RESINS.

Epoxy resins in civil engineering and construction

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This paper highlights the importance of epoxy resins and systems in the construction/civil engineering applications such as repairing of cracks, patching and grouting of concrete, industrial flooring, structural adhesives, anti-corrosive linings, etc. Various types of resins, hardeners and modified epoxy systems commonly used in buildings/construction are briefly described. Research work on epoxy resins carried out at the Central Building Research Institute (CBRI), Roorkee, with special reference to construction/civil engineering applications is also outlined. Considerable attention has been given to various end-use applications including some successful field experience of epoxy resins in many civil engineering structures and this will be of practical help.

Use of epoxy resins has been rising steadily all over the world since their commercial introduction in the early 1950s. The growing demand for epoxy resins has been due to their good mechanical strength, chemical resistance and ease of working. The best known applications in civil engineering/construction are: high-performance coatings, flooring, grouting, adhesives or injection systems, etc.

The first large-scale application of epoxy resins in India in the construction/civil engineering field was in 1968 for sealing of cracks in the main body of Koyna dam, caused by a major earthquake. Since then consumption of epoxy resins in building and civil engineering/construction sector has increased many folds. At present, there are about a dozen manufacturers of epoxy resins and systems in India and total installed capacity is around 4500 tonnes. *Table* 1 lists names of the manufacturing units and their installed capacities.

The total production of epoxy resins in India was about 3500 tonnes in 1989-1990 as compared to 1500 tonnes in 1983-1984. It may be noted that consumption of epoxy resins has been registering a growth rate of 23.6 percent per annum. Pattern of consumption of epoxy resin in different industries is shown in *Table* 2[1].

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Epoxy resins

Epoxy resins are characterised by a three-membered ring known as the epoxy/epoxide/oxirane or ethoxyline group, *Fig* 1(a).

It contains, on an average, more than one epoxide groups per molecule. Basic epoxy resin commonly used in the building industry is "DiGlycidyl Ether of Bisphenol-A" (DGEBA) and can be represented as given in *Fig* 1(b).

In its simplest and most standard form, epoxy resin is the condensation product of bisphenol-A and epichlorohydrin. Depending upon the amount of excess of epichlorohydrin to bisphenol-A used in the manufacturing process, epoxy resins ranging from low molecular weight liquids to high molecular weight solids can be obtained. However, basic resin of this type is not suitable for many applications because of its higher viscosity. Modification of basic resin is therefore necessary to achieve the required wetability, curing rate and numerous other properties in addition to lower viscosity[2,3].

Multifunctional epoxy resins such as epoxy-phenolic novolac (EPN), bisphenol-F and cycloaliphatic-based epoxy resin[4] are also used in the civil structures for specialised applica-

Table 1 : Unit-wise installed production capacity of epoxy resins in India

Sr. no.	Name of the unit	Location	Installed capacity, t
1.	Ciba tul Ltd.	Valsad	1,800
2.	Dr Beck & Co.	Pune	500
3.	Sip Resins Ltd.	Madras	800
4.	Bharat General Textiles	Gujarat	350
5.	Synthetics & Polymers	Ahmedabad	150
6.	Resins & Plastics	Taloja	100
7.	Escon Polymers P. Ltd.	Delhi	200
8.	Shreeji Resins & Adhesives	Ahmedabad	100
9.	Kira Polymers	Ahmedabad	120
10.	Others (Including Hindustan Ciba, Noble Synthetics, Asian Paints etc.)		380
	Total		4,500

tions. These resins cure according to the same mechanism as the difunctional resins. On account of their higher epoxide value these resins provide superior solvent resistance as compared to bisphenol-A. Some typical properties of multifunctional epoxy resins alongwith bisphenol-A are given in *Table* 3.

Curing agents (hardeners)

The basic epoxy resin most often used in the construction industry is a light amber-coloured liquid having viscosity similar to that of heavy motor oil. To use it as an adhesive, a hardener must be added. This hardener combines with the epoxy resin and changes it from a liquid to a solid. The process of setting, together with the terminology most often used is illustrated in *Fig* 2. A vast number of compounds have been screened for their suitability as curing agents. Among these, the most commonly used curing agents are polyamides, polyamines and their adducts form (room-temperature) curing compositions relevant to construction applications. The proper choice of a curing agent can be as important as the choice of resin itself, both playing a significant role in determining the extent and nature of intermolecular crosslinking.

Amines

Both aliphatic and aromatic amines[5-8] and polyamides are good curing agents for epoxy resins. The chemistry of aromatic polyamine curing agents is generally similar to that of aliphatic polyamines. However, they react faster with cycloaliphatic epoxides and are adaptable to a controlled degree of reaction. The properties of some common nitrogen-containing hardeners are given in *Table* 4.

Aliphatic amines are used as such or in adduct form for ambient temperature curing. They have critical mix ratios, toxicity, high-vapour pressure and brushing tendency. Aromatic amines are solid at room temperature. Adducts of these alongwith accelerators like salicylic acid are used for ambient temperature curing. Polyamides are used as such or in adduct form with or without accelerator for ambient temperature curing. The chief advantages are low toxicity, convenient mix ratio and good flexibility. The main disadvantages are high cost, high viscosity and poor heat and solvent resistance compared to amine-cured system.

Some other resins/elastomers such as phenol- formaldehyde resin, thermosetting acrylics[9], isocyanates[10] and polysulphides are also used as co-crosslinking agents (10-50 percent by weight of total resins) with amines to obtain the desired properties of the finished products. They are mostly used for corrosion resistant linings, food and beverages containers/tank coatings, kitchen appliances coatings etc.

Modified epoxy systems

Diluents

Diluents affect properties of the cured system, and in particular, lower the viscosity in order to improve handling characteristics. Diluents can be classified into reactive and non-reactive types. Reactive diluents are mostly low molecular weight (130-210) glycidyl ethers with low viscosity which reduce the crosslink density of the system. Other cycloaliphatic resins, because of their low viscosity, have also been used with the liquid diglycidyl ether resins or with the solid epoxidised novolac resins.

Non-reactive diluents such as toluene, xylene and other aromatic hydrocarbons can bring about significant reduction in the viscosity of low molecular weight resins. The casting have inferior chemical resistance and if it is heat cured, the diluent can be volatile and cause blow holes or bubbles. A popular non-reactive diluent is dibutylphthalate, used at a concentration of 15-17 percent with a liquid resin.

Coal tar-epoxy system

Coal tar-epoxy resin combinations have been widely used as water-resistant protective coatings for ships and other marine structures. Various papers[11,12] have been published outlining formulations for marine applications and describing the problems encountered with this type of coating system in practice. Coal tar plays an important part in the improvement of corrosion resistance of epoxy resin system. This is confirmed when tested tar modified epoxy resin/polyamine combination in water and fatty acid immersion and found that the tar modi-

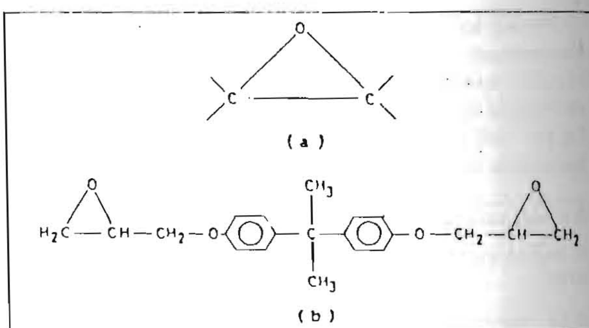

Fig 1 *(a)* Epoxide group *(b)* DGEBA

Table 2 : Consumption pattern of epoxy resins in different sectors

Sr. no.	End-use-sector	Percent consumption	
		1985-86	1989-90
1.	Electrical insulation	40	30
2.	Chemically-resistant linings and surface coatings	40	32
3.	Civil engineering	05	16
4.	Adhesives and putties	10	12
5.	Reinforced plastics, tooling and electronic components	05	10
Total	Quantity consumed in tonnes	1500	3500

fied system gave satisfactory results, while the unmodified system failed in four months. Investigations on the effect of various grades of coal tar, coal tar content addition of different fillers and hardeners on the properties of epoxy resin have been studied[13,14].

Rubber-modified epoxy system

Unmodified epoxy resin based on bisphenol-A and epichlorohydrin exhibits brittleness and low elongation after curing with hardeners such as polyamines and anhydrides. This drawback has limited the applications of this resin to situations where the stress is relatively low and the loads are preferably static. Since 1960s the technology for the development of tougheners for thermosets has been gradually evolved. Notable successes have been achieved in toughening certain types of epoxies. However, desirable levels of toughening have not been attained in every case, especially in case of high cross-linked epoxy.

For sometime, it was believed that to obtain an epoxy with high toughness, one must use an elastomeric toughener. The effectiveness of a given toughening agent depends perhaps more significantly on the nature of epoxide matrix than on the detailed characteristics of the elastomer. The incorporation of small amount of elastomer particles promotes absorption of strain energy by interactions involving craze and shear formation. Craze formation is promoted by 1-5 micron particles and shear formation by 0.5 micron particles. Systems possessing both small and large particles provide maximum toughness[15]. The most widely used toughener in epoxy resin is a liquid carboxy terminated butadiene-acrylonitrile.

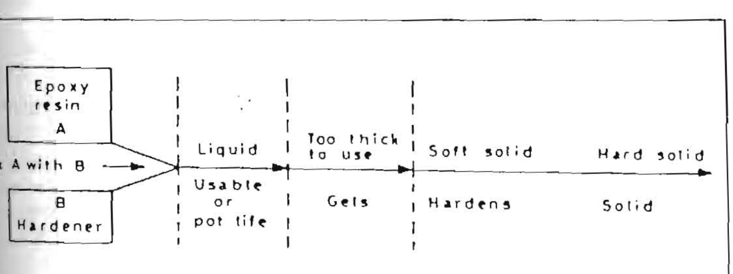

Fig 2 The process of setting

Table 3 : Some typical properties of bisphenol-A based epoxy resin, epoxy-phenolic novolac resin (EPN) and bisphenol-F based epoxy resin

Sr. no.	Properties	Bisphenol-A epoxy resin	EPN resin	Bisphenol-F epoxy resin
1.	Epoxy content, eq/kg min	5.20-5.45	5.50-5.70	5.40-5.80
2.	Epoxide equivalent, g/equiv	171-200	175-220	-
3.	Viscosity, (MPa s)			
	at 25°C	9,000-12,000	-	6,000
	at 53°C	-	20,000-50,000	-
4.	Specific gravity	1.20	1.15-1.20	-
5	Hydrolysable chlorine, percent maximum	0.2	0.2	-

Epoxy mortar and concrete

Epoxy resins are used with aggregate (silica sand) to produce epoxy mortar or epoxy concrete which is used for repairs of flooring, foundation grouting, roads and bridges, industrial pavings, etc. They are normally used where the volume of materials is not large and where rapid curing can be obtained. The repair of pot holes and spalled joints on Portland-cement concrete highways and bridge decks is a good example for the use of epoxy mortar especially where a lane can not be closed to traffic for long hours. The rate of curing of the epoxy mortar is directly dependent on the ambient temperature. In cold weather, small patches of mortar can be easily heated artificially to provide a rapid cure. Clean, dried, specially-graded silica sand is used as filler with resin-hardener mixture.

Addition of sand helps in reducing shrinkage, improves abrasion, thermal shock resistance and lowers the thermal coefficient of expansion making it nearer to concrete.

R&D work at CBRI

Research work on epoxy resins is in progress at a number of R&D institutions in India for over three decades. Major work reported has been confined mainly to synthesis of epoxy resin from low cost polyols[16,17], development of suitable curing agents[18,19], modified epoxy resins for corrosion resistant linings[20] and epoxy mortar and concrete[21]. A brief review of work carried out at CBRI with special reference to applications in construction and civil engineering is outlined here.

The effect of different proportions of epoxy in tar/epoxy paint on their chemical resistance was investigated at this institute by Singh[22]. Tar-epoxy mixtures of 70:30, 60:40, 50:50 and 40:60 were studied. Polyamine hardener was used for curing epoxy resin. Free films of the paints and paints applied on mild steel test panels were examined for chemical resistance, hardness, extensibility, water absorption and water

Table 4 : Properties of nitrogen-containing hardeners

Type	Polyamide (A)	Amine adduct	Polyamide (B)	Low viscosity polyamide	Aromatic amine adduct
Viscosity (25°C (MPa s)	10-20	3,000-5,500	9,000-16,000	3,000-4,500	6,000-20,000
Amount recommended, (gm.eq/epoxide)	16-20	40	110-190	140-200	100-120
Nature	sl. volatile, irritant	less volatile	non volatile, not strong smelling	non volatile, not strong smelling	non volatile, not smelling
Haze or blush	Marked	V. slight	Almost nil	almost nil	nil
Flexibility and impact resistance	Poor	Poor	Good	Good	Better than amines and amine adducts
Chemical resistance	Better	Better	Good	Good	Excellent
Water resistance	Moderate	Moderate	Good	Good	Excellent

vapour permeability. It was concluded from this study that a tar/epoxy composition of 40:60 was best for the formulation of tar/epoxy paint. Performance of commercially-available epoxy, epoxy- coal tar and other organic coatings on concrete were evaluated under aggressive actions of some fertilizers[23]. Epoxy coatings were found to give good performance upto 30 percent concentration of ammonium sulphate, ammonium chloride and ammonium nitrate solutions. Other coatings were found suitable for less stringent conditions.

Another attempt was made to modify conventional epoxy resin with a low-cost indigenously available phenolic resin to obtain optimum properties[24]. The simultaneous polymerisation technique was used for the preparation of interpenetrating polymeric network (IPN) systems. Various properties such as mechanical, chemical, thermal and morphology of developed IPNs were studied and compared with neat epoxy resin, *Table* 5. The developed IPN systems could be used as barrier coatings for anti-corrosive protection of building materials in highly aggressive environment. The epoxy-phenolic IPN systems developed by CBRI have found commercial applications and have been used on a large scale. A few examples are illustrated with the help of photographs, *Figs* 3 and 4.

R&D on epoxy mortar using higher filler loadings and part replacement of epoxy with a low cost resin (LCR) have been thoroughly studied[25]. It was shown from this work that maximum strength of epoxy mortar is obtained at a resin-sand ratio of 1:7. The strength decreases as the sand content increases. The mix becomes stiff and does not remain workable after 1:10 composition. It is seen from the results (*Table* 6) that inspite of resin content having gone down from 12.5 percent (resin:sand::1:7) to 9 percent (Resin:sand::1:10), the corresponding decrease in strength properties is quite moderate. To bring down the cost of epoxy resin-sand system, a part of the epoxy resin was replaced by a low-cost resin and coal tar. The results show a reduction of strength as the amount of low-cost resin increases in the mix. Replacement with coal tar results into a much faster deterioration in strength. Various sand-resin formulations given in *Table* 6 could be used for repairing, patching, grouting etc. and a maximum saving in cost upto 40 percent could be achieved.

Fig 3 IPN coating application on a badly damaged ceiling in a urea plant

Applications of epoxy resins

Industrial flooring

Epoxy mortar floor toppings are used to render industrial floors sterile, dustproof, chemical resistant and antistatic. They are used in heavy engineering industries for resisting metal-wheeled trolley movement. However, epoxy flooring is not used for domestic flooring because of high cost and not-so-pleasing appearance.

There are three main types of epoxy flooring systems:

(*i*) trowelled floors,

(*ii*) pourable self-levelling seamless floors, and

(*iii*) terrazzo floors.

Screeded floors are usually laid by trowel, the resinous component being heavily filled with a blend of hard wearing abrasion-resistance aggregate such as corborundum, calcined bauxite and metal aggregates.

Table 5 : Comparative properties of neat epoxy and epoxy/phenolic IPN system

Coating system	Tensile strength, kg/cm²	Elongation, percent	Hardness, shore-D	Shear bond strength, kg/cm²	Vicat softening point, °C
IPN	280	17.5	83	47.3	61
Epoxy	260	5	85	46	65

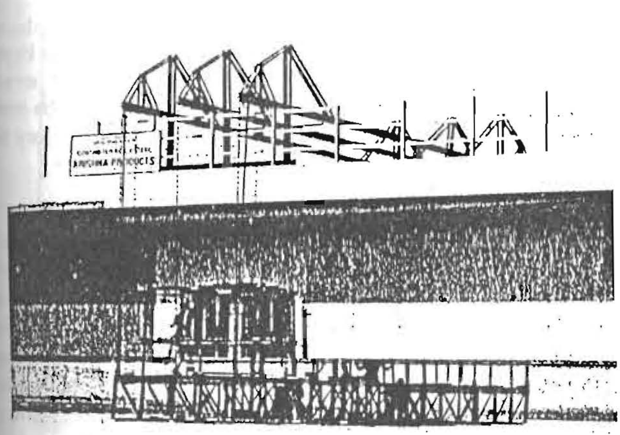

Fig 4 Application of IPN polymer for a bridge superstructure. Top coating with polyurethane under progress

The self-levelling floor is generally applied by mixing the components, and pouring the resulting mix on to the substrate. As the name implies, once the resin has been spread with a comb, it levels out on standing to produce a smooth floor 2.54 mm (0.1 inch) to 3.175 mm (0.125 inch) thick. Coloured PVC flakes may be sprinkled on to the partially cured resin to give an added decorative effect. It is a normal practice to apply a coat of clear sealer if flakes have been used.

In epoxy terrazzo floors, an epoxy binder replaces cement matrix in a marble aggregate flooring and provides impact resistance, mechanical strength and adhesion.

Some of the important locations where such floorings have been used are given in *Table* 7.

Anti-corrosive coatings

It has been estimated that the total corrosion losses in India lies between Rs 1,200 to 1,500 crores per year and it is considered that 25 percent of this cost could be saved with better application of existing knowledge of methods of corrosion prevention. Many of the suitable anti-corrosive coatings and some of the non metallic components that can be used in chemical plant construction and maintenance are based on epoxy resins. The most commonly used corrosion resistant epoxy-based coatings are : epoxy/phenolic, epoxy/ester, epoxy powder coatings and two-pack ambient temperature curing systems.

In a large number of projects in India, epoxy mortar is being used for anti-corrosive linings of effluent pits, drains,prilling towers, floors and structures in chemical handling areas of demineralised (DM) water plants. There are many case histories in India on the use of epoxies in fertiliser industries for protection of structure with longer service life, *Table* 8. A few examples are illustrated with the help of photographs, *Figs* 5 to 8.

Kali nadi bridge : Pure epoxy-pigmented coatings have been used in a number of flyovers/marine creek bridges in and around Bombay with satisfactory service life exceeding 7 years. The Kalinadi bridge near Karwar has been protected with an epoxy coating since 1985.

Thane Creek bridge : Thane Creek bridge has been constructed across the Thane Creek near Bombay on Bombay-Bangalore highway. Due to the aggressive saline atmosphere, mild steel and prestressing steel has been corroded causing cracks in the piers and girders. The corrosion to steel reinforcement and pretensioning steel cables posed a challenge to the safety of the bridge and heavy vehicular traffic. About 5000 kg of epoxy resin was used for repair of cracks by pressure grouting, filling of pot holes and cavities with epoxy mortar and coating entire bridge surface with solventless epoxy system. Additional external prestressing cables now assure safe traffic movement.

Fusion-bonded epoxy coating : Fusion bonded epoxy powder coating to reinforcing rods have become popular in western countries. This process provides a tough film which can withstand bar bending without cracking. In India also, this technology is at the trial stage. The HBJ pipeline is being protected by a system comprising of, among others, a primer of fusion-bonded powder coating. The use of fusion-bonded epoxy coated reinforcement in some of the flyovers recently constructed in Bombay and the railway stations buildings in New Bombay is a good beginning.

Reducing water leakages

Epoxy coatings, in conjunction with epoxy grouting, have been used to render leaking roofs, toilets and bath rooms impervious. Some of the notable structures where such coatings have been used are listed below.

Hemispherical dome, Pune : A low viscosity epoxy resin system(1500 kg) was used for reducing water leakages in the hemispherical dome of the Sudan Block at the National De-

Table 6 : Physical properties of polymer concrete using low-cost resin

Resin system	*Resin sand ratio*	*Density, g/cc*	*C.S, kg/cm²*	*T.S., kg/cm²*	*F.S., kg/cm²*	*B.S., kg/cm²*	*Shrinkage, percent*	*Cost saving over control, percent*
Epoxy (control)	1:7	1:87	804	124	295	136	0.03	-
Epxoy:LCR								
80:20	1:7	1.94	682	118	231	120	0.07	22.5
70:30	1:7	1.93	557	114	225	67	0.08	32.5
60:40	1:7	1.89	259	90	15	55	0.04	42.5
Epoxy:LCR								
80:20	1:8	1.94	528	114	157	92	0.03	30.9
	1:9	1.92	472	112	190	86	0.03	38.3
	1:10	1.93	461	88	113	58	0.02	43.5
Epoxy:coaltar								
80:20	1:7	1.94	546	104	218	112	0.10	-
70:30	1:7	1.92	336	88	170	65	0.12	-

C.S. : Compressive strength, T.S. : Tensile strength, F.S. : Flexural strength, B.S. : Bond strength

Table 7 : Field applications of epoxy resin systems as flooring

Sr. no.	Locations	Type of flooring	Quantity of materials used	Year of use/performance
1.	Military engineering services, Engine Assembly Shop, 512, Army-Base workshop, Kirkee, Pune.	High impact abrasion resistant dust proof flooring	15,000 kg	1986 (satisfactory till date)
2.	Bajaj Tempo Ltd. (Paint shop), Pune	Chemical resistant flooring	200 kg	1984 (satisfactory till date)
3.	TELCO, Pimpri, Pune	Dust and abrasion resistant flooring	10,000 kg	1986 (satisfactory till date) (Local damage areas periodically repaired by giving brush coat)
4.	Bharat Heavy Electricals Ltd. (Electronics assembly shop), Bangalore	-do-	335 kg	1988 (satisfactory till date)
5.	Fulford India	Self levelling	-	-

fence Academy, Khadakwasla, Pune. The hemispherical dome is a masterpiece of architecture constructed in 1956-57 in Jaipur using pink stone masonry over 150-mm thick concrete for structural support. Over the thirty years of existence, weathering had caused cracks in the stone masonry at places and the painting mortar too had come out of the joints causing severe water leakage during monsoons. After the epoxy treatment, the dome has not shown any leakage or seepage in the monsoons since 1986.

Bhima aqueduct : One km long Bhima aqueduct has been constructed across the river Bhima near Sholapur to carry water from Ujaini Dam for irrigation purpose. In order to reduce the permeability of the aqueduct, 7700 kg of epoxy resin was used. Two brush coats of epoxy resin were applied on the inside surface of the aqueduct. No leakage has been reported till date.

I.S.R.O., Bangalore : At the satellite assembly and testing centre, Indian Space Research Organisation, (I.S.R.O.) Bangalore, an excavated tunnel of rectangular cross section [4.5 m (W) x 5.0 m (H)] and of length 100 m carrying air to the clean room where satellites are assembled and tested, was having excessive water leakages. The concrete structure was treated with about 5500 kg of epoxy resin system by applying a primer coat of epoxy resin followed by emulsion bonded glass fibre epoxy lining. Also, 4000 kg of epoxy resin system was used for pressure injection grouting of locations causing water leakages. The epoxy treatment effectively stopped the water leakages and enabled achievement of clean room conditions since 1988.

In another locations epoxy coatings have been employed for lining of water storage tanks(250 kg) in Padamjee Paper Co. at Chinchwad and for reducing water leakages of terrace (300 kg) in Backau Woulf India Ltd., Pune. These jobs were done in 1986 and the performance has been satisfactory till date.

Structural adhesives

A significant increase in the use of epoxy adhesives in the civil engineering industry has taken place over the last few years mainly due to its high bond strength and faster rate of curing as compared to conventional materials. The first successful epoxy adhesive for bonding plastic concrete to hardened concrete was based on epoxy resin-polysulphide polymer mixtures which have proven reliable. Early adhesive systems were considerably viscous, quite often solvents were added on the job sites or included in the original formulation. The entrapment of solvent used as plasticiser reduces the strength of adhesive. As the state-of-the-art improved, the viscosity of epoxy resin bonding compounds was lowered without the use of solvents, thus increasing the safety factor in their use. Adhesives for this purpose must be slow curing systems. If the adhesive cures before the new concrete has hardened, it will act as a bond-breaker rather than an adhesive. For bonding hardened concrete to hardened concrete, fast curing systems may be employed.

The use of epoxy adhesives and grouts can be classified broadly into :

(*i*) remedial work such as strengthening and repair of existing structure (concrete crack repair, bonding reinforcements, bonding concrete to concrete etc.).

(*ii*) new work where the use of adhesive is envisaged at the design stage.

Suitably-formulated epoxy resin mortars are used as adhesives to bond together huge precast/matchcast concrete segments in the building of bridges and other structures by the technique of segmental construction. This method has been

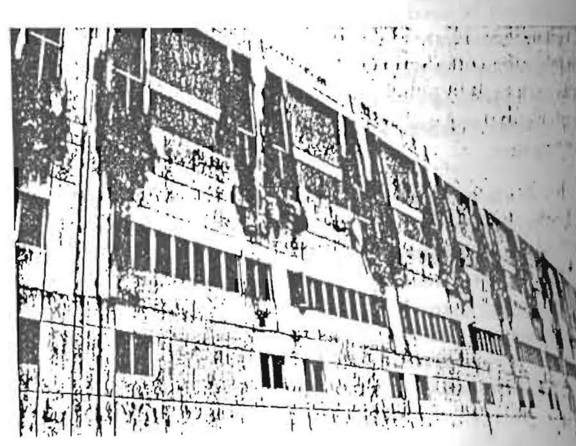

Fig 5 Patches of urea attack in a bagging plant

Fig 6 Urea attack on a staircase slab

followed in the construction of 5.6-km long Mahatma Gandhi Sethu -- the world's longest river bridge across Ganges, near Patna. The weight of the segments in this case ranged from 28 to 80 tonnes.

The Indian Railways are regularly employing epoxy mortars for quick bonding of precast concrete bed blocks to bridge piers in their scheme to replace damaged bed blocks. One kilometre long Bhima aqueduct has been constructed by casting precast concrete sections of 4.8 x 3.93 x 32.6 m size at ground, hoisting them up at a height of about 50 m above the ground level, joining each section and then tensioning with cables. Epoxy mortar was used for joining of precast sections.

A high strength epoxy adhesive had been used to glue glass chips to themselves and to the marble facade to create a multi-coloured college in one of the buildings at Shiv Sagar Estate in Bombay. This assembly has withstood the ravage of weather and pollution for over 22 years.

Table 8 : Use of epoxy system as anti-corrosive linings

Sr. no.	*Areas*	*Organisations*	*Maximum trouble-free services reported*
1.	D.M. water treatment plant	SAIL-Bokaro IOC-Haldia Baraunl, Mathura, Baroda NTPC-Aunta and Auraiya IPCL-Baroda FCI-Sindri Unit	More than 10 years in FCI Mathura
2.	Urea prilling tower	FCI-Gorakhpur, Sindri Unit, Ramgundam Talcher HFC-Namrup NFL-Nangal *Atash Leasing Industries- Khopali	More than 14 years in Sindri
3.	Silo and bagging plant, floor, wall, mettalic structures	NFL-Nangal, Vijaipur HFC-Namrup IISCO-Burnpur GNFC-Bharuch	More than 14 years in Nangal
4.	Steel structures and pipe lines, coke-oven gas pipe line, air separation unit, raw gas header, vessels etc.	NFL-Nangal, FCI-Ramagundam Talcher and Sindri IISCL-Bokaro BHPV-Vishakha patnum SAIL-Bokaro Globe-Hi-Fab-New Delhi etc.	More than 9 years in coke-oven gas pipe line at Durgapur (BBVL)
5.	Concrete surface-(urea bagging plant, beams and slabs near schute, wall, conveyor-belt etc.)	IFFCO-Phulpur	Approximately 10 years
6.	Concrete and steel structures - (NPK plant, conveyor-belt, steel trusses, RCC columns, walls etc.)	Zuari Agro Chemicals - Goa	Approximately 6 years
7.	Concrete surface (Girders)	Vasai Creek Bridge-Bombay	Approximately 6 years

Repairing of cracks

The method of structurally repairing concrete cracks by the injection of epoxy compounds has evolved over the past 10-20 years. It has been used in numerous critical applications, with significant cost savings over alternative methods of repairing damaged concrete. The resin system penetrates the cracks, reaching all voids and by setting inside, thus rendering the structure crack-free. This process is applicable to all cracks wider than 0.012mm (0.005 in). Success in these extremely small cracks is entirely dependent on the specific conditions encountered and in general it is impossible to say whether or not injection will be successful unless an actual field test is performed. Even in cracks wider than 0.012mm, it is possible to encounter severe contamination or deposits that prevent effective injection.

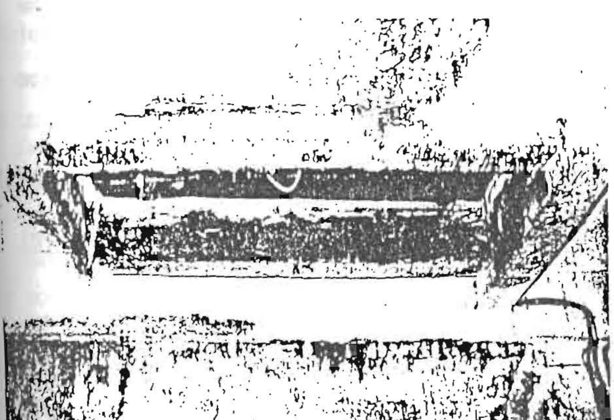

Fig 7 Deposition of urea on the ceiling of slab

Uses in hydraulic structures

Epoxy resins are widely used in many hydro-electric projects in India for repair of cracks in eroded concrete. Some major field applications are given in *Table 9*[26].

Sallal Hydro-electric Project : In the Sallal Hydro-electric Project it was observed through model studies that negative pressures of the order of 4-m height of water will develop in

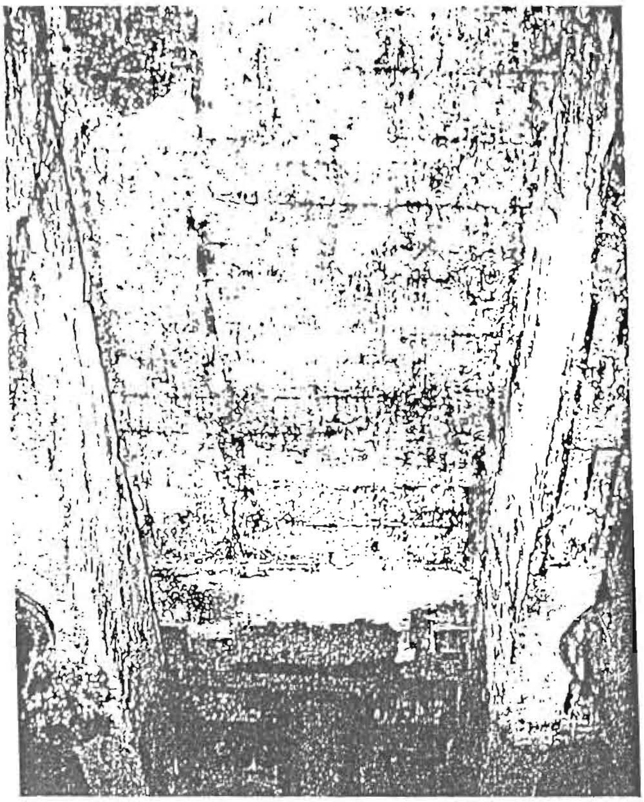

Fig 8 Corrosion distressed slab

1/3 portion on the top of diversion tunnel for the portion of 10 m x 200 m length. The velocity of water was estimated at 24.4 m/sec. A 5-mm thick epoxy mortar lining has been employed with satisfactory performance to meet the conditions. Besides this, epoxy mortar lining has been employed in other areas of the project like tunnels, spillways, aprons, schutes, etc.

Jawahar Sagar dam : A 5-mm thick epoxy mortar lining has been applied on the entire concrete surface of speed breakers and stilling basin of Jawahar Sagar dam. Epoxy mortar formulations are being regularly used by all the major dams for repair of cavitation/abrasion damages in concrete.

Virbhadra-Hardwara barrage : Abrasion-resistant epoxy mortar/concrete formulations are being used at Virbhadra-Hardwar barrage in boulder stage rivers of U.P. Epoxy mortars are used to avoid dislodging of the stone blocks (610 x 460 x 460 mm) used on the entire barrage floor to safeguard against excessive abrasion of concrete surface due to high discharge intensity and boulder movement. The joints are partially painted with epoxy mortar/concrete to achieve this.

Gomti aqueduct : Epoxy coatings have been used to line precast prestressed aqueduct across river Gomti near Lucknow. The epoxy coatings are used here to protect the concrete against abrasion caused by silt carried in water with high discharge rate.

Bhakra dam : In Bhakra dam, epoxy resin formulations are being used for repair of damages to the stilling basin. In this application, suitable epoxy formulations are required which can be applied on damp surface under wet condition.

Hirakud dam project : In Hirakud project, epoxy formulations are being used to reduce leakages in the joints of upstream of the dam with the help of divers. Besides, epoxy which can set in wet condition is being grouted under pressure.

Grouting of heavy machinery

A large number of heavy-duty equipment like reciprocating and centrifugal compressors, large pumps,diesel generators, etc. in fertiliser, petrochemicals, oil and cement industries have been grouted with flowable epoxy grouts.

Rourkela Steel Plant : A large number of new foundation bolts of size 28-mm diameter have been grouted with epoxy mortar in 32-mm diameter pneumatically drilled holes in existing Rourkela Steel Plant. This saved considerable time in the modernisation/revamping project involving installation of new machines in the existing foundations. The efficacy of the grouting method has been confirmed by the load tests.

Bangaigaon Thermal Power Station : For Bangaigaon Thermal Power Station, Staker reclaimer 400 t/hour capacity crane required the support frame to be grouted on properly levelled base. Filled epoxy resin containing steel powder as filler was used for fixing the support frame and beam. The cured epoxy resin between the gap of base and support frame

Table 9 : Major hydro-electric projects where epoxy resins have been used

Sr. no.	*Project (Location)*	*Application*	*Approximate quantity of epoxy consumed, kg*
1.	Koyna Dam, Maharashtra	Grouting of cracks	3,000
2.	Bhandardara Dam, Maharashtra	Grouting of cracks	1,850
3.	Kundha Hydro-electric Project, Kundha, Tamil Nadu	Repair of water carrying tunnel	250
4.	Kodayar Hydro-electric Project, Papanasam, Tamil Nadu	Repair of water carrying tunnel	1,000
5.	Barvi Dam, Maharashtra	Bonding of old to guniting concrete layer	2,500
6.	Pench Hydro-electric Project, Maharashtra	Grouting of cracks in bus shaft and water proof coating	2,000
7.	Panshet Dam, Maharashtra	Filling of cavities in concrete by grouting	700
8.	Hirakud Dam, Orissa	Repair of cracks	2,000
9	Rihand Dam, Uttar Pradesh	Repair of beams and columns in power house	1,000

has to withstand vibration and impact loading during continuous operation of the crane.

Metro Railway, Calcutta : In the Metro Railway Project at Calcutta, ballastless tracks have been employed to ensure practically a maintenance-free track. In this project, epoxy resin mortar is being used to grout high density polyethylene inserts or malleable cast iron inserts at appropriate position and in correct levels in the holes left in the concrete bed. The epoxy resin mortar was chosen after extensive field and lab trials at RDSO, Lucknow, investigating the fatigue, vibration resistance behaviour etc. Epoxy mortar is also being used to grout rail tracks on top of deep beams in coal handling areas of super thermal power stations.

Conclusion

Epoxy resins and systems are being increasingly used in the construction/civil engineering applications such as structural adhesives, repairing of cracks, reducing water leakages, corrosion resistant linings etc. A large number of cost-effective epoxy resin formulations are readily available commercially. The proper choice of resins and its formulations with other modifiers is essential for obtaining the optimum performance in actual-use conditions. The advances in epoxy resin systems, application developmental studies and field experience have evolved considerable information as to the capability and limitations in the usage of these materials.

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