UPV values related to Lift Well also indicate **Poor Quality**, since **all of the values** (including debonded concrete) **are below 3.0 Km/sec** (even though this category may have been discontinued post 2019 review). Due cognizance of this fact has not been taken into consideration. The poor quality of concrete can also be corroborated by visual distress as reported by BVIL.

(iii) When majority of test results are in "**Doubtful**" category, no attempt has been made in the report to clarify what further tests are required as per the code and what has actually been carried out.

(iv) No analysis based on the provision of **Para 2.5.3** of **IS 516 (Part 5/Sec 1): 2018** has been carried out (refer Para 11&12 above). The same should be provided for all the test areas.

(b) Similarly, for Tower C, **47% and 53%** of the test results indicate "**Good**" and "**Doubtful**" category respectively. However, **85%** of locations were found ineligible for testing in the lift wells because of **debonding** of concrete. A combined reading of the results would reveal that the situation is alarming.

(c) Overall, the conclusions drawn from the results of the UPV tests appear to **lack scientific rigour and professional approach**, resulting in the analysis being invalid in the present state.

<u>Rebound Hammer Test Results And Their Interpretations</u>

17. The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. Rebound numbers do not indicate if a particular concrete member has internal micro-cracking, flaws or heterogeneity across the cross-section. Therefore, the estimation of strength of concrete by rebound hammer method cannot be held to be very accurate and probable accuracy of prediction of concrete strength in a structure can be up to ± 25 percent depending upon correlation curve and methodology adopted for establishing correlation between rebound index and likely compressive strength.

18. The rebound numbers are influenced by a number of factors, the most significant among them is the influence of carbonation of concrete surface. According to **Para 7.1.5 of IS 516 (Part 5/Sec 4): 2019**, carbonated concrete gives an **overestimate of strength** which in extreme cases

can be up to 50 percent. According to the IS Code, the same is required to be reproduced in the test report. As per **Para 8.5 of Inferences** in BVIL Report, the "***carbonation front has reached up to reinforcement level*** *from the surface in most of the tested RC members of Tower-B*". Rebound hammer tests have been carried out on RC slabs and shear walls of Tower-B&C at random. According to extant IS Code, the **test report** is required to include **the details of carbonation of the tested area in case the structure is more than 6 months old**. This aspect has not been considered in the BVIL Report (see summarized table in section containing details on carbonation which present test results which are very few in numbers and do not match with the locations where rebound hammer tests have been conducted).

19. According to **Para 8.1 on Interpretation of Results** in the subject IS Code of rebound hammer tests, keeping into account various limitations in rebound hammer test, the **combined use of ultrasonic pulse velocity (UPV) test and rebound hammer test is a must for proper interpretation**. No attempt has been made in the BVIL report on any combined use of the methods listed in IS Code referred above, to interpret the results. It is **possible to establish a relationship between compressive strength of concrete, rebound number and ultrasonic pulse velocity** if the ingredients of the concrete mix and their proportions are known like cement, aggregate and admixtures[1]. In fact, as per **Para 8.2 of Inferences** in BVIL Report**,** it has been inferred from the results of Rebound Hammer Test that, "*the estimated strength of concrete nearer to surface /surface hardness of tested RC members of Tower-B is found to be* ***satisfactory"***. Inference drawn purely on the basis of rebound number is against the guidelines given in the subject IS Code, hence renders the inference invalid in the present state.

20. The IS Code further clarifies that if the quality of concrete assessed by ultrasonic pulse velocity method is **3.75 Km/sec or above**, **only then the in-situ compressive strength assessed from the rebound hammer test is valid**. It would be pertinent to have a look at the UPV test results of the members provided by BVIL Report. The summary is as under:

Sl No	Location of Testing	Nos of UPV Test values which are			Remarks
		Above 3.75 Km/sec	Below 3.75 Km/sec	Total UPV values	
1	Columns	59 (24%)	191 (76%)	250	
2	Beams	38 (25%)	117 (75%)	155	
3	Slabs	14 (70%)	6 (30%)	20	UPV values obtained for 9th floor upwards
4	Lift 1	0	11 (100%)	26	15 readings ineligible due to **debonding**
5	Lift 2	0	10 (100%)	16	6 readings ineligible
6	Lift 3	0	10 (100%)	21	11 readings ineligible
7	Lift 4	0	8 (100%)	14	6 readings ineligible
8	Lift 5	0	18 (100%)	21	3 readings ineligible
	Total	**111**	**371**	**523**	**41 readings** ineligible
9	**Percentage Overall**	**23%**	**77%** **Doubtful category**		Considered out of 482 results Refer Para 10 above

[1] Guidebook on non-destructive testing of concrete structures, International Atomic Energy Agency, Vienna, 2002, Para 11.5.2, page 123.

Table 4. Analysis of rebound hammer test results.

21. **Para 8.1 of Interpretation of Results** in the IS Code, has also clarified that **in cases the quality of concrete assessed by UPV is** "**Doubtful**", no assessment of concrete strength shall be made from rebound hammer test. The test results as shown above and inference on rebound hammer test provided by BVIL Report **is in contravention to the above guideline, which renders the inference invalid in the present state**.

22. **<u>Comments on the Inference of Rebound Hammer Tests by BVIL</u>**. Since 77% of UPV values are less than 3.75 Km/sec (100% for lifts) as in the case of Tower B and similarly, 53% for Tower C (see Para 16 (b)), which puts the quality of concrete in the "**Doubtful" category**, the **validity of the Rebound Hammer Tests cannot be established**. The following reasons make the interpretations of rebound hammer test results **invalid in the present state**:

(a) The provision of IS Code makes it imperative to employ both the UPV test and the rebound hammer test in combination to properly interpret the results which has not been carried out by BVIL.

(b) The potential **impact of carbonation of concrete on the rebound hammer test results for RC members has not been taken into account**.

(c) The guideline specifying that no assessment of concrete strength should be derived from the rebound hammer test **renders the test itself invalid**, particularly when **over three-quarters of the UPV test results in the case of lifts indicate a "Doubtful" category for the concrete quality**.

<u>Half-Cell Potential Test Results And Their Interpretations</u>

23. As per **Para 5.6 of** BVIL Report, half-cell potential measurement tests have been carried out on RC members of Tower-B & C at random using Copper-Copper Sulphate Half-Cell to assess the probability of corrosion in reinforcing bars. According to the report, tests have been conducted as per guidelines in **ASTM C876-15 (Reapproved 2015)**. As per this code, the *Numeric Magnitude Technique and the values of potentials with their interpretations for Copper-Copper Sulphate reference electrode are as under:*

(a) If potentials over an area are more positive than **−0.20 V CSE**, there is a **greater than 90 % probability** that no reinforcing steel corrosion is occurring in that area at the time of measurement.

(b) If potentials over an area are in the range of **−0.20 to −0.35 V CSE**, corrosion activity of the reinforcing steel in that area is uncertain.

(c) If potentials over an area are more negative than **−0.35 V CSE**, there is a greater than 90 % probability that reinforcing steel corrosion is occurring in that area at the time of measurement.

24. As per **Para X1.1.4** of **ASTM C876-15 (Reapproved 2015)**, two of the following conditions in which the **above criteria should not normally be utilized** unless experience or destructive examination of some areas, or both, suggest their applicability are:

(a) To evaluate reinforcing steel in concrete that has carbonated to the level of the embedded steel.

(b) To evaluate indoor concrete that has not been subjected to frequent wetting unless it has been protected from drying after casting.

25. The applicability and validity of the half-cell potential tests in view of the above limitations of test as given in the subject code is not known. The fact that most of the locations where carbonation depth has been evaluated have all reported that carbonation has reached up to level of the reinforcement steel, renders the tests invalid if one goes by the above (a) limitation. The second limitation holds true for the slabs tested within the individual apartments.

26. The **Test Report** for Results of Half-Cell Potential Difference Measurement Test as in page 272 of the BVIL Report (Page No. 1 of 7) has listed **IS 516 (Part 5/Sec 2): 2021** as the **Technical Reference**. According to **Para 4.1 of** IS Code as above, the criteria for corrosion condition of rebar in concrete for different half-cells with their likely condition, is as under:

Sl No	$Cu/CuSO_4$ electrode	Hg/Hg_2C1_2 electrode	Ag/AgCl electrode	Likely corrosion condition
(1)	(2)	(3)	(4)	(5)
i)	> -200 mV or less negative than -200 mV	> -126 mV	> -106 mV	Low (there is a greater than 90 percent probability that no reinforcing steel corrosion is occurring in that area at the time of measurement.)
ii)	-200 to -350 mV	-126 to -276 mV	-106 to -256 mV	Corrosion activity of the reinforcing steel in that area is uncertain
iii)	< -350 mV or more negative than -350 mV	< -276 mV	< -256 mV	High (there is a greater than 90 percent probability that reinforcing steel corrosion is occurring in that area at the time of measurement)
iv)	< - 500 mV	< - 426 mV	< - 406 mV	Severe corrosion

Table 5. Various corrosion categories for half-cell potential results.

27. According to **Para 8.4** of BVIL Report of Tower B, it has been inferred from the results of half-cell potential measurement test that there is "***Moderate to advance stage of corrosion** in the tested RC members of Tower-B*". The summary of results as per **Para 5.6 are**:

Sl No	Floor	Interpretation of results as per Para 5.6				Remarks
		Slab	Shear wall	Staircase waist slab	Beam	
1	Ground floor	U	HP			Lift-4
2	1st floor		HP			Lift-1
3	2nd floor	U	HP			Lift-1
4	3rd floor	U				
5	4th floor	LP-U				
6	7th floor	LP-U				7th Floor RC Slab, 5b-8b/Ab-Bb -244 / -193 / -362 -225 / -257 / -222 -252 / -333 / -316
7	8th floor	LP-U				
	9th floor			LP-U		
	10th floor	LP-U			U	
	12th floor				LP-U	
	14th floor				LP-U	
	18th floor				LP-U	
	19th floor				U-HP	No results appended
	21st floor	LP				
	23rd floor				LP	
Note: **U**-Uncertainty of corrosion; **HP**- High probability of corrosion; **LP**-Low probability of corrosion; **LP-U**-Low probability to uncertainty of corrosion; **U-HP**- Uncertainty to high probability of corrosion.						

Table 6. Summary of test results for half-cell potential values for Tower B as per BVIL Report.

28. As per **Para 8 of IS 516 (Part 5/Sec 2): 2021**, the report should consist among other details, the following:

(a) Details of the structure/member being tested and **visual indications of corrosion of steel**, if any.

(b) The method for pre-wetting the concrete member and the method of attaching the voltmeter lead to the reinforcing steel.

(c) An equipotential contour map, showing the location of reinforcing steel contact, or a plot of the cumulative frequency distribution of the half-cell potentials, or both.

(d) The **percentage of the total half-cell potentials that are more negative than −0.35**

(e) The **percentage of the total half-cell potentials that are less negative than −0.20 V**.

29. A summary of visual observations of distress in Tower-B as per BVIL Report indicates moderate to major cracks in “isolated locations” to “most locations” within the lift wells from the ground to 22nd floor. However, the tests have been conducted *randomly* only on the ground floor, 1st and 2nd floors (see Para 24), especially when high probability of corrosion in these locations has been observed and corroborated also through the tests. Also, in the case of staircase waist slabs, visual distress has been recorded in the form of cracks in most of the locations from stilt to 3rd floor and few locations continuously thereafter up to 16th floor. There should have been an attempt to understand the cause of these cracks, whether they are due to corrosion or otherwise. However, no tests have been reported in those floors. **The core objective of half-cell potential measurements, which is to identify corroding reinforcement bars during condition assessment or repair activities, appears to have been not satisfied by BVIL by not conducting adequate half-cell potential tests in visually distressed members**.

30. As per both IS and ASTM Codes, the test results are supposed to be depicted in the form of **Equipotential Contour Maps** or **Cumulative Frequency Distribution Diagrams** (see representative figures below). However, the report has just depicted the readings in tabular form with likely corrosion possibilities.

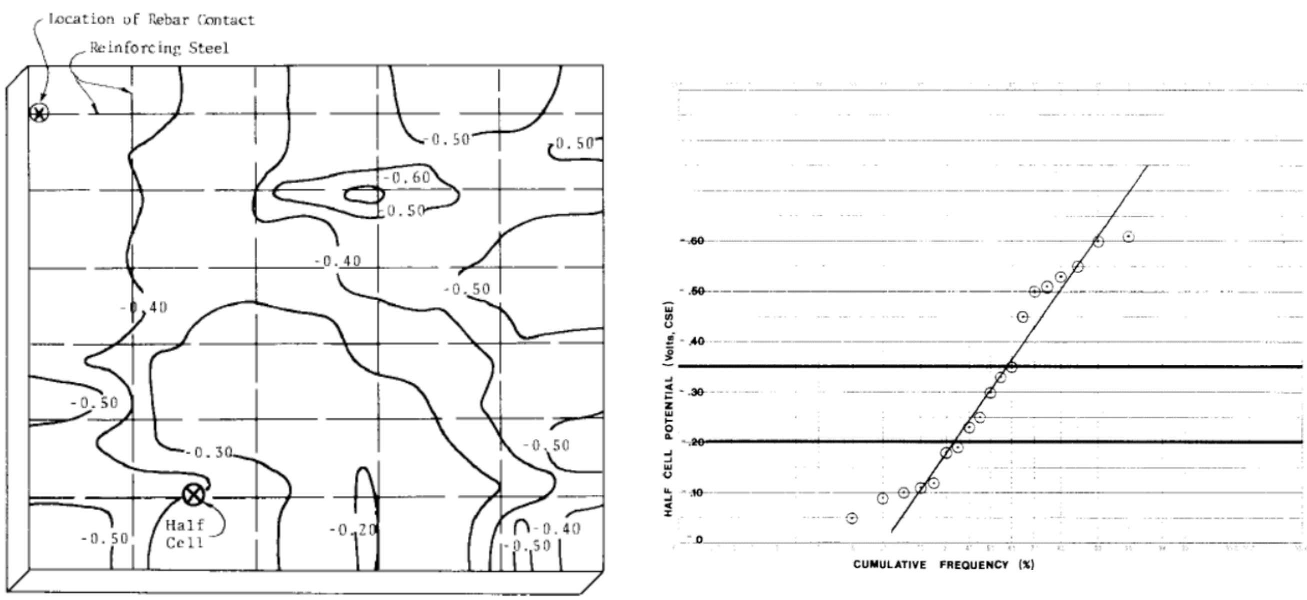

Fig 2 a & b. Equipotential contour map and cumulative frequency distribution diagram, which are used for depicting the results of half-cell potential tests by Indian and American codes.

31. Another important use of half-cell potential test is that based on half-cell potential maps, the corroding zones can be identified and the **layout of the anodes can be optimized**: critical areas can be protected by isolated anodes and connected separately to the rectifier or the amount of anode material can be increased or decreased accordingly. European Standard EN12696 also states that **potential mapping should be carried out on representative areas, in particular**

for locating spots for reference electrodes to be placed[2]. However, from the BoQ submitted, it has been seen that sacrificial anode protection has been proposed only for additional rebars used for strengthening in both Towers B and C and no solution has been proposed for arresting the further corrosion of rebars within the already visually distressed members. **Furthermore, in the case of the retaining wall, which exhibits severe corrosion along all three sides facing the waterfront, including noticeable rust stains, no measures have been suggested to halt the ongoing corrosion. Surprisingly, no half-cell potential tests have been conducted on the retaining wall, despite the critical nature of this issue**.

32. **<u>Comments on the Inference of Half-cell Potential Tests by BVIL</u>**. The analysis based on Half-Cell Potential tests do not pass the test of validity for the following reasons:

(a) The areas where half-cell potential tests have been conducted are **notably limited**, and do not contribute to the confirmation of the root causes of corrosion affecting Towers B and C. Additionally, there is a **lack of inclusion of visual evidence** (as per IS Code) in the report, pertaining to the corrosion of reinforcement bars at the tested locations. Apart from carrying out some tests for the sake of records, there does not appear to be any effort to carryout analysis based on the recommendation in the codes.

(b) The presentation and assessment of the results **do not align with the stipulations outlined in either Indian or American codes**. The study has not adopted the recommended methods such as **Equipotential Contour Maps and Cumulative Frequency Distribution** for result analysis.

(c) The fundamental purpose of the half-cell potential test, namely identifying corroded reinforcement bars during condition assessment, has not been satisfied. Consequently, the proposed restoration method, primarily necessitated by the premature onset of distress from corrosion, would be **highly compromised**.

(d) Sacrificial Zinc anode have been proposed to be provided as per standard practice/manufacturer specification to slabs and shear walls (refer treatment for corrosion distressed slab, page 6096 and 6097 of BVIL Report for Tower B). However, there is no indication of the slabs which have been identified for cathodic protection or if all slabs are proposed to be provided with cathodic protection in both towers.

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[2] RILEM TC 154-EMC: ‘Electrochemical Techniques for Measuring Metallic Corrosion’, Recommendations for Half-cell potential measurements-P0tential mapping on reinforced concrete structures, ed. B. Elsener with contributions from C. Andrade, J. Gulikers, R. Polder and M. Raupach, *Materials and Structures,* Vol 36, August-September 2003, pp 461-471.

Carbonation Test Results And Their Interpretations

33. According to **IS 516 (Part 5/Sec 3): 2021**, Carbonation is a process in which carbon dioxide from the atmosphere diffuses through the porous cover concrete and **may reduce the pH to 8 or 9** at which the passivating oxide film is no longer stable. The process involves two stages: First is the atmospheric carbon dioxide reacting with water in the concrete pores to form carbonic acid. This is followed by reaction of the carbolic acid with calcium hydroxide to form calcium carbonate. This process leads to cause a **reduction in the pH value of the pore solution from 12.5-13.5 to around 8 to 9**. The following table summarizes the results of carbonation and chemical test for pH.

Sl No	Floor	Carbonation test values (mm)					Remarks
		Column	Beam	Slab	Shear wall	Stair waist slab	
Tower-B							
1	Ground floor	32-45	22-32				
2	2nd floor		20-28	12-22		10-16	
3	4th floor		22-32				
4	6th floor				24-30		
5	8th floor			13-18			
6	9th floor				21-28		
7	12th floor				25-30		
Tower-B&C Common Area in the Basement							
1	Common basement floor	20-50	25-40	30-35			
		13.64-13.92	**13.61-13.85**		**13.83-13.92**		pH values reported
Tower-C							
1	Ground floor	28-48	20-35				
		13.78-13.88	**13.85-13.90**				pH values reported
2	2nd floor		15-25	10-15		15-20	
			13.37-13.45	**13.21-13.44**		**13.51**	pH values reported
3	5th floor	35-40		8-12			
		13.93		**13.37**			pH values reported
4	7th floor			12-18	22-28		
				13.46	**13.43**		pH values reported
5	12th floor		25-30				
			13.38				pH values reported
6	14th floor	25-32					
		13.47					pH values reported
7	24th floor				18-24		
					13.49		pH values reported

Table 7. Summarized results of carbonation test and pH values for Towers B&C as per BVIL Report.

pH Test Results And Their Interpretations

34. Apropos, carbonation of concrete and change in pH values due to carbonation need to be **evaluated and analyzed together** to fully understand the chemical process preceding the initiation of corrosion. A summary of the test results of both estimation of carbonation depth and pH values reported at the same location as in the BVIL Report is reproduced below:

Sl No	Member	Grid identification	Depth of carbonation (mm)	pH value at the same location	Remarks
Tower B					
Basement Floor					
1	RC Beam	Ab/9b-10b	25-32	13.61	Page Nos 267-271 and 293 to 299 of BVIL Report
2	RC Shear Wall	Eb-Fb/2b-3b	30-35	13.88	
3	RC Column	Cb/1b	40-50	13.81	
4	RC Column	Cb/12b	38-45	13.86	
5	RC Column	Mb/2b	25-30	13.74	
6	RC Column	Cb/3b	30-40	13.79	
7	RC Beam	Eb/10b-11b	20-28	13.85	
8	RC Column	Lb/1b	34-38	13.81	
9	RC Column	Kb/9b	40-45	13.68	
10	RC Beam	10b/Ab-Bb	20-25	13.84	
11	RC Column	Bb/8b	35-40	13.82	
12	RC Beam	1b/Fb-Gb	30-35	13.75	
Ground Floor					
13	RC Beam	Ab/9b-10b	28-35	13.85	Page Nos 267-271 and 293 to 299 of BVIL Report
14	RC Column	Lb/5b	40-48	13.84	
15	RC Beam	Mb/3b-4b	30-32	13.85	
16	RC Column	Kb/1b	32-40	13.86	
Tower C					
Basement Floor					
17	RC Column	Cc/11c	40-45	13.85	Page Nos 267-271 and 293 to 299 of BVIL Report
18	RC Column	Bc/1c	38-40	13.86	
19	RC Shear Wall	Hc/10c-11c	30-35	13.92	
20	RC Shear Wall	Ec/2c-3c	25-30	13.83	
21	RC Column	Cc/5c	35-40	13.89	
22	RC Column	Kc/6c	30-38	13.92	
23	RC Column	Kc/12c	45-48	13.87	
Ground Floor					
24	RC Column	Ac/12c	38-40	13.80	Page Nos 267-271 & 293 to 299 BVIL Report
25	RC Beam	Ac/8c-10c	20-22	13.90	
26	RC Beam	Mc/3c-5c	25-28	13.88	

Second Floor					
27	RC Slab	Lc-Kc/9c-10c	10-14	13.44	C-0204
28	RC Beam	Refuge area	20-25	13.45	East side
29	RC Beam	Refuge area	15-20	13.37	West side
30	RC Slab	Refuge area	12-15	13.21	East side
31	RC Waist Slab	Main staircase	15-20	13.51	
Fifth Floor					
32	RC Slab	Refuge area	8-12	13.37	East side
33	RC Column	Cc/6c	35-40	13.93	
Seventh Floor					
34	RC Slab	Refuge area	12-18	13.46	East side
35	RC Shear Wall	Hc/10c-11c	22-28	13.43	
Twelfth Floor					
36	RC Beam	North side	25-30	13.38	C-1203
Fourteenth Floor					
37	RC Column	Cc/8c	25-32	13.47	
Twenty Fourth Floor					
38	RC Shear Wall	Ec/2c-3c	18-24	13.49	

Table 8. Results of carbonation test and pH values recorded at the same location of Towers B&C as per BVIL Report.

35. **<u>Comments on the Inference of Carbonation Tests And pH Tests by BVIL</u>**. As per **Para 5.7** of BVIL Report of Tower B**,** the results of carbonation test indicate that the **carbonation front in concrete has reached up to reinforcement level** in most of the tested RC members indicating that the **cover concrete has already lost its alkalinity** which is essential to protect the reinforcing bars against **potential corrosion**. The report on Tower C under **Para 5.9**, has found the level of pH in the tested RC members to be **within the desirable limit in common basement of Tower B&C and Tower C**. This may be true if the results are seen in isolation. In fact, the comments appear to contradict the fundamental principles that guide the rationale for conducting carbonation tests in conjunction with the assessment of pH values, as outlined in the established codes. As per Table 8 above, **high pH values** at the corresponding carbonation test locations **do not support the reasoning that corrosion is due to carbonation**. The inference by BVIL does not appear to be supported by any scientific basis, hence lacks validity in the present state.

<u>Chloride Content Test Results And Their Interpretations</u>

36. Whenever there is chloride in concrete there is an increased risk of corrosion of embedded metal. The higher the chloride content, or if subsequently exposed to warm, moist conditions, the greater the risk of corrosion. The **maximum total allowable acid soluble chloride content in RC** or PC containing embedded metal as per **IS 456: 2000** is **0.6 kg/cum**.

37. The chloride content of concrete can be determined by chemical analysis of concrete in the laboratory. A rotary percussion drill is used to collect a pulverized sample of concrete and a

special acid extracts the chlorides. The amount of acid soluble chloride is determined directly by a chloride sensitive electrode connected to an electrometer[3].

38. Summary of results as per BVIL Report (pages 293-294 and 297-298 of report on Tower C refers) is reproduced as under:

Sl No	Floor	Grid No	Chloride content-acid soluble in (kg/cum)					Remarks
			Column	Beam	Slab	Staircase waist slab	Shear wall	
Tower B								
1	Basement	Kb-9b	0.13					
2		Ab/9b-10b		0.17				
3		cb-1b	0.12					
4		Mb-2b	0.041					
5		1b/fb-Gb		0.051				
6		CC-10c	0.068					
7		Mc-3C/5C		0.26				
8		FC-1C	0.31					
9		9b-10b/ mb		0.034				
10		Eb-Fb/2b-3b					0.014	
11		cb-12b	0.034					
12		cb-3b	0.034					
13		Eb/10b-11b		0.041				
14		Lb-1b	0.068					
15		10b/Ab-Bb		0.051				
16		8b-Bb	0.034					
17	Ground floor	9b-10b/Ab		0.27				
18		Lb-5b	0.017					
19		Mb/3b-4b		0.041				
20		kb-1b	0.085					
21	Main staircase	Gf-ff				**0.82**		
22	2nd floor	5b-8b/Bb			0.58			West side
23		Kb-Lb/5b-8b			1.08			East balcony
24		5b-8b/Lb		0.43				
25		10b/Hb				0.47		
26	4th floor	Hb/9b-10b		0.50				South side
27	6th floor	10b-11b/Eb					0.24	
28	8th floor	Bb/9b-8b			**0.70**			
29	9th floor	Hb/9b-10b					0.49	
30	12th floor	TB?					0.28	

Table 9. Results of chloride tests on members at various floors of Tower B as per BVIL Report of Apr 2023.

[3] Para 3.5 Test for chloride content of concrete of Non-Destructive Testing of bridges by Indian Railways Institute of Civil Engineering, Nov 2021.

Sl No	Floor	Grid No	Chloride content-acid soluble in (kg/cum)					Remarks
			Column	Beam	Slab	Staircase waist slab	Shear wall	
Tower C								
1	Basement	Ec-2c/3c					0.058	
2		1C-BC	0.43					
3		CC-12C	0.12					
4		CC-5C	**1.12**					
5		CC-11C	0.17					
6		KC-6C	0.17					
7		12c/Kc	0.085					
8		10C-11C/HC					0.041	
9	Ground floor	3C-MC	0.037					
10		Lc-10C	0.034					
11		Ac/8C-10C		0.26				
12		12C/AC	0.068					
13		3C-5C/Mc		0.21				
14		1C-MC	0.058					
15		10C-11C/CC		0.041				
16		Kc-3C	0.085					
17		AC-10C	0.34					
18	2nd floor	Lc-Kc/9c-10c			**0.63**			C0204
19				0.42				East side
20					**0.91**			
21						**0.88**		
22				0.60				West side
23	5th floor				0.12			East side
24		Cc/6c	0.11					
25	7th floor				0.26			East side
26		Hc/10c-11c					0.10	
27	12th floor			0.10				C1203
28	14th floor	Cc/8c	0.10					
29	24th floor	Ec/2c-3c					0.11	

Table 10. Results of chloride tests on members at various floors of Tower C as per BVIL Report of Apr 2023.

39. From the above tables on the results of chloride content test, it is seen that only **10% of the test results indicate excess chloride content** in the hardened concrete. This is in contrast to the results obtained by BVIL in their previous report submitted in **Apr 2021**, the summary of which is appended below:

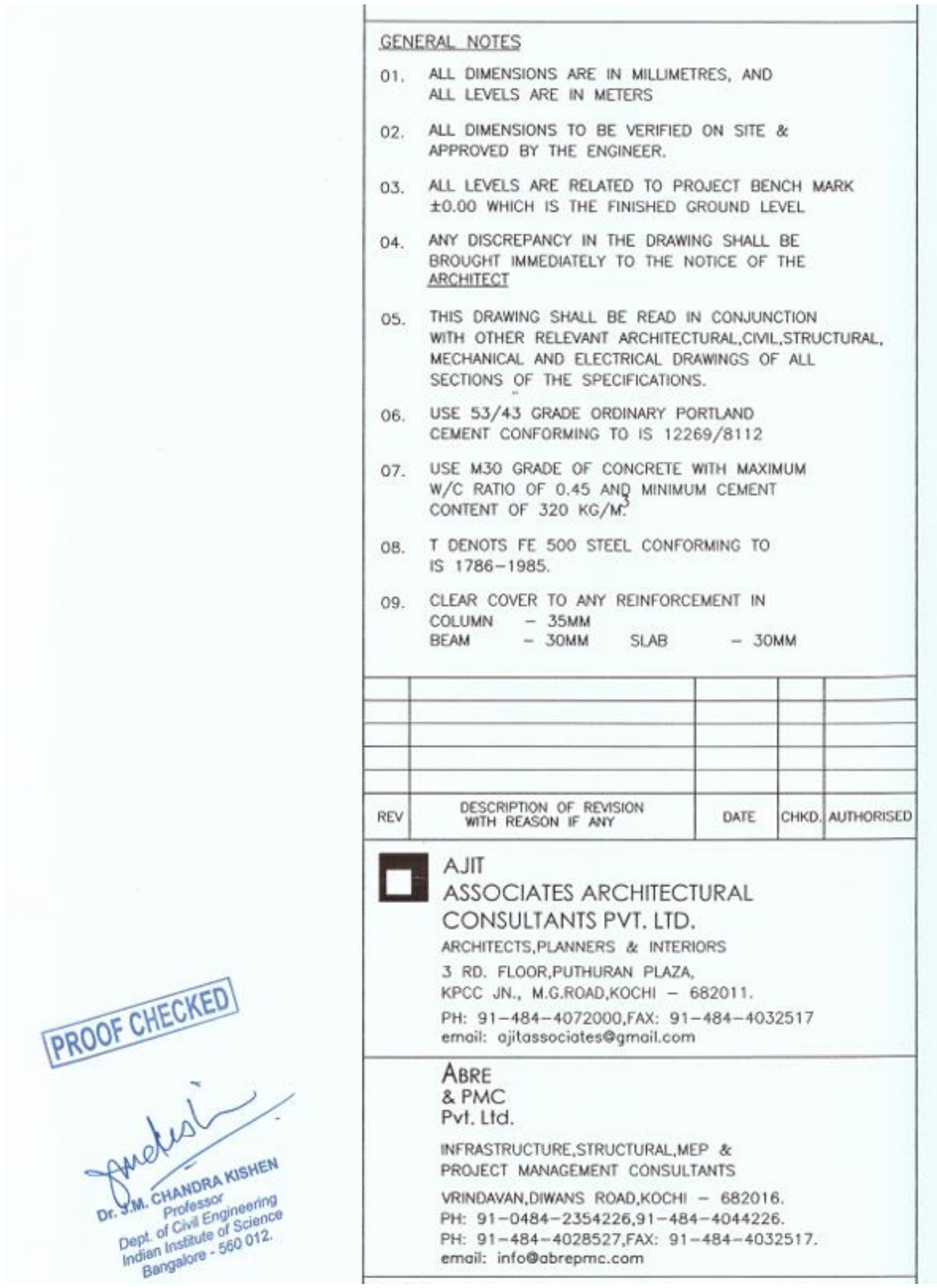
SI No	Floor	Chloride content-acid soluble in (kg/cum)						Remarks
		Column	Beam	Slab	Staircase			
					beam	landing slab	waist slab	
Tower B								
1			**0.68**					B29-B32
2	Basement		0.10					B9=B26
3		**1.11**						B23
4		**0.83**						B32
5	2nd to 3rd						**2.64**	BS1 to BS2
6	7th to 8th						**2.61**	BS5 to BS6
7	8th to 9th	**2.59**						Lift wall
Tower C								
8			**0.85**					C3-C4
9			0.60					C24-C27
10	Basement	**0.75**						C43
11		**1.10**						C39
12		**1.10**						C30
13	Stilt floor	**2.47**						CS4
14		**2.82**						C15
15	3rd floor						**2.78**	
16	5th floor	**2.80**						
17	10th floor						**2.59**	
18	13th to 14th floor						**2.80**	Near CS5-CS6

Table 11. Results of chloride tests on members at various floors of Tower B & C as per BVIL Report of Apr 2021.

40. The drastic variation between the earlier test results (2021) and the present test results raise a number of questions on the validity of the tests. The previous tests were conducted about two years earlier, hence, considering the continuing corrosion, the present results should have given more negative results. The physical observation, photos and videos also show worsening of corrosion. However, the present report shows improvement in the quality of concrete. This raises doubts about the integrity of the tests and validity of the whole structural analysis report.

41. **<u>Covermeter Test Results and Interpretations</u>**. A significant observation is the omission of the information that the design cover to reinforcement for the columns, beams, and slabs in the proof-checked drawings submitted by AWHO to BVIL is 35 mm, 30 mm, and 30 mm, respectively. Additionally, the report's presentation of the readings is deceptive and misleading. The inference of the test results suggests that the majority of the sites where the rebars were covered were found to be inadequate. The test findings, however, are listed under the heading "**Range of cover concrete (mm)+**," and a comment that "+" denotes "**inclusive of plaster**" is included at the conclusion of the table, whereas technically, the cover thickness should be exclusive of plaster. It is for the authorities to establish whether the aforementioned recording of findings is a deliberate

attempt to conceal the **existence of 'design defects'** while also misleading the reader about the thickness of the cover concrete without plaster by presenting the results discreetly.



GENERAL NOTES

01. ALL DIMENSIONS ARE IN MILLIMETRES, AND ALL LEVELS ARE IN METERS

02. ALL DIMENSIONS TO BE VERIFIED ON SITE & APPROVED BY THE ENGINEER.

03. ALL LEVELS ARE RELATED TO PROJECT BENCH MARK ±0.00 WHICH IS THE FINISHED GROUND LEVEL

04. ANY DISCREPANCY IN THE DRAWING SHALL BE BROUGHT IMMEDIATELY TO THE NOTICE OF THE ARCHITECT

05. THIS DRAWING SHALL BE READ IN CONJUNCTION WITH OTHER RELEVANT ARCHITECTURAL,CIVIL,STRUCTURAL, MECHANICAL AND ELECTRICAL DRAWINGS OF ALL SECTIONS OF THE SPECIFICATIONS.

06. USE 53/43 GRADE ORDINARY PORTLAND CEMENT CONFORMING TO IS 12269/8112

07. USE M30 GRADE OF CONCRETE WITH MAXIMUM W/C RATIO OF 0.45 AND MINIMUM CEMENT CONTENT OF 320 KG/M^3

08. T DENOTS FE 500 STEEL CONFORMING TO IS 1786-1985.

09. CLEAR COVER TO ANY REINFORCEMENT IN
COLUMN - 35MM
BEAM - 30MM SLAB - 30MM

REV	DESCRIPTION OF REVISION WITH REASON IF ANY	DATE	CHKD.	AUTHORISED

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42. **Resipod Test Results and Interpretations**. This test is used to measure the electrical resistance of the cover concrete. Once the reinforcement bar loses its passivity, the corrosion rate depends on the availability of oxygen for the cathodic reaction. It also depends on the concrete, which controls the ease with which ions migrate through the concrete between anodic and cathodic site. Electrical resistance in turn depends on the microstructure of the paste and the moisture content of the concrete. The system should not be used in isolation because it gives better indication of corrosion in reinforced concrete if used in combination with half-cell potential meter.

43. Summary of results are as under:-

Sl No	Floor	RESIPOD test results in terms of risk of corrosion (M=Moderate, H=High)												Remarks
		Column			Beam			Slab			Shear wall			
		No of tests	M	H	No of tests	M	H	No of tests	M	H	No of tests	M	H	
1	Basement Tower B	38	34	-	12	11	-	21	21	-				Blank spaces no tests done
2	Basement Tower C	42	31	4	13	12	-				2*	-	-	* In low-risk category
	Sub total	80	**65**	**4**	25	23	-	21	**21**	-	2	-	-	
3	4^{th} floor							1	1	-				
4	6^{th} floor							2	2	-				
5	7^{th} floor				1	1	-	1	1	-				**Tower B**
6	8^{th} floor				1	1	-	3	3	-				
7	9^{th} floor				1	1	-	1*	-	-				
8	Ground floor	8#	1	-	3	2	-	6	2	-				
9	1^{st} floor	3	1	-	4	2	-							
10	2^{nd} floor	6	1	-	2	-	-	3	2	-				
11	3^{rd} floor	2	-	-				2	-	-				
12	4^{th} floor	3	-	-				1	-	-				
13	5^{th} floor	3	-	-	3	3	-	2	2	-				
14	6^{th} floor	4	-	-	3	-	-							
15	7^{th} floor	3	-	-	3	-	-	2	-	-				
16	8^{th} floor	3	-	-	2	-	-	3	1	-				
17	9^{th} floor	4	-	-	4	-	-	2	-	-				**Tower C**
18	10^{th} floor	2	-	-	4	-	-	5	-	-				#Balance in low category
19	11^{th} floor				1	-	-	4	1	-				
20	12^{th} floor	4	-	-	1	-	-	4	4	-				
21	13^{th} floor	2	2	-	1	-	-	2	2	-				
22	14^{th} floor	3	1	-	1	-	-	4	4	-				
23	15^{th} floor	1	-	-	1	-	-	2	1	-				
24	16^{th} floor	4	1	-	2	-	-	4	3	-				
25	17^{th} floor	3	2	-	1	1	-	4	2	-				
26	18^{th} floor	2	-	-	2	-	-	3	2	-				
27	19^{th} floor	2	1	-	1	-	-	3	3	-				
28	20^{th} floor	2	-	-	1	-	-	3	2	-				
29	21^{st} floor	2	-	-	1	-	-	1	-	-				
30	22^{nd} floor	2	-	-	1	-	-	2	1	-				
	G total	110	**75**	**4**	70	**34**	-	91	**60**	-	2	-	-	

44. The Resipod test results show **81% Column locations** and **100% Slab locations** tested in the basement of Towers B and C to have **Moderate risk of corrosion** as per chart. The corresponding tests on chloride content in the basement do not corroborate the results of Resipod tests. The upper floors of Tower B have not been tested for columns. The shear walls also haven't been tested.

REFERENCE LIKELIHOOD OF CORROSION CHART FOR RESIPOD TEST

Equipment	:	RESIPOD
Make	:	M/S. Proceq, Switzerland
Technical Reference	:	1.RILEM TC 154-EMC: Electrochemical techniques for measuring metallic corrosion. 2. Instrument manual furnished by M/S. Proceq, Switzerland

Resistivity Measurements	Estimation of the likelihood of corrosion
When > 100 kΩcm	Negligible risk of corrosion
When = 50 to 100 kΩcm	Low risk of corrosion
When= 10 to 50 kΩcm	Moderate risk of corrosion
When < 10 kΩcm	High risk of corrosion

45. **<u>Cause of Premature Distress</u>**. The visual picture of distress seen in the towers of B and C gives clear indication of corrosion of steel reinforcement, majorly affecting the basement of the common area of the two towers. Apart from visual observations, the NDT are used for investigations in order to establish the likelihood of corrosion and to find out the extent of corrosion, based on which the restoration methods are decided. As per **Para 27 of 6.2.10 of Tower C Report** (page 102), "*The main cause of distress to the structure is attributed to the* ***enhanced rate of corrosion of steel reinforcement****. This is due to the* ***high chloride content in concrete and high rate of carbonation of cover concrete****, as evident from the test results given in Bureau Veritas Report. While adopting the retrofitting process, it is* ***recommended to provide proper Cathodic protection to the steel reinforcement****, so as to avoid chances of corrosion of reinforcement in future. An expert opinion on procedure adopted for Cathodic protection shall be taken and the same shall be added suitably adopted."* The BVIL Report, however, fails on this account, as the results of the tests have not been able to establish either the rate of corrosion or the extent of corrosion.

46. The above fact is further confirmed in **Para 6.2.4 Reinforcement consideration in Distress evaluation** (page 78 of report on Tower C) in which the report says; "*The building vertical element columns and shear walls having corrosion of reinforcement, the* ***extent of rebar corrosion assumed as 5% to 10% for the main reinforcement of the vertical elements and for 50% for the shear links/stirrups***". Given the lack of clear links from the test results on corrosion detection, there appears to be no basis for the above assumptions of % corrosion, other than a mere assumption. Therefore, the validity of the said assumption cannot be established in the present state.

47. **Para 6.2.5 Analysis and Distress Evaluation** in the Report on Tower B (Part 1) (page 79) further states; "*There is distress in slabs and beams due to corrosion of rebar, the capacity of the beam and slab with reduction in rebar area by 20% (assumed) have been established and presented in annexure*". However, the report does not provide clear information regarding the basis for making this 20% reduction assumption.

48. **Para 6.2.6 Beams Evaluation** in the Report on Tower B (Part 1) (page numbered 77 but actually page 90) states; "*Few beams are requiring strengthening due to degradation due to corrosion of rebars at various floors, refer annexure 13 to 17*". Table 2 (page 90 onwards) showing beams to be strengthened is only upto 15^{th} floor. There is **no table showing any beams required** to be strengthened **above 15^{th} floor**, whereas in the physical observations reported (page 23 onwards on Tower B), cracks have been reported in RC beams in 16^{th}, 17^{th}, 18^{th} and 19^{th} floors also.

49. **Summary of Evaluation**. The purpose of evaluating the Bureau Veritas India Pvt Ltd (BVIL) report of May 2023 on the structural stability assessment of Towers B and C of Chander Kunj Army Towers, Silver Sand Island, Kochi, is to assess whether the non-destructive testing (NDT) results align with the observed damages and distress in the buildings and to identify any discrepancies or omissions in the findings. The summary of the evaluation findings is as follows:

(a) The report presents challenges due to major NDT tests and analysis appearing unscientific. For instance, it uses categories like "**Doubtful to Good"** in the Ultrasonic Pulse Velocity (UPV) tests, without any percentage values for individual categories. Failure to adhere to the guidelines provided in the relevant Codes has rendered the results to be misleading.

(b) Interpretation of results in the BVIL report disregards well established codal provisions. For instance, the report fails to account for carbonation levels in rebound hammer test results, which can lead to overestimation of strength. Such oversight has compromised the validity of the results.

(c) The **report lacks comprehensive analysis** as specified in the Codes despite the known limitations of individual tests. Combining test results as recommended by codes to gain a holistic understanding of the distress present is essential. Ignoring codal provisions such as not discarding rebound values when UPV values are below 3.75 km/sec, is **unscientific, rendering the findings invalid**.

(d) The **limited number of tests** conducted on two 28 storey towers is **insufficient** for **meaningful extrapolation** of the test results to the entire structure. **Attempting to extrapolate results from a limited set of tests** to an entire concrete structure, despite knowing the inherent heterogeneity of concrete, is both **unscientific and misleading**.

(e) The purpose of these tests should also be to provide solutions for the buildings' longevity, particularly in preventing further corrosion through the use of sacrificial anodes. Even though the summarized BoQ has indicated use of anodes, however, the report **lacks a detailed study to optimize anode placement** based on half-cell potential tests.

(f) The report's handling of **carbonation and chloride content tests raises questions about its credibility**. High pH values where carbonation front has reached the level of the reinforcement, suggest inconsistency either with the testing procedure or the readings, or with both. Similarly, the chloride content results are inconsistent with previous tests, casting doubts on their accuracy. In fact, both the test results of carbonation and chloride tests instead of providing answers to the question of causes of corrosion, **raises more questions**.

(g) **Lack of any tests in the foundation for corrosion is a cause of concern**, especially when the **overground structure** presents a visual picture of **high probability of corrosion** in most of the locations in the two towers (refer the pictorial representation of visual distress).

(h) The **insufficient testing conducted on the retaining wall**, combined with the **absence of drawings of retaining wall provided by AWHO**, raises concerns regarding the effectiveness of the proposed remedial measures. It leaves doubt whether these measures will adequately address the current corrosion of steel, particularly considering the expanding rust stains on the wall. Additionally, it is uncertain whether these measures will effectively prevent future corrosion if rectification is not carried out from the positive side.

50. No inference has been made out in the report regarding the safety of the present structure for occupation even though that is one of the important purposes of the entire exercise from the client's point of view. From the above evaluation, **the condition of the structure may be classified as 'unsafe for occupation' due to the following findings**:

(a) 77% and 53% results of UPV tests in 'doubtful' category in respect of Tower B and C respectively ('Doubtful' being the worst category).

(b) Lack of validity of Rebound Hammer tests.

(c) Lack of validity in Half-Cell Potential tests.

(d) Large and unexplained variation in Chloride content between the earlier tests (2021) and the present tests (2023).

(e) Lack of validity of carbonation test as a probable cause of corrosion in respect of high pH values at the same locations.

(f) The cover meter tests conducted were invalidated as they included the thickness of the cement plaster in the cover thickness measurement.

(g) 81% column and 100% slab locations as in Resipod test results indicate moderate risk of corrosion which is a serious condition.

(h) Unscientific assumptions have been made regarding the percentage reduction of diameter in steel reinforcement due to corrosion. Based on the test results, site observations of highly corroded steel reinforcement and physical distress observed (refer pictorial representation of distress in the towers), it is reasonable to assess that the reduction in reinforcement diameter due to corrosion may exceed 50%.

(i) Further, there has been no attempts to review and co-relate results of all the test results to obtain an overall understanding of the extent of the problem.

Comments on Service Life Calculations

51. Details of Service Life, comprising predominantly of theories, have been presented from pages 99 to 124 of the BVIL Report on Tower B and pages 103 to page 128 of the report on Tower C. Following methods have been explained for Service Life Prediction Models:

(a) Bazant's Model
(b) Morinaga's Model
(c) Wang and Zhao's Model
(d) IV-IRC Model

However, only the IRC Model has been adopted without assigning any reason or rationale.

52. The Service Life predictions and remedial measures appear to be ad-hoc due to the following:

(a) Details of calculations for Service Life Prediction have not been included in the report. Calculations are required for **at least three methods** and comparison of the results is imperative for a project of this magnitude.

(b) The piles have not been tested. Hence, the present condition of the foundation is unknown. Effects of this aspect have not been brought out in the assessment of service life of both the towers.

(c) Service life of the retaining wall has not been included as a separate structure in the report. It is crucial to recognize that the retaining wall is exposed to different conditions compared to the two towers, and therefore they should not be treated as one entity for proposing restoration methods.

(d) Basis of the remedial/restoration measures have not been given. Details of the same are to be explained.

(e) As already explained earlier, more than 70% of the test results have ample cause for concern. Despite this grave situation, correlation of the various test results has not been done.

(f) Towers B and C exhibit varying degrees of damage from corrosion, with Tower C facing a more severe situation (refer pictorial representation of visual distress). Yet, the service life predictions for both are same, i.e., 8-10 years without any rectifications and 28-30 years post restoration. No explanations for the similarity in their service life predictions have been presented with supporting calculations.

53. In light of the above findings, it may be concluded that the entire exercise of structural analysis including visual observation, physical testing, chemical testing and service life analysis does not satisfy the scientific criteria as laid down in the relevant Codes, hence may have to be declared invalid in the present state. Whether it is because of lack of professional competence or a deliberate attempt to misinterpret the factual condition, is for the authorities to decide.

***