EPOXY ADHESIVES IN PRECAST PRESTRESSED CONCRETE CONSTRUCTION

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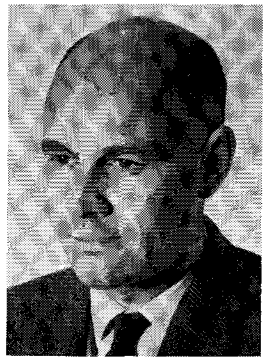
Although epoxy adhesives have been used for many years in the construction industry, they are now being used to an increasing degree in precast prestressed concrete applications. This is especially evident in segmental bridge construction.
The author reviews the properties of structural adhesives and lists the important criteria for selecting epoxy adhesives.
In particular, he emphasizes the importance of obtaining reliable data on creep deformation, heat stability, and moisture resistance.
The properties of epoxies are greatly influenced by variations in temperature.
The test results of a comprehensive laboratory program on the creep behavior of epoxy mortars are presented.
Suggested items for specifications are listed together with several pointers in applying the adhesive.
For example, it is very important not to exceed the allowable time period between mixing and epoxy application.
Some suggestions are given on field testing and items needed to be tested.
Finally, the application of epoxies to two specific bridge projects is described.

Epoxy resins have been employed in the construction industry for many years. For example, they have been used as anti-corrosion coatings, industrial flooring, interlayer sealing membranes, anti-skid surface dressings, adhesives, injection and grouting systems.

There are, therefore, great variations in the properties required of the binder or the ready-for-use products in the different types of applications.

When epoxies are used to transmit loads, they must possess very unique properties since both the stability and durability of a structure must be guaranteed over its life span.

Segmental precast concrete bridges fit into this category. For some practical applications of epoxy adhesives in segmental construction refer to the end section of this paper.



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CRITERIA FOR SELECTING EPOXY ADHESIVES

What properties should an engineer consider in selecting an epoxy resin? Which properties have an important bearing in formulating the job specifications?

To answer these questions we must carefully weigh two separate aspects of the problem.

1. The anticipated requirements of the adhesive demanded by the job.
2. The known physical and chemical properties of the selected cold-curing epoxy resin system.

Because cement has been used as a binder for a very long time, we are familiar with its properties. Unfortunately, this is not the case with epoxy resins.

Therefore, it is helpful to compare the influence temperature has on the properties of cement and epoxies.

In general, cement (an inorganic binder) is largely insensitive to temperatures ranging up to 350 C (662 F).

On the other hand, the properties of epoxies (organic binders) are greatly influenced by variations in temperature. For example, viscosity, workability, pot life, processing time, curing speed, degree of cross-linking, durability, and short-term and long-term behavior are all gravely affected by large temperature variations.

Because of this sensitivity to temperature, the testing of epoxies is expensive and time consuming.

Ideally, a structural adhesive should possess the following properties:

1. Easy workability at different temperatures and in various kinds of weather.
2. Proper consistency to allow application of desired coat thickness.
3. Long processing time.
4. Curing independent of temperature and humidity.
5. Good adhesion to concrete with passage of time and varying humidity conditions.
6. Negligible creep deformation.
7. Resistance to temperature variations.

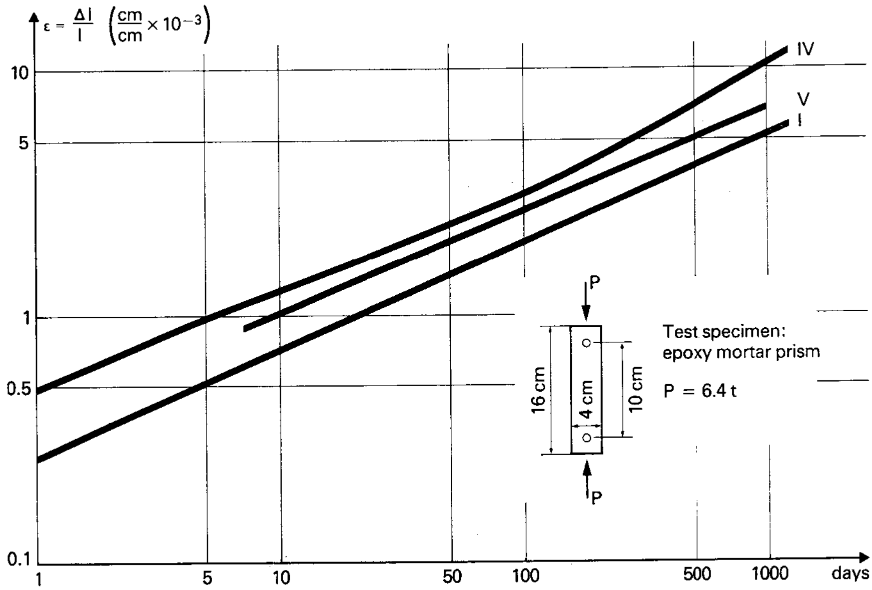


Fig. 1. Creep deformation of three epoxy mortars at a compressive stress of 400 kp/cm² (5690 psi) at 20 C (68 F); Systems I, IV, and V. Note: 1 in. = 2.54 cm.

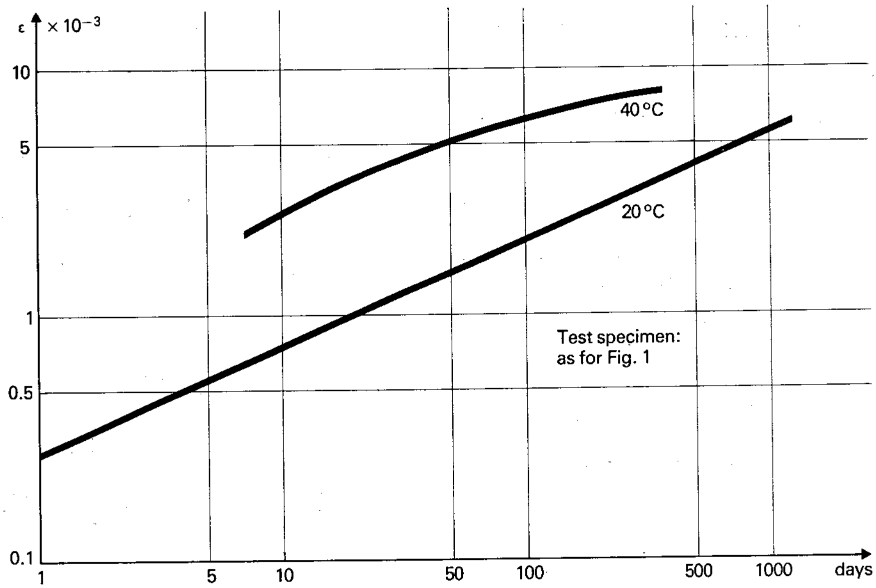


Fig. 2. Creep deformation of an epoxy mortar at a compressive stress of 400 kp/cm² (5690 psi) at 20 C and 40 C (68 F and 104 F); System I (see Fig. 1).

8. High early strength relative to method of construction used and speed of erection.

Unfortunately, in practice, a few compromises must be made depending on the job concerned. Not all the above properties can be met simultaneously with any given epoxy system. Because the performance of an epoxy adhesive (especially cold-curing synthetic resins) is dependent on temperature, when selecting an epoxy it is helpful to classify the properties into "*not* primarily decisive" and "primarily decisive" categories.

Not primarily decisive properties

1. Reactivity.
2. Short-term mechanical strength.
3. Adhesion to concrete.

Primarily decisive properties

1. Long-term behavior.
   (a) Creep.
   (b) Temperature resistance.
   (c) Resistance to water and alkalis.
2. Relative insensitivity to incorrect mixing ratio.

Reactivity, i.e., pot life and curing speed, is heavily dependent on the type of system used and the prevailing field temperature. However, reactivity is not a reliable criterion for selection because it provides little indication of the other properties.

The short-term strengths (compression, flexure, shear strength, lap shear strength, and modulus of elasticity) are usually deceptively high. Furthermore, they can easily give the erroneous impression that the mechanical strength of an epoxy system is always greater than that of the concrete to be bonded.

If the concrete is being bonded under mild conditions, the requirement "failure in concrete" is easy to fulfill under most prevailing stresses. The adhesive strength of the epoxy can be assumed to be greater than the ultimate strength of the concrete and is therefore not a governing criterion.

TEST RESULTS

Creep deformation under permanent load is one of the most important properties in selecting an epoxy system. Although creep is very hard to measure in a joint, data on plastic deformation are essential. This is because such data provide basic information on long-term behavior and loading capacity.

A comprehensive laboratory program was undertaken at Ciba-Geigy Limited to test the long-term creep behavior of epoxy mortars under high temperature variations.

Figs. 1 through 4 show some typical creep deformation curves obtained with various epoxy systems. An explanation of these systems is given below:

System I—Highly reactive system curing at low temperatures. Maximum temperature resistance. Filling ratio (binder/aggregates) 1:3.5.

System IV—Highly reactive system curing at 0 C (32 F) and above. Good adhesion to wet concrete. Filling ratio 1:4.3.

System V—Suitable system for application at elevated temperatures up to 35 C (95 F). Filling ratio 1:3.7.

It can be assumed that, at a temperature of 20 C (68 F) and lower, the ultimate creep rate of highly cross-linked epoxy systems is about three to four times as high as that of the concrete to be bonded.

The most important criterion for selecting an appropriate adhesive is its behavior under rising temperature conditions. This is the critical point for all cold-curing binders (and not only for epoxy resins).

Data on creep deformation with rising temperature (such as Fig. 5) is essential prior to selecting an adhesive.

Measurements on 4 x 4 x 16 cm (ap-

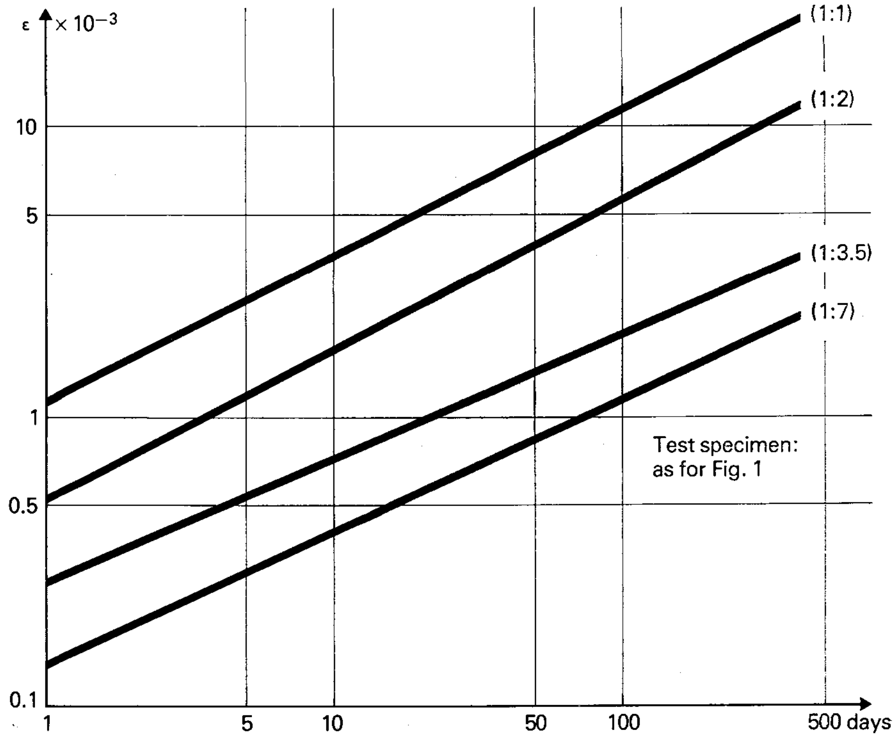


Fig. 3. Creep as a function of filling ratio (binder/aggregates) at 20 C (68 F); compressive stress 400 kp/cm² (5690 psi); System I (see Fig. 1).

prox. 1½ x 1½ x 6½ in.) epoxy mortar prisms [see Fig. 5 and Table 1, Note (a)] indicate that highly cross-linked systems start to lose their strength at temperatures of about 45 C to 55 C (113 F to 131 F).

Nevertheless, thin layers of adhesive in bonded joints perform much better than prisms when exposed to rising temperatures. Compression tests on diagonally bonded concrete prisms, with a joint width up to 5mm [see Table 1, Note (b)], and also lap shear tests on bonded metal strips [see Table 1, Note (c)], have shown that a loading of 25 percent of the short-term ultimate load does not cause failure in the highest quality epoxy adhesives until a temperature of 95 C to 100 C (203 F to 212 F) is attained.

SUPPLEMENTARY CONSIDERATIONS

Another important criterion in selecting an adhesive is its resistance to water and alkalis. To test this property, bonded cement mortar prisms are immersed in water for periods up to 2 years. At the end of this testing period, good binder systems should show no loss of strength.

In some applications (e.g., in the building industry), errors in the mixing

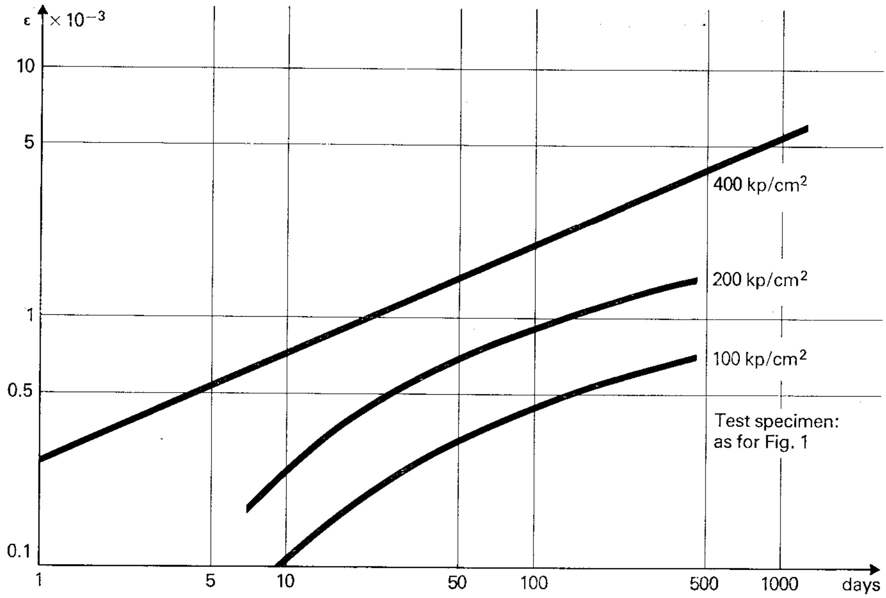


Fig. 4. Creep as a function of compressive stress of 400, 200, and 100 kp/cm² (5690, 2845, and 1423 psi) at 20 C (68 F); System I (see Fig. 1).

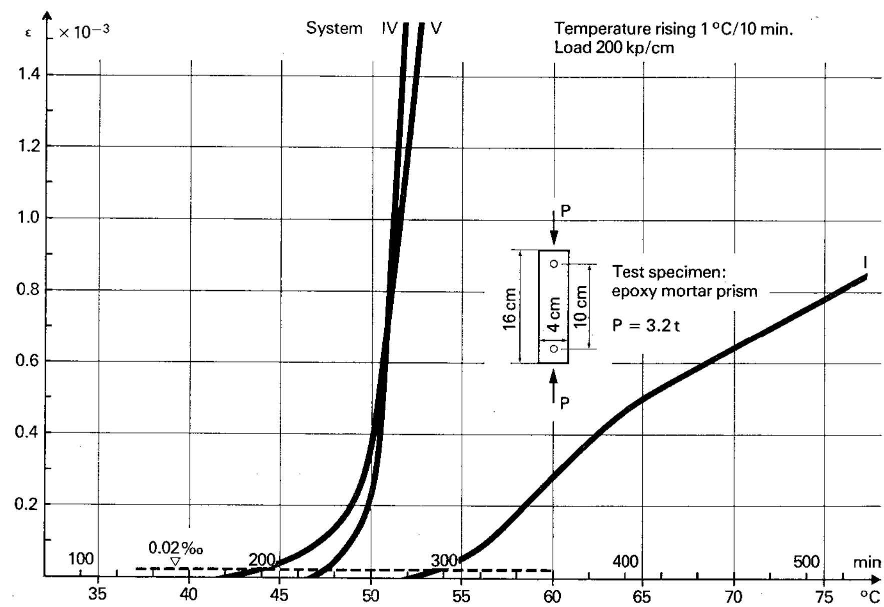
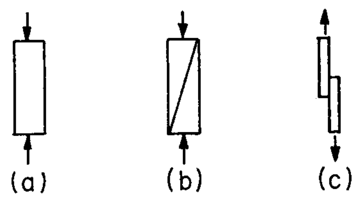


Fig. 5. Epoxy mortar creep with rising temperatures.

Table 1. Behavior of epoxy mortars and adhesives at elevated temperatures. Note: 1 in. = 2.54 cm.

System	Properties	Epoxy mortar, filling ratio 1:3.5-1:4.3 Transition temperature 1	Epoxy adhesives, filling ratio 1:1.8 Failure at 2
I	Highly reactive system curing at low temperatures. Highest temperature resistance.	54 C (129.2 F)	103 C (217.4 F)
IV	Highly reactive system curing at 0 C (32 F) and above. Good adhesion to wet concrete.	47 C (116 F)	62 C (143.6 F)
V	System for application at elevated temperatures up to 35 C (95 F).	44 C (111.2 F)	103 C (217.4 F)
(a) Epoxy mortar prism, 4x4x16 cm. (b) Diagonally bonded cement mortar prism (4x4x16 cm) or cylinder of adequate size (Arizona cylinder test). (c) Metal-to-metal lap shear joint.			

* To facilitate comparison between the various epoxy mortar and adhesive systems, the tests carried out were given the character of discontinued long-term tests under the loadings cited. In each case, the maximum permissible service temperature as a function of loading would have to be determined by supplementary long-term tests.

ratio can have a detrimental effect on the end product.

To test the effect of mixing errors, the author's company instigated a laboratory program on normally-cured and hot-cured specimens. Data were obtained on short-term strengths at 20 C and 70 C (68 F and 158 F), as well as the effect of mixing ratio errors on creep, water absorption, and reactivity.

The test results showed that the binder systems performed well even with a margin of error of 20 percent in the mixing ratio. However, this relative insensitivity should not be regarded as a license to indulge in careless mixing.

From the governing criteria, it is seen that only highly cross-linked epoxy resin systems (high strength, rapid curing, and high heat stability) should be used as structural adhesives.

Unfortunately, highly cross-linked systems are usually extremely reactive, their pot life is relatively short, and their "contact time" is relatively limited. On the job site, this means that the mixing and application of the adhesive should be carried out just before the element being bonded is ready for installation.

The dependency of binder performance on temperature also means that different reactive systems should be used at different seasons of the year. As a rule, it is sufficient to use one formulation for the summer and a different one for the winter.

SUGGESTED SPECIFICATIONS

Now, having reviewed the significant properties of a quality adhesive, we would like to know what data we should include in a job specification.

Let us first list what does *not* belong in a specification. Data that give us little information on the properties of resins and hardeners are: epoxy equivalent, ash content, specific gravity, viscosity of H-active equivalent, water content, and alkalinity. As for the cured adhesive, data on water absorption, Martens point, tensile strength and elongation, strengths at high temperatures, and resistance to chemical agents are not only of little value, but often misleading.

Data that should be included in a specification are as follows:

1. Pot life and contact time at various temperatures.

2. Compressive and flexural strength, and possibly shear strength, tested after curing for 7 days at 20 C (58 F).

3. Development of mechanical strength at various temperatures.

4. Modulus of elasticity at 20 C (68 F).

5. Shear strength of bonded concrete prisms at 20 C (58 F). The actual time when failure occurs in the concrete is also significant.

6. Lap shear strength of bonded metal strips cured for 7 days at 20 C (68 F).

7. Heat stability of bonded metal strips cured for 7 days at 20 C (68 F) at 25 percent of the ultimate load [normally 40 kp/cm^2 (570 psi)].

In addition, information should be requested on the formulation of the binder (resin/hardener system) used to formulate the adhesive, data on creep and mechanical behavior of bonded cement mortar prisms following immersion in water.

The above suggestions might deviate somewhat from past practice. However, the important point to remember is that an adhesive must be structurally compatible with the material being bonded (i.e., the concrete).

POINTERS IN APPLYING THE ADHESIVE

These suggestions come from experiences in segmental bridge construction.

1. In the *liquid state,* the epoxy acts simultaneously as a lubricant, which facilitates joining, and as an equalization layer, which evens out irregularities.

2. In the *cured state,* the epoxy functions as a sealer to protect the post-tensioning tendons, and transmits shear forces.

Several important checks must be made and various points observed during the mixing and application of the adhesive, and during the installation of the bridge segment.

1. The condition of the surfaces to be joined must be checked.

2. The resin and hardener components of the adhesive should be supplied to the job site in closed cans.

3. Damaged cans should never be used.

4. Mixing should only be started when the element to be joined is about to be installed.

5. The adhesive mortar should be

mixed until it has a uniform color. (Resin and hardener components should be colored differently, e.g., white/black.)

6. A slow mixer should be used (about 600 revolutions per minute) so that a minimum of air is stirred in.

7. The temperature of the mix should be checked.

8. The adhesive should be applied immediately after mixing and before its pot life elapses (15 to 30 minutes).

9. The adhesive should be applied in a uniform layer and preferably to both concrete surfaces.

10. The surfaces around the cable ducts should be left sufficiently free so that an adhesive will not be pressed into the ducts during prestressing.

11. Temporary prestressing should be done within the contact time of the adhesive (75 to 90 minutes).

12. The joint should be checked. If the right amount of adhesive has been applied, a small amount of it will be pressed out of the joint during the post-tensioning operation.

13. Preferably the same work crew should be used on the entire job.

14. The work crew should be trained carefully. They must know how to mix and apply the adhesive properly.

15. Tools should be cleaned immediately after use and the work area cleaned up.

FIELD TESTING

In general, epoxy adhesives are not field tested to the same degree as concrete materials. This is an area which the author believes needs improving. For example, to make sure that field test data are interpreted reliably, the temperature at the construction site must always be recorded.

Supervision

In general, responsibility for supervising the application of the adhesive rests with the epoxy supplier or his agent.

Preparation of test specimens

These should be prepared jointly by the epoxy supplier and the general contractor.

Conduct of tests

As a rule, the laboratory tests are carried out by an independent testing agency. The general contractor and the epoxy supplier should agree on the types of tests to be carried out and on the number of test specimens to be prepared.

What should be tested?

The following is a suggested list of items that should be tested. These suggestions are based on experiences gained during the construction of the Rio-Niteroi Bridge in Brazil.

1. Pot life of the adhesive (spot checks).

2. Condition of the concrete elements being joined.

3. Dryness of the concrete (assessed visually).

4. Mixing of the mortar and color of the ready-to-use mix. Resin and hardener components have different colors (white/black). The mixed adhesive is gray similar to concrete. By checking this mixed color visually, an incorrect mixing ratio can be detected, thus avoiding unnecessary mixing errors.

5. Application of the adhesive.

6. Preparation of specimens (prisms) to be tested for flexural strength as a function of temperature and reactivity of the adhesive. (Even more useful results are obtained if the shear strength and/or the splitting tensile strength can be determined.)

7. Joining of diagonally cut concrete cylinders or prisms (e.g., the Arizona cylinder test) for testing under axial compression.

8. Lastly, testing of the cured joints

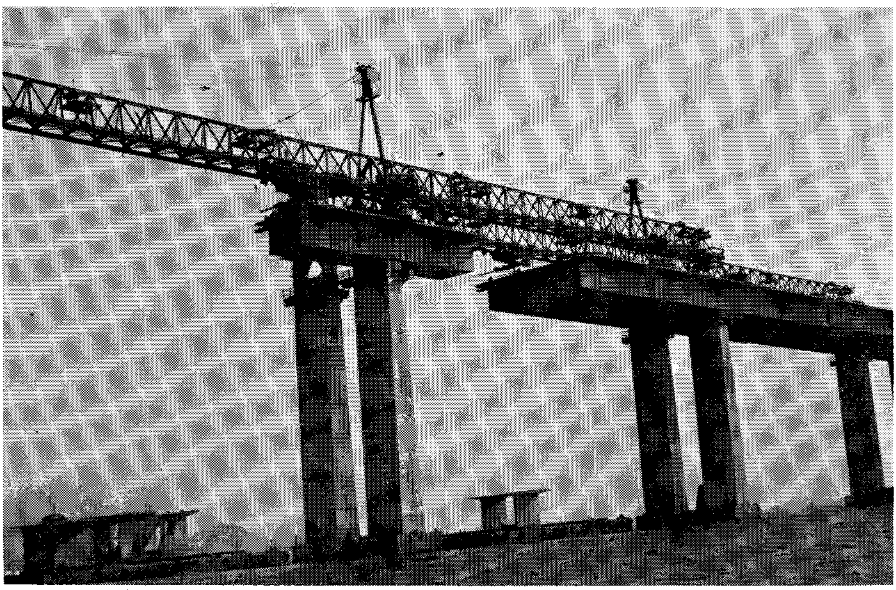


Fig. 6. Launching trusses used in construction of Rio-Niteroi Bridge (Brazil). The precast concrete segments were ferried to the site by raft and then joined together with an epoxy adhesive.

("drill cores") for crushing strength. The drilled concrete cylinders should have an axial bond line.

Finally, the test reports should be compiled and signed by both the epoxy supplier and the independent testing agency.

These reports should include data on: number of the joint, date, weather, temperature, batch number of adhesive, time period of use, flexural strength, breaking load and type of fracture of the diagonally bonded cylinders or prisms.

APPLICATIONS

The epoxy adhesives discussed in this paper have been applied successfully in many different types of concrete construction. For example, in prestressed segmental construction these epoxies are particularly advantageous in splicing the precast concrete elements together.

Segmental construction is very efficient in congested urban areas and over long stretches of water or rugged terrain. Expensive falsework is eliminated and there is minimal interference with the environment.

Two major projects (Brazil's Rio-Niteroi Bridge and Switzerland's Chillon Viaduct) are particularly significant because they showed that epoxies can be used efficiently and economically in segmental construction.

Rio-Niteroi Bridge

Brazil's Rio-Niteroi Bridge is 14 km (about 8.7 miles) long and has two 3-lane roadways. The precast concrete

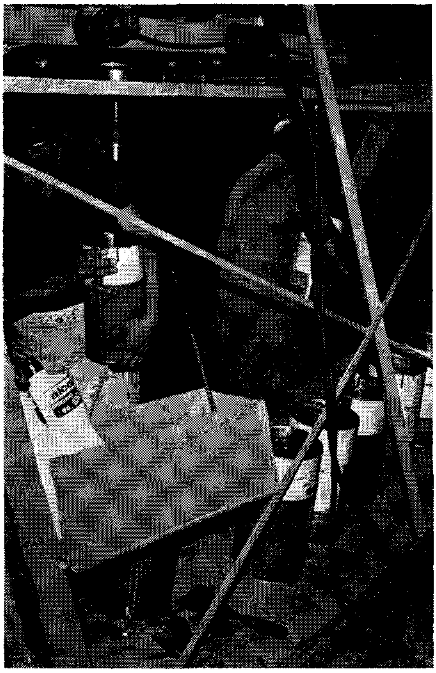


Fig. 7. Epoxy resin and hardener being readied for stirring (Rio-Niteroi Bridge, Brazil). In general, it is preferable to use a low-speed stirrer. On this job electric drill motors were mounted in line to mix six 11-lb batches of epoxy.

Fig. 8. Upended pan of thixotropic adhesive being handed to worker on deck of Rio-Niteroi Bridge (Brazil). The epoxy adhesive was applied to adjoining segment surfaces using wooden spatulas. Note post-tensioning tendon in gap at left.

segments were ferried to the site by raft from an on-shore factory. In addition to being glued together with epoxy adhesive, the segments were post-tensioned longitudinally. Subsequently, the parallel bridge decks were coupled using transverse post-tensioning. The bridge was finished in about 18 months.

Fig. 6 shows the two steel launching trusses used in the construction of the Rio-Niteroi Bridge. These launching trusses were employed in transporting and adjusting the segments into position.

Prior to application the epoxy adhesive must be mixed. In general, the epoxy resin and hardener are best mixed with a low-speed stirrer. On the Rio-Niteroi job, the electric drill motors were mounted in line to mix six 5 kg (11 lb.) batches of epoxy (see Fig. 7).

Fig. 8 shows a construction man handing over an upended pan of thixotropic adhesive to his partner on the deck of the Rio-Niteroi Bridge. To his left, in the gap, can be seen a post-tensioning tendon.

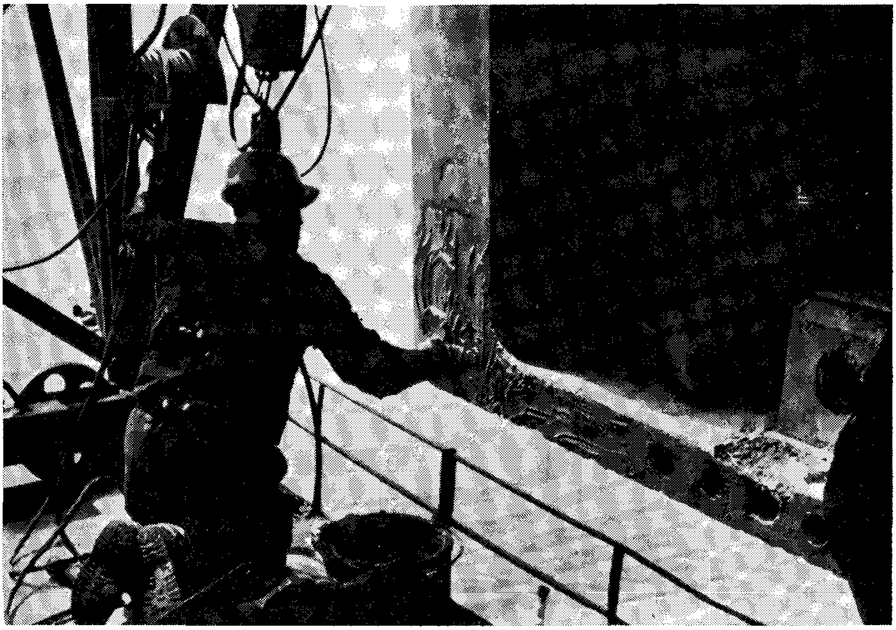


Fig. 9. Manual application of epoxy adhesive on precast concrete segment (Chillon Viaduct, Switzerland). On an average it takes about 30 minutes using two men to complete the epoxy coating and initial post-tensioning operation.

The epoxy adhesive was applied to adjoining segment surfaces with wooden spatulas. During this operation the adjoining segments are about 30 to 40 cm (approx. 12 to 16 in.) apart.

In general, only two men are required to apply the epoxy. However, on the Rio-Niteroi job, two men were employed on the deck and four to six men inside the segment. It took about 45 mintes per segment to mix and apply the epoxy (including the initial post-tensioning operation). However, on other jobs this time has been somewhat reduced.

Chillon Viaduct

The other noteworthy project using epoxy bonded segments is Switzerland's Chillon Viaduct, located near the historic Chillon Castle. In such a scenic setting it was important to leave the natural environment unscathed. Segmental construction proved to be an ideal mode of erection.

Fig. 9 shows a construction man, on a finished deck, manually applying an epoxy adhesive to a new segment as it is gradually lowered into place. On the Chillon job, the mixing and application of the epoxy (including the initial post-tensioning) took about 30 minutes.

In Fig. 10 the adhesive has been applied to the far side of the segment. Simultaneously, the tendons and stressing equipment are being readied for the initial post-tensioning operation.

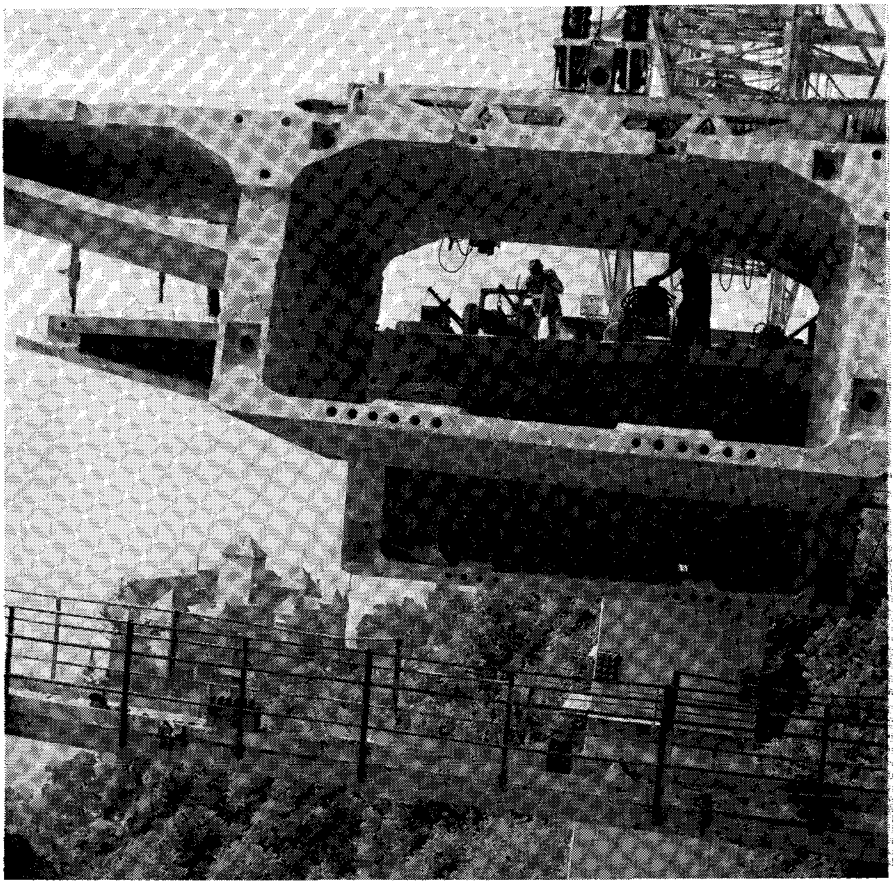


Fig. 10. Dramatic shot of precast concrete segment being lowered into position just after the epoxy adhesive was applied to the far side of the segment (Chillon Viaduct, Switzerland). In the background one can see the famous Chillon Castle.

TECHNICAL INQUIRIES

Technical inquiries within North America regarding the epoxies discussed in this paper should be directed to:

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