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Structural Integrity of "Gulmarg Gondola Project" using Modern Techniques

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Abstract*: NIT Srinagar was requested to carry out Non-destructive test of civil work of Gulmarg Gondola Project (cable car project) at Gulmarg (J&K) under J&K State Cable Car Corporation. So as to assess the present strength of R.C.C. columns of project the non-destructive testing of various columns along with condition survey was carried out to assess integrity of structural members. Investigation was carried out to check the concrete quality, corrosion in reinforcing bars and carbonation of concrete. The concrete quality was found out by using Ultrasonic technique and Hammer Rebound method. The carbonation was determined by use of Phenolphthalein test. The visual examination was carried to find out (locate) the dampness, cracks and other defects in the buildings. The purpose of the survey is to collect sufficient data to pinpoint the cause and source of the problem and to determine the extent of the damage. Durability of concrete is a function of the performance of concrete with respect to time in the service conditions. The concrete is said to be durable when it can withstand the conditions, for which it is designed, over a period of time without getting damaged or deteriorated. Protected concrete has shown more resistance against carbonation and chloride ingress when compared to unprotected concrete. It is myth to believe that concrete is a maintenance free construction material if subjected to different exposure conditions and durability is an actually a function of water entry in concrete.

The objective of the investigation is to test the structural integrity of various RCC members by assessing the deterioration with respect to quality and strength of concrete, permeability, corrosion, cracks and other defects causing distress.

Index Terms: Ultrasonic Technique, Hammer Rebound, Phenolphthalein, Visual Examination, RCC Members, Corrosion and Cracks.

I. INTRODUCTION

Modern structures need to be tested early which are suspected to any strength failure to maintain their sustainability evaluation. Presently, all constructed modern structures need to be investigated for evaluating the serviceability and safeties from time to time. The structural engineers must use these results achieved through proper analysis to specify whether the structure should be reinforced or not. Further, there is a common technique used by many companies to provide information on the quality control and to maintain the design criteria for reinforcing suspicious structure [1, 2]. Especially, great technical and useful importance has been obtained when using the non-destructive testing (NDT) of concrete. The main advantage of using non-destructive test method is to avoid the damage of components of building structure [3]. The examination of empirical research carried out for improving the concrete quality many non-destructive methods have been already used [4, 5]. In this aspect, numerous data and correlation relationships between the pulse velocities of concrete have been arranged and a regression analysis to predict compressive strength of concrete based on sound characteristics like UPV, estimated concrete strength and damping constant [6, 7].

All samples must be at the same age moisture condition and the same carbonation degree and was found that compressive strength of high strength concrete without exposure to temperature (200-400-600-800^{o}C) for one hour [8]. It was also found that for equal compressive strengths concrete made with crushed limestone coarse aggregate show rebound numbers approximately 7 points lower than those for concrete made with gravel coarse aggregate, representing approximately 7MPa difference in compressive strength. Also, the surface and internal moisture effects on rebound hammer and the type of cement significantly affects the rebound number readings [9]. However, research work has been published in which the relation between compressive strength and UPV in columns was studied [10]. Another research work has been published on UPV characteristics [11]. An empirical relationship between concrete compressive strength and UPV has been also derived [12]. The pulse velocity is not affected by the level of stress in the element under test [13]. Further a model was proposed to analyse the compressive strength of concrete in different environments using UPV and probabilistic to predict compressive strength from UPV [14].

Protected concrete has shown more resistance against carbonation and chloride ingress when compared to unprotected concrete. Durability is an actually a function of water entry in concrete. Thus, the objective of the present work is to test the structural integrity of various RCC members by assessing the deterioration with respect to quality and strength of concrete, permeability, corrosion, cracks and other defects causing distress using many modern techniques.

II. PROBLEM OVERVIEW

A. Analysis for the Integrity of Buildings

There are some events when a structure shows signs of failure despite of the high durability of concrete when used as construction material.

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Further, there are numerous causes for the occurrence of damages in structures, like sudden high-loading, foundation settlement or (construction faults) and poor workmanship. Corrosion is the more common cause of damage of reinforcement, which leads to further cracking as well as spalling of the concrete cover. To determine the percentage of damage and enhance the integrity of modern structures these concretes need to be specifically inspected early, which are in use under severe conditions. For assessing the condition monitoring of such structures several techniques and methods are available here. It is necessary to determine whether the major portion of the structure is of good quality and knowledge about the extent of damage is required for applying an appropriate repair method. The aims of the present investigation should be; to identify the cause of damage and determine the percept of damage, estimate all material properties, evaluate the safety (or serviceability) of the structure, provide recommendations on remedial and preventive measures, and estimate the cost of replacement.

Presently, many modern techniques can be applied on the structures for finding out its quality and strength. However, the typical methods used here for inspecting the concrete structures may be simply classified as; visual inspection, mechanical inspection, chemical analysis and electrochemical testing. The surface layer of concrete over the reinforcement is called concrete cover. This cover thickness includes the cement skin, mortar and concrete skin. This concrete cover controls the following:

- Absorption
- Permeability
- Service life of the structure

Cracking, cover and concrete quality is three major interactive and inter related parameters influencing steel corrosion. Cover is an important factor that preserves the electrochemical stability of steel in chloride-contaminated concrete. A cover thickness survey is useful to determine what cover exists in a specific location where a damage has been identified and elsewhere for comparison on the same structure. The cover to reinforcement, or any other embedded steel is required to be known so that the results of other tests, such as carbonation and chloride concentration, can be correctly interpreted with respect to future performance of the concrete structure. The cover thickness can be measured non-destructively using commercially known cover meters. All cover meters work on the electromagnetic interaction between the search-head, which is moved over the surface of the concrete. Care must be taken to check the results of such a survey by physically removing the concrete cover at one or more locations and measuring the depth of the steel. This will ensure that the type of steel or type of aggregate is not influencing the result, and that the cover meter is correctly calibrated. The detailed structural drawing will give an idea in the cover thickness survey. Table1 shows how the cover meter readings are to be interpreted for corrosion assessment.

TABLE 1: COVER METER READINGS

S. No	Test Results	Interpretations
1.	Required cover thickness and good quality	Not corrosion prone
2.	Required cover thickness and bad quality cover concrete.	Corrosion prone
3.	Very less cover thickness, yet good quality cover concrete.	Corrosion prone

Mostly, the concrete is alkaline in nature and the pH value of concrete at the time of construction is around 12.5. During the course of time; carbon-di-oxide from external environment enters inside the concrete. Because of the chemical action of carbon-di-oxide on calcium carbonate, the alkaline environment changes to acidic environment. This is one of the necessary conditions for corrosion. This change can be detected by phenolphthalein test. A solution of phenolphthalein in dilute alcohol is usually used because it has a very strong dark blue color that is easily visible on any kind of concrete surface, which has retained its alkalinity. But it changes its color on the concrete surface which no longer remains alkaline due to the action of carbon-di-oxide, thus paving the way for the corrosion of steel rebar's. The change in color of phenolphthalein takes place as pH value changes from 12.5 towards lower pH. Once the pH value reduces below 10, passive layer in the rebar is broken. The freshly broken concrete surface is sprayed with phenolphthalein indicator solution. The outer most part of the freshly broken concrete surface will be carbonated and will not be stained. The inner part of concrete will not be carbonated. The boundary of color stain will clearly show how far carbonation has penetrated into the concrete. The position of steel reinforcement at that zone is determined. If carbonation has penetrated up to the steel reinforcement and beyond, the rusting is slow. When concrete is alternatively wet and dry, the steel starts rusting rapidly. In case of salty environment, the change of alkalinity and the presence of chloride fasten the rusting of steel. Measuring the depth of carbonation into the concrete is a test, which can give warning of rusting before serious damage will occur. A rainbow indicator gives the value of PH, mentioned in Table 2.

TABLE 2: PH RANGE OF CONCRETE WITH RESPECT TO COLOUR

S. No	Color	pH
1.	Orange	5-6
2.	Yellow	7-8
3.	Green	9-10
4.	Violet	11-12
5.	Dark Blue	13

Planning the condition survey includes selection of the most appropriate tests, the extent or number of test points to reflect the existing conditions of the structural members, and the location of these test points. It is good practice to obtain sufficient test result to make a statistical analysis. However, the number of test points adopted is usually a compromise between reliability, time, cost, and damage. Sometimes the survey is carried out in two

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stages: first, a preliminary survey with a few test points to establish the necessity for repair; and second, a thorough survey to allow a repair scheme to be designed and cost estimated.

While a condition survey may begin with a definite plan, modifications often become necessary as work proceeds and the initial test data becomes available. If the results deviate significantly from expectation, the scope and nature of the survey should be modified accordingly.

Assessment of material strengths normally forms part of the condition survey. This part of the work is essential if structural adequately is in doubt.

The concrete strength is determined by non-destructive testing on site. It is important to distinguish between the concrete strength in general and the concrete strength of a particular member. For general assessment, the sampling locations should be randomly chosen, and a sufficient number of samples taken to arrive at a reliable indication of the average strength and the degree of variation. Reinforcement corrosion has been recognized as one of the serious problems in concrete structures as it contributes to substantial damage in a structure exposed to aggressive environments. Corrosion results in the reduction of effective cross sectional area of reinforcing steel and also results in cracking, spalling-delamination of cover concrete finally leading to total failure of the structure. Thus, the principal factors, which influence corrosion, are:

- PH value of concrete: The pH value of the fresh concrete is normally about 12-13 & thus providing an alkaline environment to inhibit corrosion. This alkaline environment is largely due to the generation of $Ca(OH)_2$, which is formed during the hydration of cement. If this pH value reduces, the alkalinity reduces making the steel vulnerable to corrosion.
- Carbonation: Carbonation occurs when CO_2 from air finds its way into the body of concrete through its pores in presence of moisture & water forms carbonic acid which neutralizes the $Ca(OH)_2$ formed due to the reaction during setting of concrete thus reducing the alkalinity of concrete. This process continues and destroys the passivation layer on steel. Carbonation is dependent on humidity of environment & porosity or permeability of the concrete.
- Chloride: The penetration of salt containing chlorides activates corrosion & destroys the passivation. The sources for chlorides could be water used for concreting & curing or the aggregates which may be contaminated with chlorides. Even chlorine gas from the environment may enter through the pores in concrete. These chloride ions tend to destroy the passivating film on steel making the surface activated locally forming a small anode while the rest of passive surface serves as the cathode. Since the latter (cathode) is much larger, the dissolution of iron in the anode is highly localized and a pit is formed. The chloride ions combine with water forming hydrogen chloride & hydroxyl ions. The hydrogen chloride further prolongs the corrosion causing an increase in the pit depth leading to pitting corrosion.
- Moisture: Corrosion is essentially an electrochemical reaction setting in galvanic cells & difference in potential. This cell activity is aided by moisture content, which makes the galvanic cell conductive.
- Oxygen: Oxygen plays a significant role in accelerating corrosion. The penetration of oxygen in differential concentrations at different places causes formation of differential aeration cells, which in turn produces potential difference, and flow of current. The oxygen ingress depends on permeability, cracks, and cover thickness and water cement ratio.
- Permeability: The permeability (K) of concrete is one of the primary factors affecting the rate at which salts, oxygen, moisture, etc. can penetrate into concrete and also influences the behaviour of both steel & concrete. The permeability depends on factors like cement content, water cement ratio, degree of compaction, age & curing of concrete.
- Cover: The cover thickness is also an important factor affecting corrosion, as the cover thickness is the path through which salts, oxygen, moisture etc. penetrate to reach the steel surface.

III. RESULTS, ANALYSIS AND DISCUSSIONS

A. Visual Examination

1. In column P2 of Station G-1 the cover of concrete is detached from the concrete and crack was also observed in same column. The hollow sound was also observed on tamping with hammer which indicates that the concrete cover is detached from the concrete column.
2. In Columns P4, P5 and P6 of Station G-1due to wooden panelling access to the columns were not possible.
3. In columns of Station G-4, 1.6 inch diameter throughout holes were observed, these holes should be filled with suitable grout.
4. In columns of the towers T18, T17 and T16 (between station G-4 and G-3), 1.6 inch diameter throughout holes were observed, these holes should be filled with suitable grout.
5. The superficial cracks were observed in columns of Tower T16, T15 and T14 (between G-4 and G-3).
6. Platform of T15 (between G-4 and G-3) is damaged to great extent and needs repair.
7. One downhill column of Tower T12 (between G-4 and G-3) was observed to be out of plumb.
8. In column of tower T7 downhill (between G-4 and G-3) hollow sound was observed on tamping with hammer. Also Downhill column had very less cover thickness; reinforcement bar is visible and has started corroding.
9. In columns of the towers T5, T4 and T2 (between station G-4 and G-3), 1 inch diameter throughout holes were observed, these holes should be filled with suitable grout.
10. In column P3 of Station G-2 a wooden strip of 12"×2" was observed, which may be left there during the construction.
11. The outer surface of column P6 of station G-2 was observed to be abrading by the materials stored in the store room. No paint/protective coating was done on this.

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12. In column P1 of Station G-3, 1.6 inch diameter throughout hole was observed, this hole should be filled with suitable grout.
13. In column of Tower T19 the bolts of base plate were unpainted and were found to be rusted.
14. In column of Tower T18 the sides of the concrete members were found to be slightly damaged.
15. In towers T9, T8, T6, T3 and T2 some of the nuts, bolts and bolt gating were found to be rusted.

Thus, the whole detailed analysis carried out for the investigation of cracks, delamination and other failure in columns using different test methods regarding structural integrity of various RCC members can be observed from Figures 1, 2, 3, 4, 5, 6, 7 and 8.

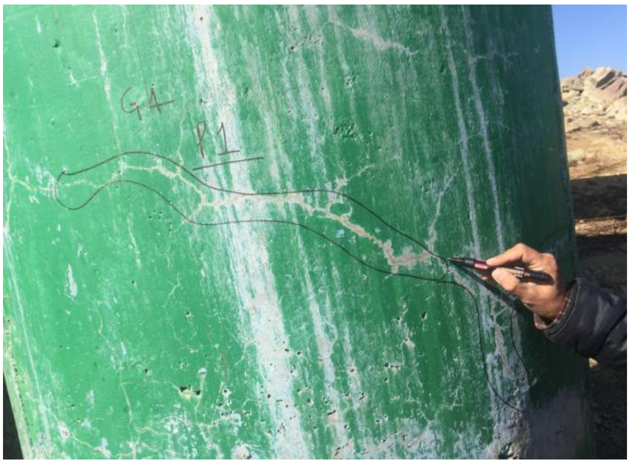

Fig.1. Superficial cracks on Column P1 of Station G-4

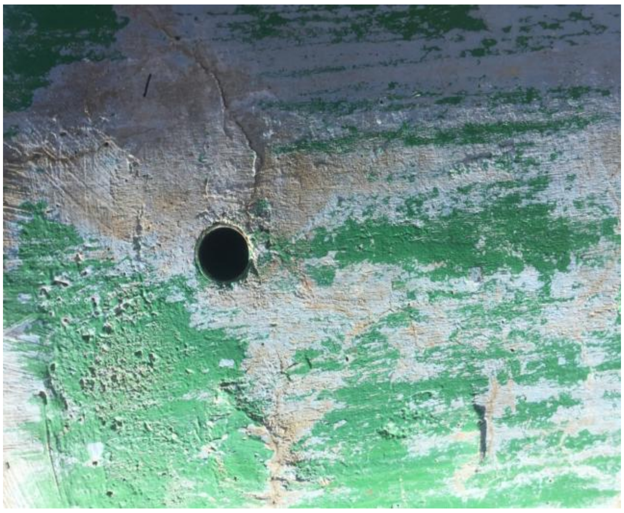

Fig.2. Column of Station G-4, 1.6 inch diameter throughout hole

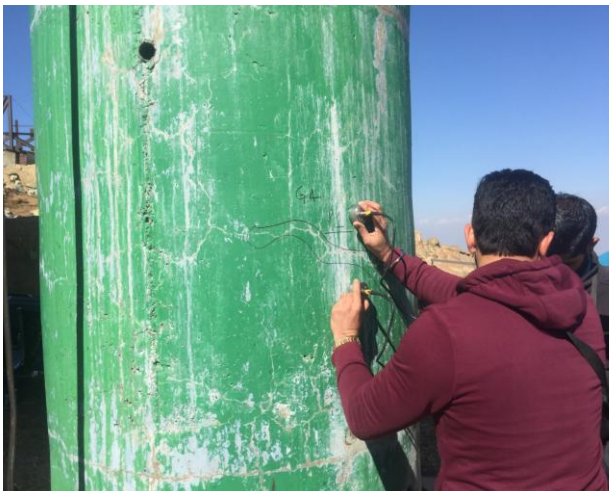

Fig.3. Testing of Column using Ultrasonic Pulse velocity test to check the crack depth

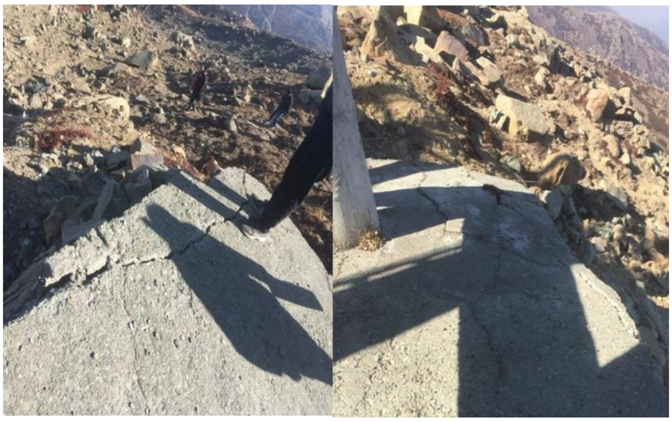

Fig.4 Damaged Platform of T-15 (between Station-G4 and G3)

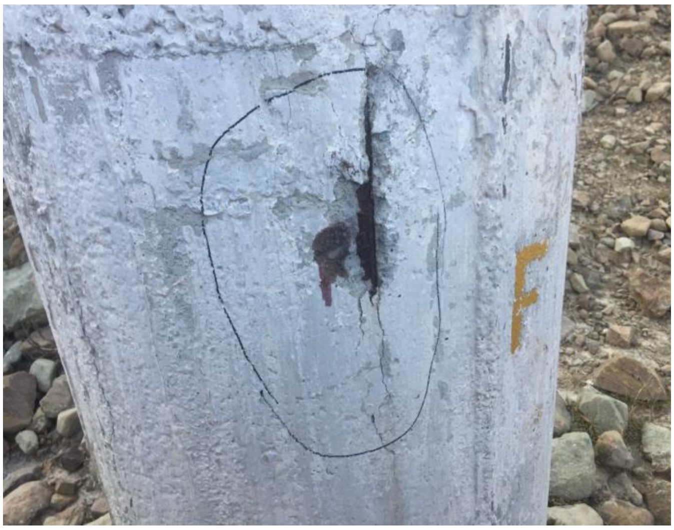

Fig.5 Column of tower T7 had very less concrete cover, reinforcement bar is visible and rusting of reinforcement has been initiated

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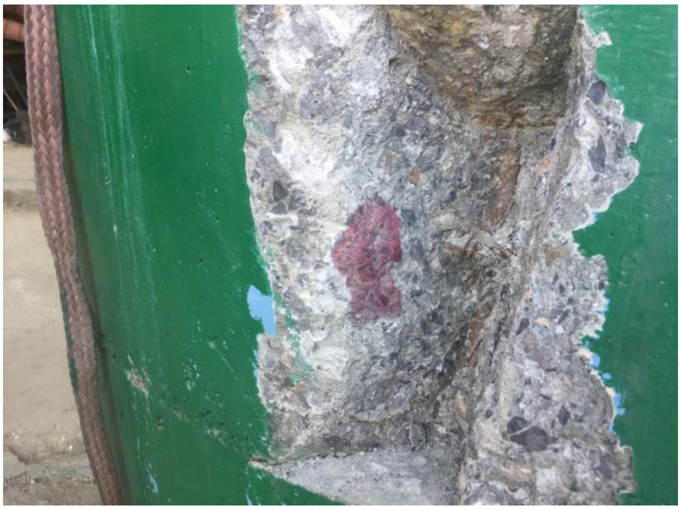

Fig.6 In column P2 of Station G-1 the Column is damaged and on carbonation test showing red colour confirming the carbonation of concrete

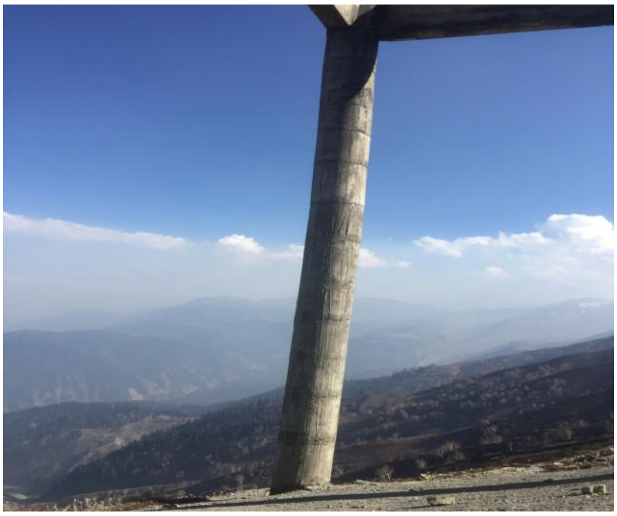

Fig.7 Downhill column of Tower T12 (between G-4 and G-3) was observed to be out of plumb

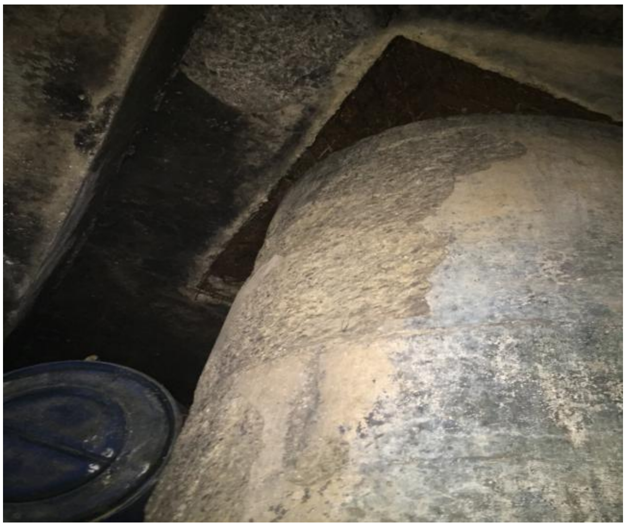

Fig.8 Outer surface of column P6 of station G-2 was observed to be abrade by the materials stored in the store room. No paint/protective coating was done on this

B. Non- Destructive Testing of Concrete Elements

The concrete elements were also tested by using rebound hammer test. The strength is obtained by the known value of rebound number corresponding to the desired strength. However, this test is sensitive to local variations, in concrete such as presence of large pieces of aggregate, voids, and cracks in concrete. As such the results obtained by ultrasonic technique are more reliable to get the quality of concrete. For rebound hammer test, the observations were taken after levelling and readings were taken at six points for each location. The non-destructive tests (NDT) such as Rebound test or Ultrasonic Pulse Velocity test provide indirect measure of strength and the quality of concrete through specified indices namely, rebound number index and ultra-sonic pulse velocity (USPV) respectively. Estimation of strength of concrete in structure through these tests is possible when established co-relations between the measured indirect indices and the strength are available. The concrete can be appraised qualitatively as excellent, good, medium or doubtful. The meaning of the term excellent, good, medium and doubtful is based on ultra-sonic pulse velocity measured at site and is as per the nomenclature of IS-13311 and other reference literature. The relevant table is reproduced here in table 1 for the purpose of reference. In-situ carbonation test gives an indication of the carbonation has occurred and the extent of cover generally provided to Rebar's at site. These two tests together give information regarding carbonation being the potential cause of corrosion. Following tests have been carried out on various structural elements besides visual observations:

1. Schmidt Rebound Hammer test.
2. Ultrasound pulse velocity test.
3. Carbonation of concrete test.

Schmidt Rebound hammer and Carbonation Test

The two tests, which have been used to assess the strength and compactness of concrete and its integrity, are the rebound hammer and the ultrasonic pulse velocity. Carbonation has been identified with the help of phenolphthalein rainbow indicator. The concrete is alkaline in nature and the phenolphthalein gives blue in colour when it comes in its contact. If the carbonation has taken place, the concrete will not turn blue. It is possible to establish the depth up to which carbonation has set in; by this procedure. The results have been presented in a tabular form (Table 3 and 4). The average relative strength of concrete varies from 15.5-44N/mm^2 corresponding to the rebound hammer test. The general quality of concrete is in the range of poor to excellent corresponding to the Ultra sonic Pulse Velocity test. The ultra-sonic pulse velocity test values, carbonation test result and rebound hammer values as determined by tests on different locations are as follows:

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Table 3: UPV, RH VALUES & CARBONATION TEST OF MAIN BUILDING

S. No.	Location	RH No	Average UPV (m/s)	pH of concrete	Compressive Strength N/mm^2	Compressive Strength after correction N/mm^2	
			Station G-1				
1.	Column P2	69.5,39,68,50,62,68=59.41	3940	5-6	48	24	33
2.	Column P2	69,67,74,70,69.5,71=70.08	4975	5-6	80	40	
3.	Column P2	68,71,69,69,66,57=66.66	4720	5-6	70	35	
4.	Column P1(Bottom)	75,75,67,73,73,74,=72.83	6610	5-6	92	46	41
5.	Column P1 (Top)	67,73,61,68,66,73=68	6250	5-6	73.5	36	
6.	Column P3 (Bottom)	75,72,75,75,72,72=73.5	6470	5-6	92	46	38.5
7.	Column P3(Top)	70,65,65,62,63,67=65.33	6330	5-6	62	31	
8.	Column P5(Top)	71,68,68,67,70,62=67.8	6250	5-6	73.5	36	
			Station-G4				
9.	Column P2	70,72,67,72,70,72 = 70.5	2300	5-6	80	40	
10.	Column P5	67,59,70,69,65,68 = 65	2270	5-6	62	31	
11.	Column P4	71,73,67,72,71,69 = 70.5	3960	5-6	80	40	
12.	Column P3	74,75,73,76,74,70.5=73	4320	5-6	92	46	
13.	Column P1	54,58,56,55,55,57=55.83	1720	5-6	40	20	
			Towers between Station G-4 and G-3				
14.	Tower T18	42,46,41.5,47,45,36.5=43	5320	7-8	22	15.5	
15.	Tower T17	46.5,57,58,54,51,56=53.66	2430	6-7	37	22	
16.	T16 (uphill side)	57,53,54,49,59,39=51.83	2490	6-7	34	20.5	
17.	T15	40,53,46,54,50.50=48.83	1740	6-7	29	17.5	
18.	T14(DHS) (G4)	57,52,53,49,58,40=51.83	2130	6-7	34	20.5	
19.	T13 DH (G4)	53,61,52,61,55,61=57.16	6170	6-7	42	25	
20.	T12 DH (G4)	59,55,62,58,58,57=58.16	4402	6-7	45	27	
21.	T11 DH (G4)	49,40,49,53,48,48=47.83	3890	6-7	27.5	17	
22.	T10 DH (G4)	51,49,56,51,46,45=49.7	3560	6-7	30	18	
23.	T9 DH (G4)	59,58,65,53,60,62=59.5	1830	5-6	48	24	
24.	T8 DH (G4)	61,57,55,63,64,68=61.33	1810	5-6	51	25	
25.	T7UH(G4)	51,51,50,45,49,45=48.5	3390	7-8	27	19	
26.	T7DH(G4)	37,40,28,36,34,42=36.66	1410	8-9	16	13	
27.	T6UH(G4)	60,52,58,57,62,52=56.8	3640	6-7	42	25	
28.	T5UH(G4)	48,50,61,42,51,43=49.16	2440	8-9	29	20	
29.	T4UH(G4)	51,55,49,52,52,46=50.83	2940	7-8	32	22	
30.	T3UH(G4)	64,64,56,54,63,55=59.33	3725	5-6	48	24	
31.	T2UH(G4)	60,62,57,47,57,52=54.8	4920	6-7	38	23	
32.	T1G4	61,63,54,56,62,56=58.66	3840	5-6	48	24	
			Station-G2				
33.	Column P1 (bottom)	74,75,60,71,68,76=70.6	3910	5-6	82	41	
34.	Column P1 (Middle)	66,67,67,70,64,73=67.83	4370	5-6	70	35	38.6
35.	Column P1 (Top)	67,74,72,59,74,74=70	4700	5-6	80	40	
36.	Column P2 (Bottom)	65,61,55,69,57,66=62.16	4020	5-6	54	27	
37.	Column P2 (Middle)	69,70,73,59,59,72=67	4630	5-6	68	34	35.6
38.	Column P2(Top)	69,75,74,70,75=72.6	6170	5-6	92	46	
39.	Column P3 (Bottom)	73,70,73,70,57,67=68.33	5600	5-6	70	35	
40.	Column P3 (Middle)	66,68,72,72,73,74=70.833	3540	5-6	82	41	41
41.	Column P3 (Top)	74,74,75,75,75,72=74.16	3920	5-6	94	47	
42.	Column P4 (Bottom)	67,70,69,65,68,63=67	4790	5-6	69	34	
43.	Column P4 (Top)	68,58,67,67,61,68=64.83	4130	5-6	62	31	33.3
44.	Support Column of P4	68,67,68,72,69,63=67.83	4630	5-6	70	35	
45.	Column P5 (Bottom)	62,64,63,65,60,62=62.66	3340	5-6	55	27.5	
46.	Column P5 (Top)	65,61,55,69,57,66=62.16	3340	5-6	54	27	27
47.	Column P6 (Middle)	70,64,65,64,65,70=65	3320	5-6	62	31	
			Station G-3				
48.	Column P1(Bottom)	76,75,79,62,73,72=72.83	4185	5-6	92	46	44
49.	Column P1(Middle)	73,70,72,75,75,71=72.66	3720	5-6	92	46	
50.	Column P1(Top)	68,72,68,73,70,71=70.33	5051	5-6	80	40	
51.	P2(Bottom)	67,71,74,66,73,69=70	4005	5-6	80	40	
52.	P2(Middle)	72,71,77,68,71,71=71.66	3811	5-6	84	42	38.33
53.	P2(Middle)	71,64,63,66,69,63=66	4380	5-6	66	33	
54.	P3(Bottom)	74,74,60,73,78,78=72.83	3745	5-6	92	46	
55.	P3(Middle)	64,68,65,66,63,64=65	3710	5-6	62	31	35
56.	P3(Top)	70,65,54,60,69,58=62.66		5-6	56	28	
57.	P4(Bottom)	71,74,63,76,69,63=69.33	3805	5-6	78	39	
58.	P4(Middle)	70,71,73,69,63,72=69.66	3420	5-6	80	40	38
59.	P4(Top)	68,65,72,65,69,71=68.33	4380	5-6	70	35	
60.	P5(Bottom)	68,71,56,71,63,66=65.83	4940	5-6	66	33	
61.	P5(Middle)	67,70,67,72,69,68=68.33	3710	5-6	70	35	
62.	P5(Top)	68,71,66,71,63,66=67.5	3380	5-6	69	34.5	34
63.	(SUPPORT column of P4)	60,66,67,61,65,57=62.66	4940	5-6	56	28	
			Towers Between Station G2 And G1				
64.	T19UH Ph1	58,50,64,55,51,54=55.33	6150	6-7	38	23	
65.	T18UH Ph1	58,47,49,52,57,56=53.16	6300	6-7	36	21.6	
66.	T17UH Ph1	46,55,43,59,52,57=52	6360	6-7	34	20.5	
67.	T16DH Ph1	51,51,62,57,52,57=55	6410	6-7	38	23	
68.	T15DH Ph1	43,63,49,52,43,60=51.66	6330	6-7	34	20.5	
69.	T14DH Ph1	58,40,53,63,59,40=52.16	6150	6-7	34	20.5	
70.	T13DH Ph1	53,48,43,51,47,49=48.5	6640	8-9	27	22	
71.	T12UH Ph1	65,62,50,62,50,56=57.5	6200	6-7	42	25	
72.	T11UH Ph1	42,43,44,49,46,35=43.16	6410	8-9	22	18	
73.	T10UH Ph1	52,54,48,50,54,52=50	6330	6-7	30	18	
74.	T9UH Ph1	57,53,35,50,45,55=49.16	5880	8-9	29	23.2	
75.	T8UH Ph1	50,48,49,50,47,49=48.83	6330	8-9	29	23.2	
76.	T7DH Ph1	33,40,40,48,47,42=41.66	6070	8-9	21	17	
77.	T6DH Ph1	49,44,49,56,50,54=50.33	6050	6-7	30	18	
78.	T5DH Ph1	55,54,52,55,61,42.5=53.25	6220	6-7	36	22	
79.	T4DH Ph1	64,56,56,53,56,63=58	6220	6-7	44	26.5	
80.	T3DH Ph1	58,50,54,65,53,54=55.6	6070	6-7	40	24	
81.	T2DHPh1	58,62,63,53,64,58=59.6	6150	5-6	50	25	
82.	T-1	53,60,61,54,57,46 = 55.16	5510	6-7	38	22.8	

TABLE 4: SUMMARY OF PROBLEMS AND DEFECTS

1.	Cracks: Superficial cracks were observed in some of the columns of the columns.
2.	Rusting: (1) Rusting was observed in some base plates, nuts and bolts of the steel tower. (2) Rusting was also observed in reinforcement of column of tower T-7 (between Station G-4 and G3)
3.	Carbonation: carbonation was observed in all the concrete members.
4.	Spalling: No spalling was observed, except at one location P2 column of Station G-1 and needs proper repair.

C. RECOMMENDATIONS FOR REPAIR OF R.C.C. STRUCTURES

Behavior of Concrete

Concrete is a strong, versatile building material that has found favor with Architects, Engineers as well as Builders doe to the ease of production and capability of being molded into a number of factors. These are mainly related to the constituents and the method of production. In the earlier times the period when most of the old RCC structures in Chandigarh were built, the emphasis was on primarily the 28 days strength of concrete. Little was known about the long-term behavior of concrete because IS 456 of 1964 (Code of Practice for Plain & Reinforced Cement Concrete), which was in vogue, then was silent on this aspect. The general belief was that good quality concrete was expected to last for at least a century. Though environmental factors were known to cause damage to concrete but for a place like Chandigarh, which at the time of its being established was free from pollution and far removed from the sea, the environmental factors were not considered of any major consequence. It was therefore considered that concrete needed no protective coating or covering and so to provide a unique character and also to ensure good quality concrete the formulators of the specifications at that time decided to provide shutter finished RCC with no coating or plaster to be provided over it for the sake uniformity. As time passed the concrete technologists realized the importance of durability and the effect of the environmental factors on the

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performance of concrete. IS 456 of 1978 introduced for the first time the aspect of `Limit State' of Design for Concrete Structures. Among the various Limit States that were set out to be satisfied, one of the important ones was the Limit State of `Durability'. However even this revision of the Code linked the durability to `Condition of Exposure' to which the structure was to be exposed and a minimum content of cement to be used was specified. This may lead to over use of cement in many cases with no control on the water cement ratio. The high cement content leads to high heat of hydration, which results in high initial cracking. This coupled with uncontrolled water cement ratio lead to increased pores in the body of the concrete. The formulators of IS 456 then realized the importance of deterioration of concrete by the process of `Carbonation' and hence the Fourth Revision issued in the year 2000. This revision has now laid down the limits of minimum cement content as well as the corresponding maximum water cement ratio for different conditions of exposure of concrete. This has been made possible with the advent of the water reducing admixtures for concrete.

The Importance of Cover

Concrete is heterogeneous material and, therefore, non-homogenous. Such in homogeneity occurs both at macro and micro levels. The cover has many non-visible micro cracks and this act as avenues for water and gas penetration. The cover, therefore, should be of proper quality, depth and Bar Spacers could be incorporated to maintain even cover depths. It is observed that when the permeability form work is uncontrolled, the water cement ratio needed is 0.10 more and the cement content gets reduced by about 45 kg/m^3 compared to the original concrete mix and therefore, the cover becomes most vulnerable to attacks.

Carbonation of Concrete

Under pure solution of pH values of up to 12.5, the reinforcement in the concrete remains in passivating conditions and does not initiate the process of corrosion.

Carbonation is the effect of CO_2 from the atmosphere reacting with alkaline component in concrete Ca $(OH)_2$ in the presence of moisture thereby converting the calcium hydroxide to Calcium Carbonate. The pH value of the pore water is reduced to less than 9.5, the reinforcement is no longer in the passivating range and corrosion occurs.

Principles of Repair

There are basically two principles for repairs;

Principle 1: Set up a cover that is sufficient in density and thickness.

Principle 2: Leave the cover as it is or set up a minimum required cover and apply a surface protection system.

The application of protective coating is an attempt to increase the effective cover. Therefore, the principle of equivalent cover is very valuable in repair strategies. Repaired concrete structures fail within a very short period of time if all steps are not properly followed or compromised due to economic limitation.

Mechanism and Principles of Corrosion and Coatings

Corrosion is an electrochemical process and most common form of corrosion in concrete is in an aqueous medium. At cathode, the reduction takes place lowering the size of reinforcement and therefore the structural ability to carry the stresses. Availability of oxygen, water and chloride ions is the basic requirements for corrosion. There are two stages of corrosion, the first one is `Initiation' and second is `Propagation' or growth. In initiation, the protective passive layer on the steel surface is destroyed either by Chloride penetration or carbonation. In propagation, oxygen, water, transport, chlorides or internal electrical resistance governs the rate of corrosion.

With the concept of equivalent cover the modern repair system are designed to have only two products. The first product is used for `corrosion inhibition' and re-proofing with inbuilt bonding agent and the second product is to provide CO_2 resistance. Research has established that a 2mm coat of such a protection will give 1.2 m of concrete equivalent cover. This would guarantee the durability of repairs.

Concrete Repair, the Material factor

The selection of material is the most important step in repair and rehabilitation programme. It is preferable to have all the materials based on some generic polymer s the materials are more compatible. The materials should have features like very good bonding characteristics, good strength development characteristics, the materials should be non-shrinking type, and above all they should be as impermeable as possible because the corrosion is accelerated only in presence of oxygen and moisture. The repaired surface should be finally coated with coatings in which the basic properly should be that the protective coating should have high resistance towards diffusion on carbon dioxide, which will further protect the concrete from the effects of carbonation. If impermeable materials (like epoxy mortars) are used for large patches, the moisture vapor will be entrapped between the concrete and topping. The entrapped moisture will cause the failure either at the bond line or within the weaker of the two materials.

The dimensional stability of the repair mortar is one of the primary requirements for successful repair. The differential shrinkage between old concrete and new repairs mortar lead to bond failure after repair. The modulus of elasticity of repair material is very important criteria for selection as materials with low modulus of elasticity deform more under given unit load than materials with high modulus of elasticity. The repair can fail when the wheel load is applied parallel to the bond line. In case corrosion is not arrested due to non-application of corrosion inhibition in the repair system, serious cracking along the junction of repair after 2/3 months is observed especially in monsoon and in most of these cases the cracks are stained with rust.

Compatibility of Materials

The most important conclusion is summarized in report of concrete society working party. Technical Report No. 38 Tiled Patch Repair of Reinforced Concrete subject to reinforcement corrosion, Model Specification and Method of Measurement. In

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the section 13 on materials, the compatibility and responsibility is highlighted and the paragraph is stated here in verbatim as follows: "It is recommended that all elements of repair and protection system (reinforcement protective system, bonding aid or primer, repair mortar, surface filler, fairing coat and protection system) are obtained from a single manufacturer. Otherwise there can be divided responsibilities if problems arise.

Coatings for Concrete

There is a marked difference between paints and protective coatings for concrete. Whereas the paints are meant to beautify the concrete, the protective concrete are meant to protect the concrete under service conditions. There are large numbers of surface treatments available in the market. Coatings applied on the concrete should not only be selected by considering only the aesthetic effect but the selection must be based on the protection criteria. It is possible to have both aesthetic and protection judiciously combined in a single swell-designed coating. Generally the protective coatings should have the following basic characteristics.

Impermeability to Water and breathing Characteristics

The coatings should be permeable to water vapor but they should be impermeable to water and other gases like oxygen, carbon dioxide etc., this means the coating should be breathable. Breath ability is that properly which enables the water vapor to move in and out of concrete with the fluctuations of temperature and humidity. This is a balancing point in well-designed coating.

Carbon Dioxide diffusivity Carbonation

The protective coatings should also be tested for diffusion of carbon dioxide to designate them as anti-carbonation coatings. It is not sufficient that protective coatings are tested for carbonation initially but they should also be tested for carbonation after exposure to weathering conditions and cycles of loading.

Stability to ultra-violet Radiations

For exterior application is mandatory that the coatings should be stable to ultraviolet radiations. The coatings should remain flexible even after exposure to sunlight without degrading. For example, epoxies do not possess adequate UV resistance. Acrylics are fully resistant to UV radiations by virtue of their basic formulation.

Flexibility and Crack Bridging Properties

The ingress of moisture, oxygen, carbon dioxide, etc. is not only through continuous capillaries but also through the cracks. Cracks bridging capacity is a function of flexibility and thickness of coatings. Polymer modified cementations flexible mortars are useful in cracks bridging as they form the base of concrete protection. The coatings should be self-curing. These coating should also have low chloride penetration characteristics. The protection function is that of a physical barrier rather than chemical composition. It is the surface of concrete we are aiming to protect and therefore, surface of concrete plays a major role, as this is a base for contact and adhesion.

D. DURABILITY OF REPAIRS

Durability of concrete is a function of the performance of concrete with respect to time in the service conditions. The concrete is said to be durable when it can withstand the conditions, for which it is designed, over a period of time without getting damaged or deteriorated. Protected concrete has shown more resistance against carbonation and chloride ingress when compared to unprotected concrete. It is myth to believe that concrete is a maintenance free construction material if subjected to different exposure conditions, Durability is an actually a function of water entry in concrete. Due to the innumerable factors like congested reinforcement, geometry of element, slump of concrete, etc. the cover of concrete is not of the same quality as that of core concrete. This weakness of concrete makes the concrete more vulnerable to deterioration. It is thus not enough to prescribe the thickness of cover alone without specifying the quality of concrete in it. The concrete cover is therefore, the first line of defense in corrosion protection. In view of atmospheric conditions coupled with polluted environments, the concrete need to be coated by suitable surface treatments, which enhance the protective quotient of concrete.

Since cover is the first line of defense to inhibit corrosion, the repair and rehabilitation is recreation of cover with highest protection quotient. Therefore, use of polymers, fibers etc. to lower the permeability and minimize the cracks in addition to bonding become important. Given actual working conditions, it is difficult to create a cover, which will be resistant to carbonation or chloride ingress. To remove this lacuna from the system, it is preferably to resort to protective coatings, which work on principles to equivalent cover to ensure durability of repairs. Therefore, the last step of concrete repair, which is anti-carbonation or chloride-ingress resistant coating, ensures the durability of repairs.

E. IMPORTANT ASPECTS OF RESTORATION

Restoration / rehabilitation of RCC Structures/members are highly specialized tasks. Such tasks must be carried out after developing detailed specifications by experts/rehabilitation consultants. The execution must be entrusted to specialized agencies only. Following points must be given adequate attention while dealing with the restoration works:

a. The structural members under restoration shall be adequately supported to transfer the loads temporarily from the member.
b. The restoration of the various members shall be done stage by stage. All members shall not be taken up simultaneously.
c. All the products shall be applied strictly as per Manufacturer's specification and preferably by their authorized applicators only.
d. All suitable precautions shall be taken to ensure the safety of work force and equipment during execution of work.
e. All the exposed reinforced concrete members shall be protected against attack by acid gases,

chloride ions, sulphates, moisture etc., by providing suitable protective coating system comprising of a silane/siloxane primer and an aliphatic acryl ate top coat.

f. For proper strength and bonding of repair materials especially repair of R.C.C., flooring and plasters, use of `epoxy based bonding agent is strongly recommended.

g. In order to ensure, restoration of the repaired surface to their original texture, color and finish, a 3mm thick fairing coat/skim coat over the repaired areas, is recommended.

IV. CONCLUSIONS

Based on the experimental research work carried out on the analysis of **s**tructural integrity of 'Gulmarg Gondola Project' using various modern techniques, the following specific conclusions can be drawn:

I. The overall stability of various structures was found to be good. The visual inspection and NDT results show that the various members are in good condition with respect to their deterioration with age.

II. The carbonation is observed in all the concrete members, in most of the columns the carbonation has not been reached up to the reinforcement level because of thickness of concrete cover. But in some of the columns of the towers of Second phase the carbonation has been reached to the reinforcement level, which results in initiation of rusting in reinforcement. Due to carbonation the surface of concrete becomes very hard, which gives wrong interpretation on rebound hammer test value. So the suitable correction factor is applied as per IS-13311 Part-I 1992.

III. In some columns carbonation has not been reached to reinforcement level, if it reaches the reinforcement level the rusting of reinforcement will start and results in spalling and Deterioration of concrete.The defects identified are to be repaired in order to prevent further deterioration.

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