Case study of the repair of a major bridge and some thoughts on repair materials

S.K. Manjrekar

The paper discusses repair and rehabilitation of a major road overbridge connecting eastern and western suburbs of Andheri, in Mumbai. While the case study is described, the author dwells upon some of the important aspects involved in the selection of appropriate materials and methodologies of repair/rehabilitation.

Rehabilitation of reinforced concrete (RC) bridges prematurely or otherwise damaged, continue to be a major problem throughout India. The problem is more serious in the coastal areas ansi is aggravated further in the highly polluted city like Mumbai. Many a bridge needs major repairs. In view of the need to maintain continuous traffic flow on the bridge the repair methodology assumes greater importance. A case in point is the repair to the Gopalkrishna Gokhale (GKG) bridge, connecting S. V. Road and the Western Express Highway in a suburb of Mumbai.

Major rehabilitation work of the western approach of this bridge has been just concluded. It was carried out in very trying conditions of continuous traffic flow matched with the serious damage taken place over the years. This paper is an effort to understand the nature of damage and then the logical solution to repairs based on the latest understanding of the materials, particularly polymers and polymer-modified mortars/concretes. An attempt is also made to explain the mechanisms involved. This is with the expectation that this case study which is possibly first example of its type in terms of the expanse of the job and large quantities of materials required can be a guidance for posterity to assess and carry out such bridge repairs in the future.

Salient features of the bridge

The salient features of the GKG bridge are as below:

1. Year of construction : 1969
2. Width of bridge : 27.45 m
3. Superstructure
   on railway track : structural steel
   on approaches : reinforced concrete T-beam and slab (total length 160 m; 100 m on the western side and 60 m on the eastern side)
4. Substructure : 12 RC columns (the area below RC approaches is enclosed and used as offices).
5. No. girders per span : 12
6. Thickness of deck slab : 250mm
7. Bearings : roller and rocker-roller type steel bearings
8. Foundation : open
9. Total length of approaches
   eastern side : 240 m
   western side : 220 m

Nature of damage

Detailed visual inspection revealed the following types of damage:

1. heavy and continuous leakages
2. development of cracks in deck, girders and columns
3. chunk of concrete mass fell off from western approach deck exposing the deck reinforcement steel

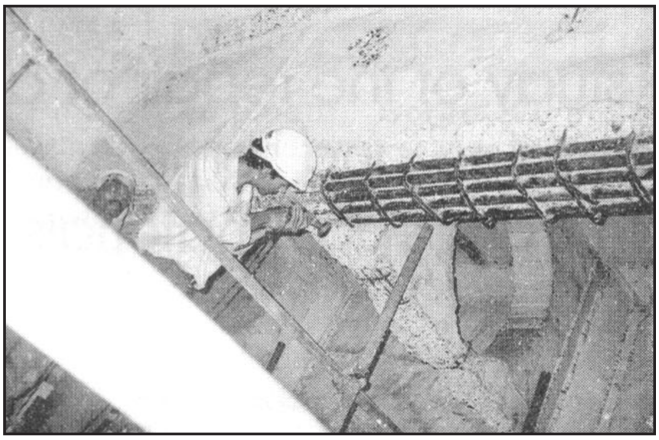

Figure 1. Cleaning corroded bars by mechanical wire-brush

Figure 2. Application of protective coating on steel

4. parapet walls cracked extensively.

Non-destructive testing was carried out involving ultrasonic pulse velocity tests, carbonation test, half cell potential mapping, determination of pH of concrete and chloride content estimation, etc. Based on the visual observations and results of non-destructive testing, consultants worked out a detailed procedure for the repairs which constituted following specifications.

1. Support the RC members by steel preps and spans appropriately, depending upon loading conditions and extent of damage of the members to be repaired.

2. Expose the member by means of chisel and hammer. Remove the loose concrete beyond the reinforcement.

3. Remove loose rust from reinforcement by means of tacha and wire brush (mechanical/manually). Apply phosphate-based rust converter capable of removing corrosion products to the reinforcement by brush or cotton waste. After 24 hours wash the reinforcement by clean water jet .

4. Providing and applying slurry of 1 part of specially formulated alkaline acrylic-based polymeric solution with 1 to 1.5 part of fresh cement and mix the solution by means of stirrer and apply it on the reinforcement by paint brush. This will act as protective coating on the reinforcement. After 24 hours apply similar second coat of such slurry. Make sure no area is left uncovered.

5. Providing and applying bond coat of single-coat co-polymeric admixture and cement in 1:1 proportion to RC members and applying polymer modified mortar to build up the thickness upto 10 mm.

6. Repairing of damaged RC member by single coat co-polymeric mortar in 1:5:15 (copolymer: cement: quartz sand) proportion and required proportion of water.

7. Curing the same by spray pump after 24 hours.

This paper lays emphasis on the material science dealing with the properties, behaviour and mechanisms of various repair materials/polymers used in the above work. For various steps involved in the work corresponding cross references are also provided for better understanding.

Repair: Some thoughts

For effectiveness of any repair the following points need thorough consideration from material properties and compatibility point of views, besides the important considerations of structural parameters.

1. ascertaining the extent of corrosion and carbonation

2. near total removal of corrosions products from the steel

3. application of a corrosion-resistant barrier film on the reinforcement (such film should inhibit further corrosion)

4. application of a useful bond coat which assures good bonding

5. rendering a strong, passive carbonation-resistant polymer modified/polymer concrete cover of proper generics, wherever necessary.

6. applying protective seal coat on the entire surface to guard against any aggressive chemical attack.

Carbonation is one of the principle causes of corrosion and it brings about various physical changes in the quality of concrete. However, it affects the alkalinity of the concrete by bringing it down considerably. Generally, the pH of good concrete which is in the vicinity of 12.5 to 13 comes down to around 9. This loss in pH causes the reinforcing steel to be susceptible to corrosion. The carbonation plane moves into the concrete from the outer surface as a result of external attack and it is dependent upon the moisture content of the concrete. This plane moves rapidly when relative humidity is between 50 to 70 percent[1]. One can find out the depth of carbonation from a formula $d = K_t\sqrt{t}$ where, d the depth of the carbonation reaction plane in mm, after time t, years. Coefficient of carbonation K_t is related to the permeability of the concrete, the amount of available free time, relative humidity[1] and the carbon dioxide (other related gases in case of polluted environments) content of the given environment.

As reported[2] in the present case study, the carbonation attack was seen to be upto 70 mm depth which was associated with highly undesirable low pH in the range of 6.5 to 8.0. Half cell readings also were fairly negative in the range of - 450 to - 600mv. These data corroborated well with the physical state of the bridge. Thus, ascertaining the extent of corrosion and carbonation proved to be very useful first step in the sequence of repairs.

The next step consisted of the process of removal of diseased/loose concrete and removal of corrosion products from the steel and preparing the surface for further applications. It needs to be mentioned here that howsoever effective the materials are, the basic surface treatment plays very important role in the efficacy of the repair operation. In addition, it is very important to see that the surrounding good concrete is not damaged. In this case chipping was done by hammers, which is most widespread method of concrete removal if the deterioration is deeper than 15 mm or more. ACI Committee 546[3] also stresses on proper selection of chipping tools, which will avoid the damage of surrounding concrete. However in recent years the introduction of the water jet technique (hydro demolition or hydrojetting or hydroblasting) has changed the prevalent method of concrete removal[4]. Besides high efficiency several other advantages listed below add to the success of this method

1. a rough and clean surface made available
2. no microcracks are introduced into the remaining concrete
3. the reinforcement is undamaged and cleaned from rust, and
4. only bad concrete is removed leaving the good concrete intact.

In fact, some comparative studies also have been made on the interface strength of a repaired matrix between sand blasted surface, mechanically chipped surface and the water jetted surface. In water jetted surface, maximum bond strength was shown followed by mechanically chipped and the sand blasted surface showed the least bond. In the present work it was however decided to adopt the chipping method using chipping tools which fits in the recommendations of ACI Committee 546.

The next important step was to ensure that the corrosion products on the steel are removed effectively. For this, it is reported that the mechanical means prove quite inadequate. Hence, it was correct to use the chemical rust remover-cumconverter material. The application of this material does not reduce the section of steel (like in sand blasting) after having removed the loose oxidation scales. It, in fact, consolidates the left over section. This treatment also helps in resisting the corrosion to an extent, though, subsequent process of pacifying the steel is very essential.

Neither chemical cleaning nor rust converting processes are permanent relief from corrosion. Hence, a protective barrier film is generally applied on the treated steel. One of the options is to apply liquid epoxy on the bars which on setting becomes almost plastic-like, resulting in substantial loss of bond with subsequently laid concrete. It is reported that as much as 40 percent bond is lose[5]. In order to overcome this bond loss fine quartz sand is sprinkled on the wet epoxy on many occasions. In addition, this treatment being only a barrier film, does not do anything so as to create non-corrodible conditions around the steel. However, despite these drawbacks epoxy treatment for bars has been found to be more effective than any other coating treatment like zinc chromate priming[6], etc.

Need of a bond coat

In order to overcome the above mentioned shortcomings, a slurry of water-based polymer emulsions and cement is applied on steel. This mixture being highly alkaline in nature keeps the environment around steel in a alkaline state. This situation helps greatly in maintaining a passive, g, Fe_2O_3 film on the steel, thereby preventing corrosion[7]. Besides, this film

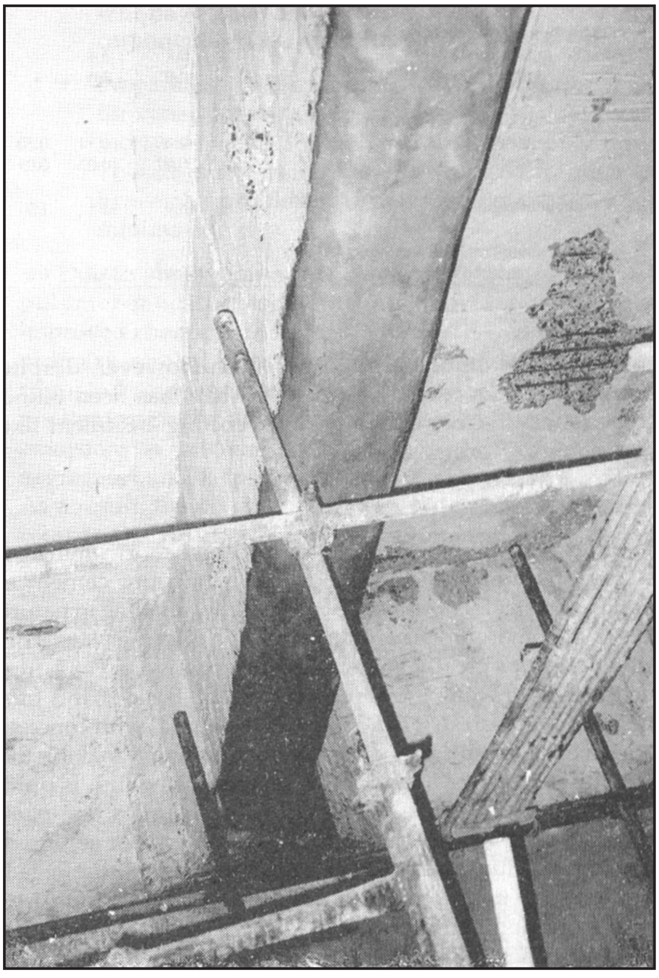

Figure 3. A portion of the beam treated with ploymer modified mortar

Table 1. Properties of polymer-cement mortars[10]

Sr no.	Properties		Polymer-cement ratio (on weight basis)		
			0	0.2	0.4
1	Adhesion to concrete, N/mm^2	dry	0.07	2.0	3.4
		wet	0.03	1.0	1.4
		wet	0.00	1.4	2.1
2	Adhesion to steel, N/mm^2	dry	0.0	2.0	1.6
		wet	0.0		1.3
3.	Tensile strength, N/mm^2	dry	3.0	6.0	4.3
		wet	1.8		3.9
4	Compressive strength, N/mm^2	dry	56.0	50.0	
5	Flexural strength, N/mm^2	dry	7.1		10.6
		wet	5.8		9.6
6	Effects of chemicals on dry flexural strength after six months immersion, N/mm^2				
	untreated		7.2	13.2	
	10 percent potassium hydroxide		6.1	12.3	
	10 percent magnesium sulphate		4.3	13.2	
	5 percent lactic asid		5.9	8.0	
	5 percent hydrochloric acid		0.0	2.2	
7	Effect of extremes of temperature N/mm^2				
	untreated		7.1	10.6	
	after 6 frees/thaw cycles at 18°C (in 10 percent brine)		0.0	10.4	
	after I year at 70°C		5.2	14.3	
8	Adhesion to concrete (dry), N/mm^2				
	untreated		0.1	3.4	
	after 6 months at 70°C		0.0	2.6	
9	Shrinkage to concrete (dry), N/mm^2				
	water-cement ratio		0.40	0.34	0.30
	percent shrinkage		0.07	0.02	0.01
10	Water penetration, $g/m^2/24$ hr		46.9	38.1	1.9
11	Water penetration with Revincx 29 Y 40 in mortar, $kg/m^2/24$ hr		100.0	35.0	0.0

being cement based, it is a compatible material with concrete and does not result in any loss of bond strength making the structural engineer's work easy. Moreover, the film is quite tough as well as flexible. In addition, being a one-pack polymer system, hardening of unused material or setting of the material due to delayed use, etc is more or less eliminated. For reasons mentioned eariier, pure acrylates, modified acrylates, modified styrene-butadine rubber (SBR), etc are used as concrete modifiers, preference being in that order too. These tailor-made formulations are easily available. For the current job the material used was acrylate-based polymeric solution which is tailor-made to protect g, Fe_2O_3 film, that is to prevent further corrosion for long time to come. As a matter of fact, this material is specially formulated to withstand even the stress corrosion when used with suitably-formulated cementitious and supplementary cementitious materials8. This step is one of "the important" steps to avoid further deterioration as well as to enhance the life of the repaired system.

Earlier we have discussed the mechanism of improving the bond strength at the stage of pretreatment of the method of removal of diseised concrete. In addition to this, in terms of additional and assured bonding methods one must consider the "Swedish Regulations for Concrete Structures" which do not permit shear transfer at interfaces of composite concrete structures. European and American concrete codes prescribe comparatively low values for the permissible shear stress at the interfaces like 0.22 to 0.62 N/min^2 (dependent on characteristic compressive concrete strengths) and 0.55 N/min^2, respectively. Consequently, reinforcement crossing the interface is needed as soon as the applied design shear stress exceeds these small values. This means the shear capacity in composite repairs can be provided by shear connectors or dowels at very close intervals which on a large area could prove very impractical and expensive. That is why to ensure further adhesion between two phases, namely, between the original concrete and the new repair material, a polymer cementitious adhesive bonding coat is considered essential.

In several cases, where traditional repairs are executed by replastering or mere concrete jacketing, or even guniting, it is often seen that the new concrete/mortar mass separates from the old concrete. This obviously happens due to dissimilar behaviour patterns of the old, already set concrete and the subsequent new concrete or mortar, which is undergoing stresses and strains while stiffening, mainly due to shrinkage. To an extent this drawback is nullified by using steel wire mesh. Although the wire mesh helps to distribute shrinkage stresses evenly it may introduce additional corrosion problems. To overcome this, galvanised wire mesh is used, but this may prove to be costly. Hence, years of experience has taught the repair specialists to use a bond coat which ensures mechanical bond between old and new concrete. However, sometimes inappropriate quantity/quality of bonding coat together with the shortcomings in workmanship results in an undesirable performance.

Liquid epoxy in tacky conditions is found to be an excellent bonding coat. However, sometimes if a large area is to be concreted, for example, jacketing of all four sides of the column, or when due to the negligence on the part of workmen, the time lag between application of the epoxy bond coat and subsequent placement of new concrete increases, it results in the epoxy being partially or fully set and consequently it acts as a debonding agent rather than a bonding agent. In such cases, separation cracks at the interface can be seen. This is not because of the failure of the material but due to the two-pack epoxy not being utilised properly. Hence, use of user-friendly material is necessary and this should preferably be a one-pack system. Bonding polymers which are based on polymer latexes, when used along with cement, give equally excellent adhesion both to old concrete as well as the new one. There is substantial reduction in cost too and the one-pack nature of the polymer keeps the tackiness of the surface for a long time. It also helps to keep the conditions around the exposed steel and exposed concrete generally alkaline, thereby preventing corrosion of steel and carbonation of the adjacent concrete. Those latexes which are mentioned earlier for steel protection are good for bonding purposes too.

In the present case study we have used a bonding coat of acrylate-based co-polymeric solution and cement in 1:1 proportion (part by weight) as a slurry. Such polymeric materials are reported to show added bonding to concrete and steel which is approximately thirty times more in concrete to concrete and almost 100 times more in case of steel and concrete[10]. Such a bonding coat can effectively replace the use of dowels at very close intervals.

Polymer-modified mortar/concrete

Providing a new cover to a repairable structure should be done only wherever necessary and the temptation to expose the entire surface - even if a part of it is unaffected strong concrete, should be avoided. Judicious removal of diseased concrete is therefore essential. If the replacement is done by unmodified concrete, it can deteriorate due to carbonation and chemical attacks.

The most important factor encountered in selecting methods and materials for repair is the compatibility of existing concrete and new materials. Many materials change volume as they initially set, and practically all of them change volume with temperature and moisture changes. Tensile stresses are induced in one material and compressive stresses in the other, causing a substantial shear at the interface. Identical patterns of stress will result from the differential shrinkage and different moduli of elasticity[11].

In the initial stages of advent of polymers for repairs, the only reliable material used for making up the lost concrete was epoxy. It is a very strong material and can easily give compressive strength of 80 to 100 N/mm^2 and high tensile strength of 20 to 30 N/mm^2. In addition, epoxy mortars which fall under the category of polymer mortars are not affected by chemical attack or carbonation. However, the following few points have made engineers and materials scientists ponder over alternatives to this system:

1. Most of the reinforced concrete members to be repaired are having concrete strengths between 20 to 25 N/mm^2. Hence, how correct is it to introduce in it intermittent pockets of very high-strength mortar?

2. The cost of epoxy repair can be high, particularly if large areas are to be rehabilitated.

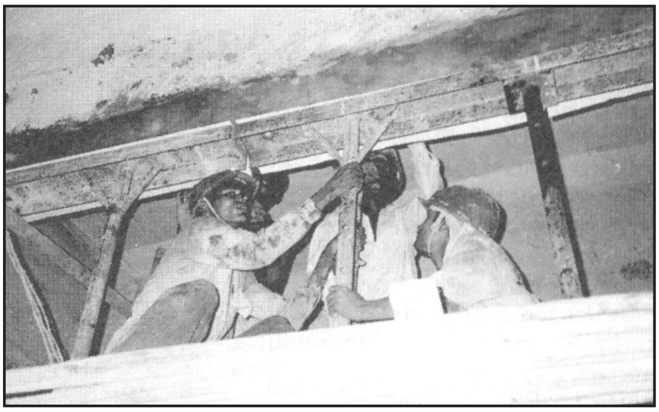

Figure 4. Propping the repaired beam

3. If faulty application is done, basically due to two pack nature of epoxy and negligence on the part of the labourers (due to its user unfriendly character), bonding and integrity of mortar suffers resulting into undesirable behaviour of the concrete.

4. Epoxy mortars are found to be susceptible to fires or fire-prone areas, wherein the mortar itself catches fire-readily. This not only leads to loss of earlier repairs but the fire also increases.

5. If user-friendly, one pack polymer cementitious mortar is used, such mortar will be more compatible with the existing reinforced concrete members and it will have good properties like chemical resistance, carbonation resistance, etc.

6. Preparation of cementitious polymer mortar is easy for construction workers, since it is a plain cement mortar in which the polymer is to be simply mixed. This does not

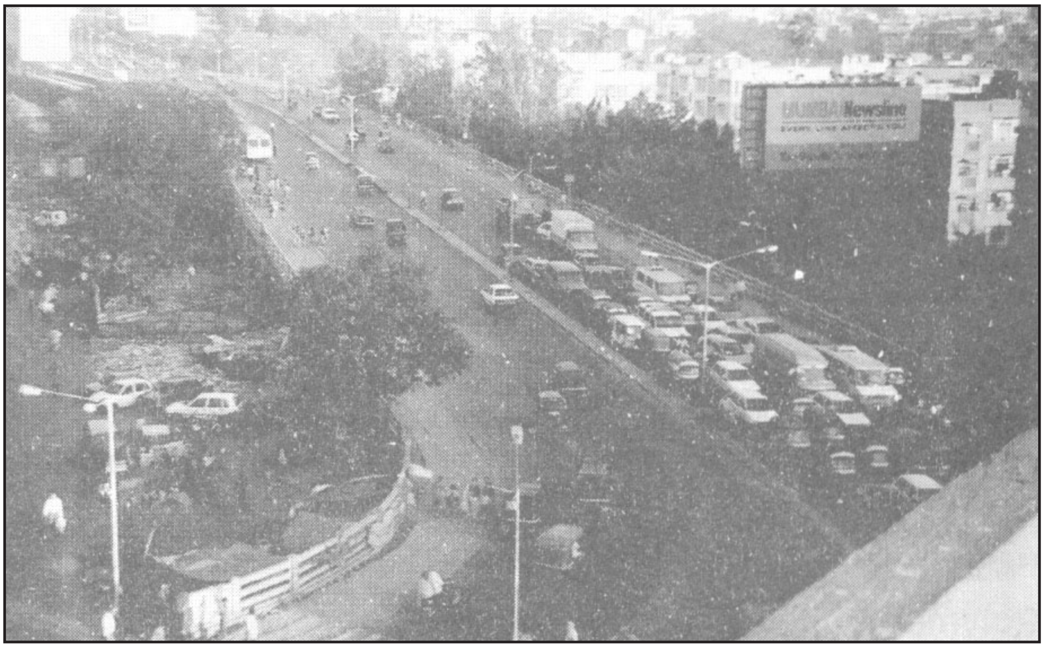

Figure 5. A view of the Andheri floyover after repairs

require any specialised training and hence the problems of poor workmanship can be minimised.

Due to above points, the trend is shifting in favour of polymer-modified cementitous mortars which have improved chemical and physical properties as compared to ordinary cement/concrete mortar. In addition to above reported properties, studies of comparative photomicrographs have shown that the addition of polymer emulsions to concrete results in bonding of the latex to the aggregates and helps in bridging the cracks as they form. As a result, the polymer relives the internal macro-stresses, retards the formation and enlargements of cracks and increases the concrete's overall strength. Moreover, as the voids and cracks are bridged bay the polymer, it results in substantially reducing the penetration of moisture and corrosion chemicals. The indicative properties of the polymers used in these mortars are given in Table The cost of these mortars is approximately 33 percent of the cost of epoxy mortar. In addition, the polymer mortar cover is of the order of 10 to 15 mm in thickness above steel. Such thickness itself can adequately take care of further chemical attack or subsequent carbonation. Remaining part of the cover can be simply finished with well-controlled plain cement/concrete mortar to get proper level. Such judicious use of polymers can further bring down the cost of rehabilitation without sacrificing on performance. In many countries such mortars find large application in repair of bridge decks where the cost of repairs due to corrosion would otherwise be colossal.

Surface protection treatment

The final step in tie rehabilitation project is the application of the penetrating sealer to entire surface including the repaired concrete parts. This helps to minimise the moisture and chloride penetration and related continuous environmental attack. Repairs are carried out on patch-work basis and these patches are repaired with polymer concrete/mortars or polymer modified mortars/concretes. Obviously at these repaired patches environmental attack or carbonation attacks are not effective, though the adjacent area may get affected. Hence, to protect the entire area from attacks and to avoid subsequent repair expenses, application of the surface coating becomes imperative. Generally, these protective seal coats are suitably pigmented so that besides protection, aesthetics of the structure can also be taken care of simultaneously. Various coatings like polyurethane, epoxy, alkyds, chlorinated rubbers, acrylic emulsions can be used for this purpose. However selection is done keeping following points in mind:

1. Adhesion to the surface
2. Compatibility with alkalinity of concrete
3. Breathing capacity at the same time the coating should be impermeable enough
4. Resistance to aggressive attacks
5. Expected longevity of the treatment
6. Capacity to absorb irregularities of the surface like slight dampness or imperfect cleaning of the surface
7. Ease in application and availability of colour shades.

In the case study reported here, specially formulated material suiting above requirements, an acrylate-based copolymer formulation was mixed into coloured cement to form a water-resistant coating to avoid any ingress of moisture/water in the concrete.

Participants in the project

Client	:	Municipal Corporation of Greater Mumbai
Consultants	:	S.J. Group, Mumbai and Structwel Designers & Consultants Pvt Ltd, Mumbai
Contractors	:	Manjalankal Construction
Supplier of construction chemicals	:	Sunanda Speciality Coatings Pvt Ltd

References

1. SMOLCYK, H.G., Physical and chemical phenomena of carbonation, Proceedings RILEM International symposium on carbonation of concrete, Cement and Concrete Association, Wexham Springs, UK, 1976, pp. 10.
2. BAHADURPLRKAR, M.G., GODHOLE, U.B. Major structural repair to GKB bridge at Andheri, National Conference on Corrosion Controlled Structure, Indian Society of Structural Engineers, 1999, pp. 345.
3. ______Guide for repair of concrete bridge superstructures, AC! 546.1 Ir-80, American Concrete Institute, Detroit, 1980, pp. 20
4. INGVARSSON, H., AND ERICKSSON, B., Hydrodemolition for bridge repairs, Nordisk Belong (Stockolm), No 2-3. 1988, pp 49-54.
5. CAons JOHN and Asnuti.AliKAM1.1, AC! Materials Journal, Vol. 91, no. 4, July-August 1994.
6. SIFF! Y CARROT. N. and Krt.ty THOMAS ENP., Concrete surface preparation coating and lining and inspection, National Association of Corrosion Engineers, Houston 1991.
7. Rion, M.A. and BREIT, A.O., Electro-chemistry methods and application, Oxford University Press, 1993 pp.361.
8. M_AMMAR, S.K., MANIREKAR R.S. and NAIR P.R.C. Role of polymer — Cement-inhibitor comatrix in corrosion control of reinforcing steel, The Indian Concrete Journal, July 1996, Vol 70, No.7, pp 389-392.
9. ________CEB/FIP Model Code for Concrete Structures, 3rd Edition, Comite Eurointernational du Beton/Federation Internationale de la Precontrainte, Paris, 1978, pp. 348
10. OHAMA Y. Study of properties and mix proportioning pf polymer modified mortars for buildings (in Japanese), Report on the Building Research Institute, No. 65, Tokyo, Japan, 1973.
11. BLLIOCK, R.F., Factors influencing concrete repairs materials, Concrete International: Design and construction, Vol 2 No. 9, September 1980, pp. 67-68.

Dr. S.K. Manjrekar, Managing Director, Sunanda Speciality Coatings Pvt. Ltd, 2, Anik Court, Pandurang Naik Marg, Mahim, Mumbai 400 016

(Source: ICJ January 2000, Vol. 74, No. 1, pp. 39-44)