A Case Study on the Corrosion Mitigation and Sealing of Crack/Porous Concrete of a Bridge with Epoxy Grout/Monopol High Molecular Weight Polymer (LV Grade) Grout

Md Firoz Ali[1], Abraham Lincoln[2] and Supia Khatun[3]

[1]M. Tech, Department of Civil Engineering, Aliah University, Kolkata-700156, West Bengal, India
[2]M. Tech, Civil Engineer, Public Works Department, Alipurduar Highway Division, West Bengal- 736121, India
[3]Associate Professor, Department of Civil Engineering, Aliah University, Kolkata-700156, West Bengal, India

Abstract. The **c**orrosion of rebars or strands is single largest deterioration mechanism which manifests durability challenges of bridges in a substantial way. Corrosion leads to pitting of the reinforced cement concrete which exhibits its strength loss and reduction of bond strength between steel bars and concrete, which ultimately leads to spalling, failure and cracking. In this project a study was made regarding the latest corrosion mitigation technologies and retrofitting of corrosion damaged Dima River bridge at Buxa forest in Kalchini area of Alipurduar, West Bengal. First of all, preliminary survey of the bridge was done and few popular NDT tests were performed such as rebound hammer test, ultrasonic pulse velocity test, measurement of crack depth with UPV. After this the cracks were marked and putty was done by Sikadur 31C comp A chemical for the sealing of the cracks. After about 24-48 hours grouting was done with the help of injector gun, where a hardener chemical Sikadur 52 Comp A (0.8 kg + 0.1 kg mix combination) and monopol, a polymer was inserted to fill the honeycombed mesh or voids inside the structure under pressure for the purpose of epoxy grouting. When the voids get filled up then a reverse pressure gets initiated which stops the filling up procedure. Monopol imparts excellent adhesion and chemical resistance. Again, after few weeks the NDT tests were performed for finding the efficiency of the retrofitting process and it proved to be highly effective.

Keywords: corrosion; monopol; NDT tests; grouting; injector gun

1 Introduction

Throughout the transportation infrastructure bridge deterioration has become a widespread problem. In order to achieve full-service lives from existing bridges implementing cost-effective and reliable repairs is necessary. It was tracked down that most of the concrete bridges require repair within the first 11 to 20 years of their service lives. Since such a large number of bridges will require work within the first 20 years of service life, it is indispensable to analyze how repairs are being conducted.[1] Escalating the reliability and efficiency of repairs that are conducted on concrete substructures could result in significant cost savings throughout the service life of the structure. Corrosion in the rebars due to chloride attack, carbonation, relative humidity is the major cause of problems in RCC structures. During the service life of the structure, de passivation occurs in the initial stage of corrosion and with the passage of time cracking and spalling occurs in the structure and ultimately collapse happens. Therefore, there is necessity for the use of proper corrosion inhibitor.[2]

2 Objective

2.1 Aim and objectives

In this project a study was made regarding the latest corrosion mitigation technologies and retrofitting of corrosion damaged Dima River bridge at Buxa forest in Kalchini area of Alipurduar, West Bengal.
The aims and objectives of repair and retrofitting are as follows:
a) To strengthen the architecture of the bridge using different techniques.
b) To know the different types of damages in the concrete structures.
c)This paper also aims to give a brief review of the NDT methods for monitoring and evaluating steel corrosion in RC structures, followed by a discussion and review of a technique based on AE developed to achieve the same objectives.
d) The field/laboratory testing of structural concrete and reinforcement is to be undertaken, basically for validating the findings of visual inspection.

3 Literature Review

Manish Kumar “Structural Rehabilitation, Retrofitting and Strengthening of Reinforced Concrete Structures”. In this paper the different methods of repair are described as per the distress category which can be cited for repair. The main finding of the study is that for the protection purpose of our structure there is a need for proper maintenance frequency and correct material to be chosen for repair. Beside this the workmanship also requires great importance for quality repairing. [1]

Prof. Dr. D.K. Kulkarni., Mr. Teke Sudhakar. S. “Health Assessment of Reinforced Concrete Structures - A Case Study”: Two tests have been chosen by the authors, viz. Schmidt ‟s Rebound Hammer test for analyzing the concrete compressive strength, and Ultrasound Pulse Velocity tests for endowing the quality of concrete. Their objective is to ascertain the strength of concrete. All of these helps in visualizing the level of weaknesses, damages, deterioration, corrosion that has taken place in past life of the structure. [2]

Vivek Kumar Yadav “Repairs and Rehabilitation of R.C.C. Structures by Fiber Reinforced Plastic- A Review”: This paper focuses on the methods of repair and rehabilitation to be initiated for structures with defects and deficiencies that requires rehabilitation. [3]

M. J. Monteiro, Prof. N. J. Pathak, “Structural Soundness of Buildings”: The authors are describing two NDT's and two Partially destructive tests, viz. RH, UPV, Carbonation and core sampling tests. They express need of evaluation of structure periodically in a systematic manner. [4]

4 Non-Destructive Testing and Methodology

4.1 About the bridge

This bridge is built on Rajbhatkhawa - Jaygaon Road at Ch. Km. - 4.50 in the district of Alipurduar. This bridge consists of nine (09 Nos.) main spans of length 21.7m with a total length of 196.00m. This superstructure consists of RCC I girders. From visual inspection, this bridge is considered as a distressed one.

Fig. 1. Dima bridge

Fig. 2. Upper view of Dima bridge

4.2 Corrosion mitigation strategies for existing structure

Reinforced concrete (RC) structures corrosion has been one of the major causes of structural failure. Early detection of the corrosion process could help limit the location and the extent of necessary repairs or replacement, as well as reduce the cost associated with rehabilitation work.

4.2.1 Non-Destructive tests for Corrosion Monitoring

For in-situ evaluation of steel corrosion in RC various non-destructive testing (NDT) methods have been found out to be useful, where the effect of steel corrosion and the integrity of the concrete structure can be evaluated effectively. An appreciative study of NDT methods for the investigation of corrosion is presented here. For new structures, the principal applications of NDT methods are likely to be quality control of the concrete conditions, while in old structures, the methods are expected to provide needed feedback on identification, monitoring and detection of damage. First of all, preliminary survey of the bridge was done and few popular NDT tests were performed and then proper mitigation solutions were applied.[5]

4.2.2 Corrosion Mitigation strategies

EPCO®-KP-200 is a hi-tech corrosion inhibitor system that functions on the Bipolar Inhibition Mechanism (B. I. M.) ®. It impedes corrosion of steel in concrete at both the poles, cathodic & anodic concurrently.

KP-200 by rectitude of its high vapour pressure & affinity for the embedded metal diffuses through densest concrete to reach the corroding steel. The migration of EPCO® KP-200 takes place over tedious period of time and hence this molecular layer shall continue to protect rebar by its constant presence. Typical application are Protection and structural rehabilitation of concrete structures, RCC elements/structures exposed to corrosive environment, Marine structures, structures exposed to saline atmosphere, coastal structures, sewerage systems, etc. like bridges, jetties, docks, mooring berths, railway sleepers, chlorinating plants, swimming pools, chimney, cooling towers, power plants, pipelines, etc. In repairs and rehabilitation of concrete structure exposed to aggressive environment, the solution for maintaining the integrity of existing RCC structure from corrosion of rebar by introducing pow throw caplets into the concrete structure, the rate of corrosion of rebar reduces significantly, thereby improving life of structures. Typical repair procedure of Corrosion mitigation strategies for existing structure are:

a) Surface preparation, b) Reinforcement treatment, c) Sealing of crack/Strengthening of core material, d) Concrete bonding, e) Sectional Reconstruction, f) Structural upgradation, g) Protective coating

NDT tests to monitor the service behaviour of concrete structures over a long period. Prominent NDT tests for concrete utilized in field are as follows:

a. Rebound Hammer Test
b. Ultrasonic Pulse Velocity Test
c. Profometer Scan
d. Strain Gauges
f. Half-Cell Potential Measurement
g. Measurement of Crack Depth with UPV
h. Tests of Carbonation, pH and Chlor-ide Content of Concrete

Rebound Hammer test is widely used as a Nondestructive test method to assess the strength of concrete. Schmidt hammer is used for the testing of existing concrete structures like bridges, buildings etc. The hammer is pressed against a smooth surface & the plunger strikes with an impact energy which yields a rebound value. The rebound values are corrected & plotted in a conversion chart to get the corresponding comprehensive strength of the concrete surface. [5]

Ultrasonic Pulse Velocity test is carried out for assessing the elastic properties as well as concrete quality. This method could be used to establish the followings: 1) The Homogeneity of the concrete. 2) The existence of voids, cracks and other defects. 3) Change in the structure of the concrete which may occur with time. 4) The quality of concrete in relation to standard requirement. 5) The quality of one element of concrete in relation to another. [5]

Strain Gauge and Crack Meter Measurement: A Strain gauge is a sensor which records change in strain due to change in load in periodic intervals through a data logger.

Vibrating Wire gauges were used in this site. The sensor produces an output signal in the form of an alternating current when electronically excited. The frequency of the alternating current can then be readily converted to a change in strain. These strains are recorded through a DT85 logger. Due to the instrument's long life and high reliability, vibrating wire strain gauge are the most robust solution to monitor strain in concrete and metal structures. On the other hand, a crack meter directly measures change in length across a crack. These instruments can give the data for monitoring opening and closing of cracks, but not the absolute length or width of cracks. [5]

Fig. 3. Rebound Hammer Test

Fig. 4. Ultrasonic Pulse Velocity Test

Fig. 5. Strain Gauge and Crack Meter Measurement

Fig. 6. Profometer Scan Test

Fig. 7. Half Cell Potential Test

Fig. 8. Drilling of Concrete Cores

Profometer Scan test: For old structures, when the detailed drawings are not available, it becomes very difficult to compute the strength of the structure which is required for the strengthening scheme of the structure. To overcome all these problems, Profometer, a small versatile instrument is used for detecting location, size of reinforcement and concrete cover. This instrument is also known as Rebar locator. For evaluation of new as well as old structures this equipment can be used adequately. Both for quality control as well as quality assurance the method can be used effectively. [5]

The half-cell potential test is the corrosion monitoring technique standardized by ASTM. It is used to ascertain the probability of corrosion within the rebar in reinforced concrete structures. In reinforced concrete structures, there is a natural protective film that forms on the surface of the bar and prevents it from corroding. With time, chlorides (from de-icing salts or marine exposure) and CO_2 penetrate the concrete and breakdown that protective layer. Profometer Corrosion One Wheel Electrode is used for this test.[5]

4.3 Overview of Test Results

Table 1. Rebound hammer test result

Bridge Name : Dima Bridge			
Location: A2 Cap in A1 Face			
Test No.	Test Position	R Value	Strength (N/mm)
RH-1	A2 CAP; 1A	54.00	24.82
RH-2	A2 CAP; 1B	59.00	26.48
RH-3	A2 CAP; 2A	52.70	24.37
RH-4	A2 CAP; 2B	50.20	23.54
RH-5	A2 CAP; 3A	39.80	20.10
RH-6	A2 CAP; 3B	41.50	20.65
RH-7	A2 CAP; 3C	38.70	19.71
RH-8	A2 CAP; 4A	55.00	25.15
RH-9	A2 CAP; 4B	50.50	23.65
RH-10	A2 CAP; 4C	47.00	22.49
RH-11	A2 CAP; 5A	49.80	23.43
RH-12	A2 CAP; 5B	49.80	23.42
RH-13	A2 CAP; 5C	42.50	20.99
RH-14	A2 CAP; 6A	36.50	18.99
RH-15	A2 CAP; 6B	51.70	24.04
RH-16	A2 CAP; 6C	41.00	20.49
RH-17	A2 CAP; 7A	50.70	23.71
RH-18	A2 CAP; 7B	49.80	23.43
RH-19	A2 CAP; 7C	43.30	21.27
RH-20	A2 CAP; 8A	51.30	23.93
RH-21	A2 CAP; 8B	55.80	25.43
RH-22	A2 CAP; 8C	42.50	20.99
RH-23	A2 CAP; 9A	39.00	19.82
RH-24	A2 CAP; 9B	49.20	23.21
RH-25	A2 CAP; 10A	51.70	24.04
RH-26	A2 CAP; 10B	52.20	24.21
RH-27	A2 CAP; 11A	50.30	23.60
RH-28	A2 CAP; 11B	55.60	25.35
Average=		48.25	22.90

Table 2. Ultra-Sonic Pulse Velocity test

Bridge Name : Dima Bridge					
Test No.	Location	Test Position	Type	Velocity (m/s)	Average Velocity (m/s)
UPV-01	P8	1A	Direct	4480	4428
UPV-02	P8	1B	Direct	4435	
UPV-03	P8	1C	Direct	4492	
UPV-04	P8	1D	Direct	4572	
UPV-05	P8	2A	Direct	3899	
UPV-06	P8	2B	Direct	4447	
UPV-07	P8	2C	Direct	4387	
UPV-08	P8	2D	Direct	4470	
UPV-09	P8	3A	Direct	4386	
UPV-10	P8	3B	Direct	4380	
UPV-11	P8	3C	Direct	4362	
UPV-12	P8	3D	Direct	4423	
UPV-13	P8	4A	Direct	4278	
UPV-14	P8	4B	Direct	4485	
UPV-15	P8	4C	Direct	4416	
UPV-16	P8	4D	Direct	4523	
UPV-17	P8	5A	Direct	4511	
UPV-18	P8	5B	Direct	4523	
UPV-19	P8	5C	Direct	4511	
UPV-20	P8	5D	Direct	4523	
UPV-21	P8	6A	Direct	4342	
UPV-22	P8	6B	Direct	4453	
UPV-23	P8	6C	Direct	4436	
UPV-24	P8	6D	Direct	4536	

Table 3. Results Of Measurement Of Crack Depth

Test ID	Location of Test	Crack Depth below Surface (cm)
CR-01	U/S Side Girder at span 9(D/S face): 2.0m from cross girder end at A2 side, 0.14m below top of girder.	9.80
CR-02	Middle Girder at span 9(U/S face): 1.74m from cross girder end at A2 side, 0.54m below top of girder.	8.20
CR-03	Middle Girder at span 9(D/S face): 1.85m from cross girder end at A2 side, 0.4m below top of girder.	10.60
CR-04	D/S Side Girder at span 9(U/S face): 3.2m from cross girder end at A2 side, 0.7m below top of girder.	11.70
CR-05	D/S Side Girder at span 1(U/S face): 1.9m from cross girder end at A1 side, 0.43m below top of girder.	11.70
CR-06	Middle Girder at span 1(D/S face): 2.8m from cross girder end at A1 side, 0.64m below top of girder.	8.60
CR-07	Middle Girder at span 1(U/S face): 2.8m from cross girder end at A1 side, 0.93m below top of girder.	10.90
CR-08	U/S Side Girder at span 1(D/S face): 2.8m from cross girder end at A1 side, 0.4m below top of girder.	9.40

Table 4. Half Cell Potential Test Results

Bridge: Dima Bridge   Test ID: HCP-01
Location: A2 Cap, in A1 face   Half-cell Solution: $Cu/CuSO_4$
X in Horizontal Rightward Direction @0.1m and Y in Downward Vertical Direction @0.1m

Line	X →	1	2	3	4	5	6	7	8
Y ↓	Distance(m)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
1	0.1	-521	-468	-447	-407	-405	-420	-422	-426
2	0.2	-309	-295	-286	-293	-312	-322	-387	-298
3	0.3	-252	-261	-275	-289	-243	-256	-255	-265
4	0.4	-254	-274	-310	-295	-301	-297	-314	-333
5	0.5	-339	-359	-382	-321	-358	-381	-337	-402
Line	X→	9	10	11	12	13	14	15	16
Y↓	Distance(m)	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
1	0.1	-394	-390	-446	-435	-587	-464	-459	-526
2	0.2	-285	-283	-291	-296	-296	-372	-349	-320
3	0.3	-276	-244	-258	-325	-329	-306	-279	-278
4	0.4	-351	-348	-342	-381	-380	-325	-302	-311
5	0.5	-410	-336	-317	-311	-280	-367	-380	-355
Line	X→	17	18	19	20	21	22	23	24
Y↓	Distance(m)	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4
1	0.1	-481	-411	-426	-422	-398	-432	-428	-458
2	0.2	-289	-291	-274	-262	-247	-248	-290	-295
3	0.3	-262	-246	-238	-269	-284	-297	-328	-377
4	0.4	-322	-300	-272	-278	-304	-317	-324	-293
5	0.5	-353	-351	-361	-367	-368	-353	-361	-361
Line	X→	25	26	27	28	29	30	31	32
Y↓	Distance(m)	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
1	0.1	-497	-576	-594	-586	-547	-535	-518	-499
2	0.2	-347	-377	-399	-482	-376	-354	-360	-342
3	0.3	-376	-345	-345	-345	-324	-290	-280	-286
4	0.4	-288	-291	-305	-312	-317	-300	-296	-308
5	0.5	-348	-369	-393	-408	-389	-400	-390	-395
Line	X→	33	34	35	36	37	38	39	40
Y↓	Distance(m)	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4
1	0.1	-434	-379	-383	-403	-400	-392	-387	-391
2	0.2	-284	-280	-283	-284	-317	-275	-321	-333
3	0.3	-262	-292	-317	-324	-334	-335	-305	-328
4	0.4	-311	-327	-373	-393	-350	-339	-333	-323
5	0.5	-352	-340	-356	-328	-366	-366	-410	-431
Line	X→	41	42	43	44	45	46	47	48
Y↓	Distance(m)	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
1	0.1	-425	-483	-457	-460	-522	-522	-430	-578
2	0.2	-409	-312	-330	-358	-359	-296	-259	-367
3	0.3	-333	-342	-354	-295	-304	-296	-337	-343
4	0.4	-327	-365	-355	-345	-328	-345	-354	-371
5	0.5	-337	-259	-365	-392	-393	-411	-375	-367

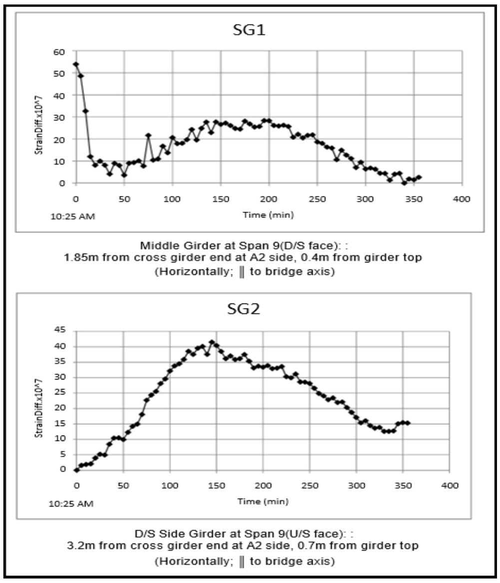

Fig.9. Strain Gauge Measurement

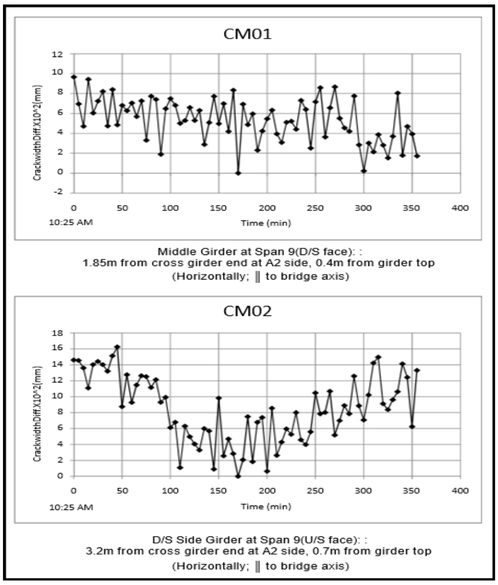

Fig.10. Crackmeter Measurement

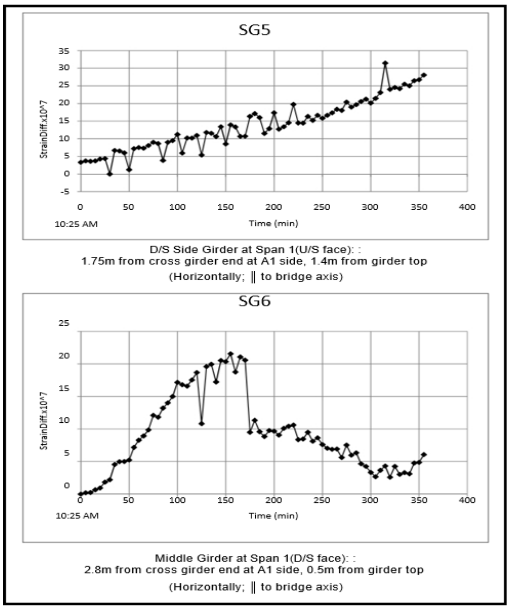

Fig.11.Strain Gauge Measurement

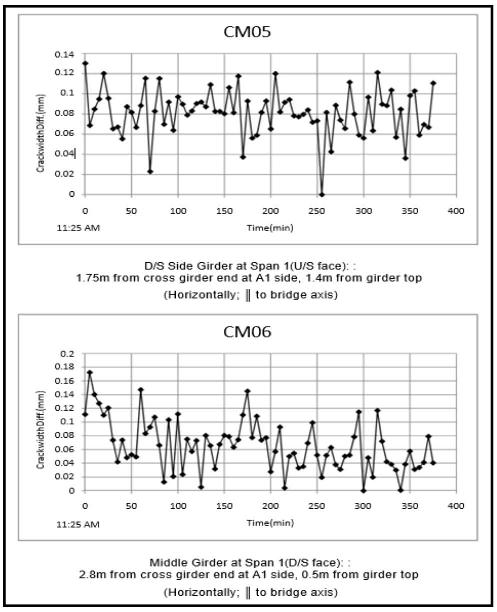

Fig.12. Crackmeter Measurement

5. Repair and retrofitting

Injection grouting for strengthening:

A. Polymer cement grouts, B. Epoxy resins for grouting, C. Monomers of grouting.

Epoxy resins for grouting: Epoxy grout shall confirm to ASTM C-882 and have following properties:

- Viscosity at 25°C maximum- 2 Pas
- Minimum gel time- 30 minutes
- 14 days' bond strength at 25°C minimum= 3.5 MPa
- Min. compressive strength= 60 MPA at 7 days
- Tensile strength 7 days minimum= 45 MPa

Sikadur®-31 C is solvent-free, moisture tolerant, two-part epoxy based thixotropic adhesive for bonding Sikadur-Combiflex® SG tape and Sika® Dilatec® tape to different substrates. For both internal and external usage, it can be applied. It should only be applied by trained applicators. It is used as adhesive for the Sikadur-Combiflex® System and Sika® Dilatec® System. These systems are used for various applications such as: Expansion Joint treatment, Construction Joint treatment, Crack treatment & Precast panels joint treatment.

Unique Advantages: Easy to mix and apply▪ Suitable for both dry and damp concrete surfaces▪ Excellent adhesion to many materials▪ Solvent free▪ Performs well within a wide temperature range▪ Completely weather and water resistant▪ Fast curing▪ Root resistant▪ Good resistance to many chemicals▪ Thixotropic – suitable for overhead and vertical applications ▪ No primer needed▪ High mechanical resistance▪ Good abrasion resistance.

Sikadur®-52 is a low viscosity injection resin with good adhesion to dry concrete, mortar, stone, steel and wood. It is used to fill and seal cracks, voids in structures such as rcc buildings and bridges, industrial buildings and water retaining structures.[6]

Unique Advantages: Solvent-free, suitable for dry conditions, usable at low temperatures, shrinkage free hardening, high mechanical and adhesive strengths, hard but not brittle, low viscosity, injectable with single component pumps.

Application Instructions: Mixing Part, A: Part B = 8:1 (by weight)

Mixing Time Pre batched packaging: Add all of part B to part A. At slow speed (max. 250 rpm) mix with an electric mixer for at least 3 minutes. Avoid entraining air and bulk packaging. Into a suitable clean, dry container add both parts in the correct proportion and mix in the same way as for the pre batched units.

Application Method / Tools: Successful application depends on very careful preparation. The surface to be treated must be structurally sound, free from standing water, oil, grease, surface contaminants. Removal of dirt, dust and other foreign materials is necessary. Concrete which is fully tarnished with oil /grease must be removed to the depth of sound & unpolluted concrete.

Injection of cracks on horizontal / vertical slabs: Injection flange / nipples are fixed along the crack line at an approximately 25 cm center-to-center distance with Sikadur®-31. Crack mouth should be unfurled and sealed with Sikadur®-31. Sikadur®-31 epoxy mortars or a suitable cementitious Sika mortar should be used for sealing the crack penetrating slabs to their soffit and also on the underside. Injection pump, such as Aliva AL-1200, AL-1250 or the Sika® Hand Pump, should be used for injecting mixed Sikadur®-52 through injection ports under pressure. As soon as injection resin oozes out of the next injection port, the first port is sealed and injection process is continued from the next port. In case of horizontal cracks, injection should start from any of the ends and to be continued and completed till the last port is used. On the other hand, for vertical cracks, injection should start from the lowest port and continued upwards. After completion of the injection process, the injection ports as well as the sealing materials between the ports are removed.

Monopol High Molecular Weight Polymer (LV Grade) Grout: Monopol® is a low viscosity high molecular weight thermoset polymer. Due to its low viscosity, cracks and honeycombs in concrete are filled up to full depth of concrete.[6]
Common applications: Strengthening of honeycombed concrete, cracks in RCC structures, reconstruction of fire and explosion damaged structures, sealer for industrial floors, concrete bridge decks, also used for sealing cracks in concrete roads, terraces, foundations, repairs of crusher foundation, TG foundations, polymer impregnated concrete applications.
Unique Advantages: By virtue of low viscosity Monopol® penetrates into the concrete even through fine hair cracks and strengthens the matrix. Monopol has viscosity of 2-5 cps which penetrates fine cracks, impregnates concrete matrix and grouting can be done by gravity pouring at a very low pressure of 5-10 psi. It also imparts excellent adhesion and chemical resistance. Ideal for strengthening of TG foundations, chimneys, kiln foundations, cement plants, concrete pavements, bridge decks, explosion & fire damaged structures.

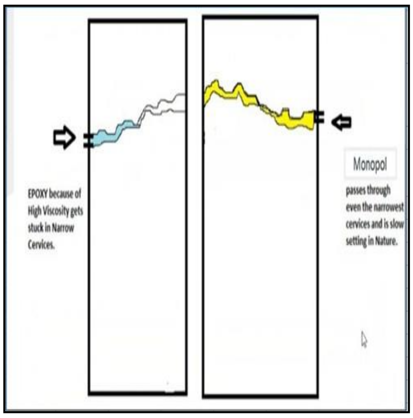

Fig. 13. Monopol v/s Epoxy Grout

Table 5. Selection of Grout RCC Structure

Crack Width	Grout	Surface Condition
Less than 1 mm	Monopol	Dry
1mm-3mm	Monopol followed by EPCO KP/HP 250SLV	Dry
1mm-3mm (Long width section)	Monopol followed by EPCO KP/HP 250SSLV	Dry
3mm-5mm	EPCO KP/HP 250	Dry
>5mm	EPCO KP/HP 250 Followed by PC Grout	Dry
<3mm	EPCO 2020LV	Moist

Observations after retrofitting: After a gap of few weeks various NDT tests were again performed to find the efficiency of the retrofitting process. The results obtained from the tests proved to be perfectly effective and also within the permissible limit.[7]

6. Conclusion

This paper provides comprehensive study of repair and retrofitting of the existed problems and its reported solutions are finely reviewed. Based on visual observation, test results and mitigation procedure the following conclusions can be made.

1. In repairs and rehabilitation of concrete structure exposed to aggressive environment, the solution for maintaining the integrity of existing RCC structure from corrosion of rebar can be done by using pow throw caplets into the concrete structure. The rate of corrosion of rebar reduces significantly, thereby improving life of structures.

2. From rebound hammer tests, it is seen that the concrete in this site have varying surface hardness with the rebound numbers ranging from 19 to 59. Sudden drop in rebound values have mostly been observed around the repaired area in girder of span-9. The corresponding strength values are in the order of 13 to 27 MPa.

Table 6. Comparison of results of crack depth before and after retrofitting process

Test Id	Location of test	Crack depth below surface (cm)- before retrofitting process	Crack depth below surface (mm)- after retrofitting process
CR-01	U/S Side Girder at span 9(D/S face): 2 m from cross girder end at A2 side, 0.14 m below top of girder	9.80	0.15
CR-02	Middle Girder at span 9(U/S face): 1.74 m from cross girder end at A2 side, 0.54 m below top of girder	8.20	0.13
CR-03	Middle Girder at span 9(D/S face): 1.85 m from cross girder end at A2 side, 0.4 m below top of girder	10.60	0.18
CR-04	D/S Side Girder at span 9(U/S face): 3.2 m from cross girder end at A2 side, 0.7 m below top of girder	11.70	0.2
CR-05	D/S Side Girder at span 1(U/S face): 1.9 m from cross girder end at A1 side, 0.43 m below top of girder	11.70	0.2
CR-06	Middle Girder at span 1(D/S face): 2.8 m from cross girder end at A1 side, 0.64 m below top of girder	8.60	0.14
CR-07	Middle Girder at span 1(U/S face): 2.8 m from cross girder end at A1 side, 0.93 m below top of girder	10.90	0.17
CR-08	U/S Side Girder at span 1(D/S face): 2.8 m from cross girder end at A1 side, 0.4 m below top of girder	9.40	0.16

Fig.14. Cracks sealed with putty

Fig.15. Grouting application procedure

3. UPV test indicates the variation of density and homogeneity of concrete within zone of influence. From Ultrasonic Pulse Velocity tests, the concrete at this site is found to be in good quality in general. However, at different places of girder in span-9 low pulse velocities have been observed near the cracks.

4. Crack depth measurement done at the present site reveals that the depth of crack is varying from 8.2cm to 11.7cm which is much more than the observed cover value and requires immediate attention. Change in strain and crack width is monitored to record the response of the bridge with variation in live load. It has been found that the strain

is varying in the order of 1.1 micro-strain to 9 micro-strain and crack width is varying between 0.09mm to 0.23mm.

5. Profometer and Half Cell Potential tests give the idea of the reinforcement condition in present concrete. The results of profometer scan are presented later in this report. In all the tested structural elements of the present site, clear cover has varied widely; as in case of Pier P8 the clear cover value varies around 23mm to 99mm. On the other hand, from the half-cell potential test it is observed that the potential difference is varying from (-)604 mV to 134 mV. Overall, the corrosion probability is high.

6. Regarding the sealing of cracks both Epoxy grout and Monopol have their advantages and disadvantages respectively. Epoxy grout chemical Sikadur®-31 C & Sikadur®-52 can be used for expansion joint treatment, crack treatment within a wide temperature range. But Epoxy because of high viscosity gets stuck in narrow cervices. Whereas Monopol with low viscosity can easily penetrate fine cracks and strengthens the matrix. Monopol seals cracks/honeycombs in concrete under very low pressure of 5 – 10 Psi and grouting can be done by gravity pouring/pressure grouting. In this project also during mitigation of cracks both the epoxy grout chemicals and monopol were used effectively under respective conditions for proper results.

7. The results of the NDT tests performed before and after the retrofitting process proved that the grouting done by epoxy resins or monopol high molecular weight polymer proved to very effective and the width of the cracks are within the permissible limit as per the standard guidelines.

References

1. Manish Kumar, (2016), “Structural Rehabilitation, Retrofitting and Strengthening of Reinforced Concrete Structures” World Academy of Science, Engineering and Technology International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:10, No:1.

2. Dr. D.K.Kulkarni, Teke Sudhakar. S, “Health Assessment of Reinforced Concrete Structures -A Case Study”, IOSR Journal of Mechanical & Civil Engineering (IOSR-JMCE), ISSN: 2278-1684, PP: 37-42.

3. Vivek Kumar Yadav, Pratiksha Malviya, (2019), “Repairs and Rehabilitation of RCC Structures by Fiber reinforced Plastic- A Review”, International Journal of Engineering Sciences & Research Technology, ISSN: 2277-9655, DOI:10.5281/zenodo.2578147

4. M. J. Monteiro, Prof. N. J. Pathak, (2011), “Structural Soundness of Buildings”, IJESE V. 04, No 06 SPL, pp. 677-680.

5. Non-Destructive Testing of Bridges-2014, Indian railway institute of civil engineering, Pune-411001.

6. Handbook on repair and rehabilitation of RCC buildings by Director General (Works), CPWD, Government of India, Nirman Bhawan.

7. Ministry of road Transport and Highways (Specification for Road and Bridge works) Fifth Revision-IRC New Delhi.