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16. Abstract

This report presents the general requirements for epoxy resins for jointing segmentally constructed prestressed concrete bridges using the cantilever erection method. The report outlines the main function of the epoxy resin material in this type structure, and discusses the development of specific performance requirements for the epoxy resins. Simple test methods and jointing conditions for evaluation of the suitability of epoxy resins for this specific application are suggested.

The report summarizes the results of acceptance tests on nine epoxy resin materials submitted by various manufacturers and formulators for consideration for use in a laboratory model and a field structure constructed of precast segments using the cantilever erection procedures. Information on pot life, flexural jointing strength, shear jointing strength, and rate of strength development are included. Experience with the materials submitted for exploratory testing indicates that no fully satisfactory material which met all of the original specifications was found in the program. However, a number of promising materials were identified which could be used with waiver of some parts of the specification. The critical surface condition in evaluation of the jointing capacity was the saturated but surface dry condition. A number of the materials tested would be suitable if used under the completely dry surface condition.

Test results indicated the importance of proper surface preparation and particularly the removal of all traces of oil from the surface of the specimens to be jointed. The report includes a recommendation in detailed specification form for epoxy resin material and jointing procedures for this construction application.

17. Key Words

design, construction, prestressed concrete bridges, epoxy resins, acceptance test procedures, jointing

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# EPOXY RESINS FOR JOINTING SEGMENTALLY CONSTRUCTED PRESTRESSED CONCRETE BRIDGES

by

S. Kashima and J. E. Breen

Research Report 121-2

Project 3-5-69-121
Design Procedures for Long Span Prestressed Concrete
Bridges of Segmental Consturction

Conducted for

The Texas Highway Department

In Cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by

CENTER FOR HIGHWAY RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

August 1974

# PREFACE

This report is the second in a series which summarizes a detailed investigation of the various problems associated with formulation of design and construction procedures for long span prestressed concrete bridges of precast segmental construction. The initial report in the series summarized the general state of the art for design and construction of this type bridge as of May 1969. This report presents a summary of the various acceptance test procedures used to evaluate the basic properties of epoxy resin materials for jointing the large precast concrete segments and provides information on the effect of typical field variable conditions on the behavior of the joints. Structural performance data for the overall structure with the epoxy joints will be presented in a subsequent report.

This work is a part of Research Project 3-5-69-121, entitled "Design Procedures for Long Span Prestressed Concrete Bridges of Segmental Construction." The studies described here were conducted as a part of the overall research program at The University of Texas Center for Highway Research. The work was sponsored jointly by the Texas Highway Department and the Federal Highway Administration under an agreement with The University of Texas at Austin and the Texas Highway Department.

Liaison with the Texas Highway Department was maintained through the contact representative, Mr. Robert L. Reed, and the State Bridge Engineer, Mr. Wayne Henneberger; Mr. D. E. Harley and Mr. Robert E. Stanford were the contact representatives for the Federal Highway Administration. The authors were particularly appreciative of the interest and assistance of Mr. Donald O'Connor of the Materials and Test Division of the Texas Highway Department.

The overall study was directed by Dr. John E. Breen, Professor of Civil Engineering, and Dr. Ned H. Burns, Professor of Civil Engineering. The "epoxy jointing" phase was the overall responsibility of Dr. Satoshi Kashima, Research Engineer, Center for Highway Research.

# SUMMARY

This report presents the general requirements for epoxy resins for jointing segmentally constructed prestressed concrete bridges using the cantilever erection method. The report outlines the main function of the epoxy resin material in this type structure, and discusses the development of specific performance requirements for the epoxy resins. Simple test methods and jointing conditions for evaluation of the suitability of epoxy resins for this specific application are suggested.

The report summarizes the results of acceptance tests on nine epoxy resin materials submitted by various manufacturers and formulators for consideration for use in a laboratory model and a field structure constructed of precast segments using the cantilever erection procedures. Information on pot life, flexural jointing strength, shear jointing strength, and rate of strength development are included. Experience with the materials submitted for exploratory testing indicates that no fully satisfactory material which met all of the original specifications was found in the program. However, a number of promising materials were identified which could be used with waiver of some parts of the specification. The critical surface condition in evaluation of the jointing capacity was the saturated but surface dry condition. A number of the materials tested would be suitable if used under the completely dry surface condition.

Test results indicated the importance of proper surface preparation and particularly the removal of all traces of oil from the surface of the specimens to be joined. The report includes a recommendation in detailed specification form for epoxy resin material and jointing procedures for this construction application.

# IMPLEMENTATION

This study clarifies the performance requirements for epoxy resin jointing in segmentally constructed prestressed concrete box girder bridges. It indicates that some of the provisions used in the specifications for epoxy resin materials in construction of the segmental bridge at Corpus Christi need revision and a new specification is suggested. Several unnecessarily restrictive requirements have been deleted and the specification has been amplified to better reflect performance requirements and improve quality control.

A number of specific methods of test are suggested for evaluating the adequacy of the epoxy resin joints for this application. No attempt is made to specify the chemical constituents or formulations for products. The use of the guideline specification included in the final recommendations of the report should result in a better understanding of the epoxy requirements by the epoxy supplier and result in fewer unacceptable materials being submitted for evaluation for possible use in this type project. The reported results of the exploratory tests of a number of materials submitted for consideration in connection with this project provide considerable insight as to the most critical test conditions and indicate the importance of surface condition at the time of jointing. The results indicate the need for careful acceptance testing of epoxy resins for this construction procedure and the report should be very informative to field personnel in highlighting what can cause difficulty in securing proper jointing in this construction method.

Since the testing program reported on was essentially an exploratory one in connection with the first specific application of epoxy resins for this jointing procedure in the State of Texas, further evaluation of important effects such as that of temperature on rate of curing, pot life, and jointing efficiency need further investigation. In addition, complete development of the specification for this application should consider some methods of testing for long term resistance to weathering, temperature stability, and creep.

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# CHAPTER 1

# INTRODUCTION

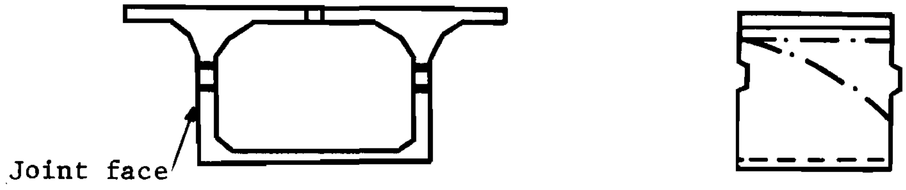
## 1.1 General

A construction technique which is attracting considerable interest in the United States is the cantilever construction of precast prestressed concrete box girder bridges. Many bridges have been constructed in foreign countries utilizing this technique and the first U.S. bridge of this type was completed in Corpus Christi, Texas, in 1973. Figure 1.1 shows the general construction scheme which uses precast segments cantilevering from a supporting pier.

Prior to 1963, cast-in-place concrete or mortar was generally used for the joints between units.[1] However, in 1963 the French[1] successfully used epoxy resins as the joint material in such bridges. The use of such epoxy resin joints has greatly shortened the construction period in the cantilever construction method. Since 1963, many additional segmental box girder bridges were constructed in France, Switzerland, Japan, and Russia using epoxy resins for the joint material.[1]

Throughout the world, epoxies have been used in various ways in concrete bridges.[1,3,4] In the United States epoxy resin has been used since 1955 in highway pavements as a crack and joint sealer, and in connection with composite bridges as a shear connector.[5] Epoxy resin was used to join 23 large concrete pontoons into a floating bridge across the Hood Canal, Washington, in 1961.[6]

While a number of guides and design specifications have been developed for the proper use of epoxy resins with both cast-in-place and precast concrete,[5,7] no specific guidance is available for the uses of epoxy resins in this application. The designer counts on the epoxy resin joint to be as



Precast segment

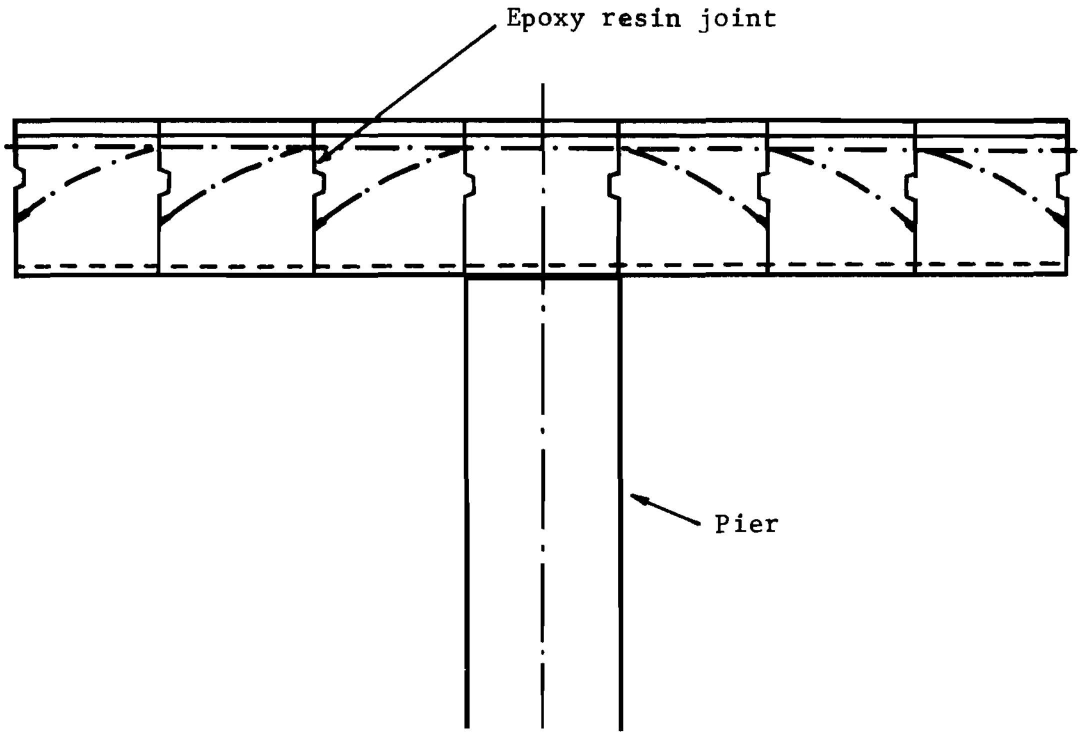


Fig. 1.1. Construction of a segmental precast concrete bridge by the cantilever construction method.

strong as the nonreinforced concrete immediately adjacent to the joint and implicit in the design assumption is that the joint between segments will not cause a plane of weakness in the structure.[4,8] Furthermore, in segmentally constructed structures in corrosive environments, the designer counts on the epoxy resin to provide a permanent joint sealant to minimize corrosion danger to the tendons. On the other hand, the constructor is most concerned with the epoxy resin in its fluid form when it serves as a lubricant between segments during the fitting process and as a medium for filling up unwanted voids and surface flaws on the jointing faces. The constructor is interested in a material which will be simple to apply, and tolerant of the time demands of the construction process.

## 1.2 Objectives

Precast concrete segmental construction methods have been widely used throughout the world to minimize both labor costs and time required for field construction, as well as to obtain a structure which has an overall higher quality. The Texas Highway Department, in planning to construct several such prestressed concrete segmental box girder bridges using epoxy resin joints, recognized that the use of such joint techniques was not well-developed in the United States. Therefore, prior to initiating the proposed construction, it was felt necessary to study typical epoxy resin joint properties under various conditions, in order to develop guideline specifications and provide a basis for selecting a suitable epoxy resin for such jointing applications. The overall development included a one-sixth scale model test of a complete segmental bridge structure. It was a further objective to select an epoxy for construction of this model.

In order to develop inclusive specifications, consideration was given both to the requirements of the structural designer and the probable factors that might affect epoxy resin joint performance in typical field applications. The following types of information were required:

(a) Time of hardening and strength development--Since one of the fundamental advantages of epoxy resin as a jointing material as compared to concrete or mortar joints is its quick hardening, permitting rapid construction, it was desirable to obtain information concerning both the pot life (or time that the material stiffens beyond the workable state in its mixing container) and the time required for development of the adhesive bond strength between units.

(b) Epoxy resin tensile strength--As a simple index for immediate assessment of epoxy resin strength, the basic tensile strength of the material was of interest.

(c) Flexural and shear strength of the joined concrete specimens--Although the design criteria adopted for the prototype structure prohibited direct tensile stresses across the joints, it was obvious that due to minor variations in construction procedures it would be possible on occasion to have minimal tensile stresses on portions of some joints. Therefore, it was felt necessary to develop an epoxy resin joint which was essentially as strong as plain concrete in both flexure and shear. Particularly in regions where maximum shear and maximum moment can occur simultaneously (near the piers), there could be a possibility of an early shear failure as the flexural cracks extend if the segments are constructed with dry or weak joints. Epoxy resin joints should substantially increase the capacity of the cracking moment at the joints and equalize it with those of the surrounding sections and, hence, distribute the cracking which might form under overloading. The ideal condition would be for any cracking to distribute as a random function along the segment, indicating both high strength and bond of the jointing material and adequate grouting of the tendons.

(d) Ease of mixing and application--Since the type of application envisioned calls for mixing and coating of essentially vertical surfaces under field conditions, it was important that relatively simple methods of preparation be required and that the materials be able to stand without severe running or sagging on vertical surfaces.

(e) Field conditions--In the practical use of the epoxy resin as a jointing method in segmentally precast box girders, several special conditions exist which could have an adverse effect on epoxy resin joint performance. Such conditions which must be considered include:

(1) In match casting of precast units in the yard, some type of bond releasing agent has to be used on the surface of the previously cast concrete segment prior to casting a new segment against it.

(2) With the prevalence of oil as a form release agent in many casting yards, the possibility of oil being put on the end forms prior to casting must be considered.

(3) Since, in this particular application, the precast segments were to be shipped by barge from the casting yard to the construction site, and at all times were exposed to the weather, the possibility exists that the precast segments may be close to saturated at the time of erection, in spite of the fact that the surfaces may have been dried.

The basic objectives of the study were to develop information relating to all of the above factors, to develop a set of guideline specifications which would ensure reasonable epoxy joint performance, and to look at a cross section of then available epoxy resin formulations to see how they met the general guidelines developed.

## 1.3 Scope of the Study

Since the evaluation program for the epoxy resin jointing materials was a minor subprogram contained in an overall research program focusing on design and construction requirements for segmentally precast concrete box girder bridges, the study scope was limited to basic procedures which would be useful in developing guidelines in selecting materials for use with the model and prototype structures. Thus, the study was not structured along repetitive statistical lines, but rather consisted of a series of exploratory probes to determine useful information to allow decision-making in the main program.

The study consisted of two basic phases:

(a) Initial study. In the early stages of the study, letters were sent to principal manufacturers and formulators of epoxy resins in the United States, requesting that they furnish information and samples of suitable epoxy resins for jointing precast concrete segments. Main requirements of a Japanese Tentative Standard for Epoxy Resin for Precast Concrete Segmental Construction[2] were furnished as a guideline to outline the general requirements of the epoxy resins (see Appendix A). Most of the manufacturers either did not respond or indicated that they did not have materials which would meet these requirements. Two companies responded with epoxy resin samples which they certified should meet the Japanese standard. One of these epoxies was stated to have been used in Japan under the standard.

A complete series of tension, flexure, shear, and pot life tests was done to evaluate the properties of these two epoxy resins under the conditions expected during the construction of the bridge. Neither of the materials met the requirements of the Japanese standard, but the results were useful in fully illustrating the various problems associated with this type of jointing procedure.

(b) Operational series. From the experience obtained in the initial series, consideration of the properties desired by the designer, and indications from U.S. manufacturers as to what might be obtainable, a set of specifications was developed in consultation with materials specialists of the Texas Highway Department and was made a part of the specifications for the prototype project in Corpus Christi (see Appendix B). Copies of these specifications were sent to numerous manufacturers and formulators. Those interested in furnishing material for use in the one-sixth scale model and the full scale bridge in Corpus Christi were invited to send samples for acceptance testing. An additional seven epoxy resins were obtained from various sources. All manufacturers or formulators indicated that the resins as submitted should meet the project specifications. A series of evaluation tests was carried out on these epoxy resin samples. Experience from the earlier series had indicated that several of the tests were by far the most critical and discriminating and most of the epoxy resins were evaluated only under these selected methods of tests. The most promising material was selected for construction of the laboratory model structure and additional tests were carried out with this epoxy to indicate its tolerance to field conditions and to illustrate the effect of potential misapplications on the strength of the joint.

This report covers results of both phases and illustrates the wide variability between commercial products in this important area.

# CHAPTER 2

# TEST PROCEDURES

## 2.1 Introduction

In the initial phase of the study considerable reliance was placed on the Japanese Prestressed Concrete Institute's recommendation[2] for adhesive requirements for this type of construction. A summary of these recommendations is given in Appendix A. It became immediately apparent that this set of recommendations was incomplete in that the requirements dealt largely with fundamental properties of the epoxy resins and did not deal sufficiently with tests of the epoxy resin as a jointing material for concrete specimens. Hence, in addition to many of the specific requirements given in Appendix A, a set of test procedures was developed to provide information on properties of the epoxy resins under the conditions expected during the construction of a typical bridge. Two concrete blocks were joined for a flexural test specimen and three blocks were joined for a shear test specimen, using the epoxy resin. The joined segments were then lightly prestressed (about 70 psi) using 3/8 in. strands inserted through the center holes cast in the blocks to spread the epoxy resin uniformly and obtain a firm fit between the segments. The level of prestress chosen represented the approximate general lower limit of stresses calculated on portions of the cross sections during most erection sequences. The strands were removed before conducting the loading tests. Various special conditions at the time of jointing were replicated in the casting and preparation of the concrete specimens.

## 2.2 Materials

2.2.1 Concrete. Since the main purpose of these tests was to determine the maximum strength of the epoxy resin joints when joining precast concrete specimens, the concrete mix was designed to produce a slightly higher strength than required for ordinary prestressed concrete construction. The 28-day design compressive strength of the mix was 7500 psi. The concrete mix design is given in Table 2.1. Actual compressive strengths ranged from 6700 to 8300 psi.

TABLE 2.1 CONCRETE MIX DESIGN

| | | |
|---|---|---|
| Design Strength | | 7500 psi |
| Cement: Type III portland cement | | |
| Coarse aggregate: Colorado River gravel | | |
| Maximum coarse aggregate - 3/4 in. | | |
| Specific gravity | 2.65 | |
| Fineness modulus | 7.40 | |
| Fine aggregate: Colorado River sand | | |
| Specific gravity | 2.60 | |
| Fineness modulus | 2.51 | |
| Slump | | 1.5-2.0 in. |
| W/C (by weight) | | 37% |
| Water | | 293 lb/cu.yd. |
| Cement | | 790 lb/cu.yd. |
| Coarse aggregate | | 1880 lb/cu.yd. |
| Fine aggregate | | 995 lb/cu.yd. |

2.2.2 Resins and Hardeners. In December 1969 contacts were made with a number of major U.S. suppliers of epoxy resins to determine availability of products suitable for jointing segmentally cast bridge units. The manufacturers and distributors were sent a copy of the tentative Japanese standards, as well as a description of the proposed method of application. Responses from several of these companies indicated that they were fully aware that such products had been used in Europe and Japan, but had relatively little direct experience with the specific formulations used. A number of the companies promised to either obtain formulations that were currently being used in Europe and Japan from their overseas affiliates, or suggest products that would appear to meet the Japanese specifications.

Through the early part of 1970, considerable discussion ensued with representatives of several firms regarding availability of possible products. In general, it seemed that the manufacturers either were unable to get the specific formulations used by their overseas affiliates or did not feel that there would be sufficient quantities of materials used in this application to justify needed research and development studies. Finally, in late 1970, a quantity of material was obtained directly from Japan, and was certified to have met the Japanese standards. Very shortly thereafter a West Coast formulator submitted a product which he felt would meet the standards and the initial phase testing began. With completion of this test series, renewed efforts were made to interest U.S. suppliers in furnishing material for possible use in the one-sixth scale model and the prototype structure planned for construction at Corpus Christi. With the commercial application becoming more readily apparent, a number of additional suppliers began to suggest formulations which they felt would meet the special specifications developed for the Corpus Christi project. Seven additional formulations were submitted for evaluation during 1971 and 1972 and have been included in this report. A summary of the results of evaluations of the epoxy material actually used in the prototype structure is also included. Several additional materials were submitted for evaluation during 1973 and 1974, but no materials were evaluated after erection of the prototype began in late 1972. It does appear that a number of epoxy resins similar to those successfully used in Europe are currently (1974) available, but experience in this program indicates that such products should be carefully scrutinized and tested before use.

Throughout the body of the report the nine materials evaluated during the testing program and the material utilized in the prototype structure are identified by the letters A to J. These materials were:

Epoxy A - A two-part epoxy system used in segmental bridge construction in Japan.

Epoxy B - An experimental two-part epoxy system developed by a U.S. formulator for this program.

Epoxy C - An experimental three-component epoxy system with an accelerator produced by a major U.S. supplier for this program.

Epoxy D - A two-part epoxy system widely used for repair of concrete and jointing to hardened concrete.

Epoxy E - A commercially available two-part epoxy used for construction of the one-sixth scale model.

Epoxy F - A two-part epoxy system submitted by a local supplier for evaluation for use in the prototype construction.

Epoxy G - A two-part system made up by a local supplier using a formulation that was indicated by the component manufacturer to have been the same formulation as that of Epoxy A. It was submitted for evaluation for use in the prototype.

Epoxy H - A two-part epoxy system suggested by a major component manufacturer and formulated by a local supplier which was submitted for evaluation for use in the prototype.

Epoxy I - This two-part widely advertized epoxy system was submitted by a major national manufacturer for evaluation for use in the prototype. The system cans were marked "for dry surfaces".

Epoxy J - This was the actual epoxy used in the prototype construction at Corpus Christi and tested by the Texas Highway Department Materials and Test Division. The two-part epoxy system was formulated by a local supplier.

All systems, with the exception of Epoxy D, were furnished by commerical suppliers after receiving descriptive material on the construction process and copies of either tentative guideline specifications, the Japanese Standard of Appendix A, or the Texas Highway Department Specification of Appendix B. All suppliers indicated the product submitted would "exceed" requirements.

## 2.3 Epoxy Application and Curing

2.3.1 Mixing Procedure. Mixing of epoxy resins was based on weight or volume according to the manufacturer's instructions. After putting the proper proportions of resin and hardener as specified by the supplier in the bowl, they were mixed by the power mixer shown in Fig. 2.1. Ma~~x~~chine mixing gives more consistent results than handmixing.[1] The mixer speed was from 80 to 100 rpm. The resins and hardeners were mixed until they became a uniform color which ordinarily took from 4 to 6 min. of mixing. Typical mix sample sizes were 3 lbs.

2.3.2 Application. The scrapers used for applying the epoxy resin to the end of the blocks are shown in Fig. 2.2. A thin layer of epoxy resin with a thickness of 0.025 to 0.035 in. was put on both of the faces to be joined. It usually took 30 min. to complete jointing of six specimens, including stressing operations.

The specimens used in this study had a centerhole for insertion of the prestressing strands. The epoxy resin would get into this hole when epoxy was applied over the whole surface. Preliminary tests indicated the area shown in Fig. 2.3 should be left free of epoxy resin to avoid flow into the centerhole.

2.3.3 Curing. Forms were stripped one day after casting. Concrete specimens were cured ten days in a moisture curing room (72° F and 100 percent relative humidity) and then stored in a constant temperature room (75°± 5°F and 40 ± 10 percent relative humidity) until jointing. Under ideal conditions, surface preparation was completed, epoxy resin was applied to the joint surface, and the blocks were joined to form the specimens on the 18th day after casting. In some of the later series, the blocks were older at time of jointing. For the saturated surface jointing series, specimens were immersed in a water bath for one day after the surface preparation was completed. They were removed from the water one hour prior to jointing and allowed to surface dry to a damp surface condition. After jointing, all specimens were cured ten days at room temperature (75°F and 40 ± 10 percent relative humidity) and then loaded to failure.

## 2.4 Epoxy Resin Tests

2.4.1 General. The main focus of the test program was on the behavior of joined concrete specimens, since epoxy resin suppliers

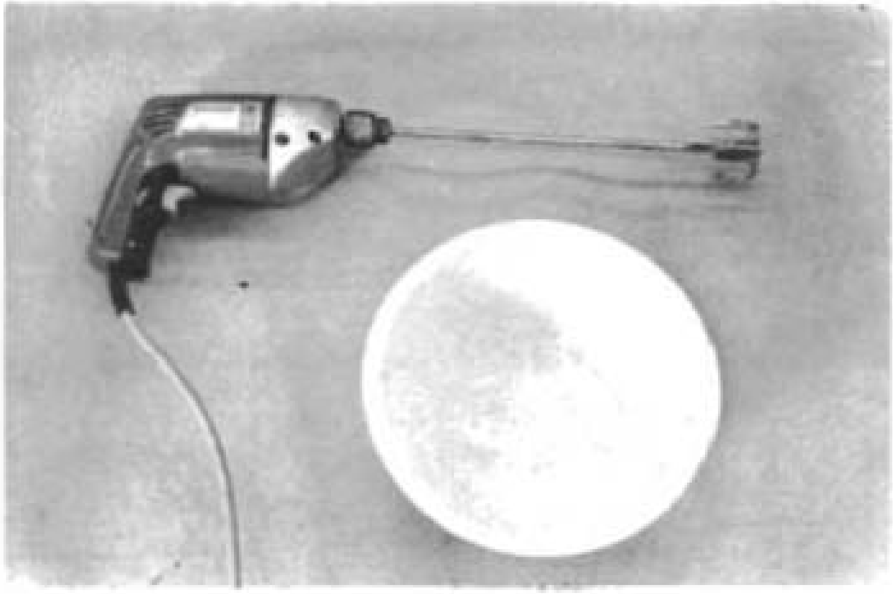


Fig. 2.1. Mixer and bowl to mix the epoxy resin.

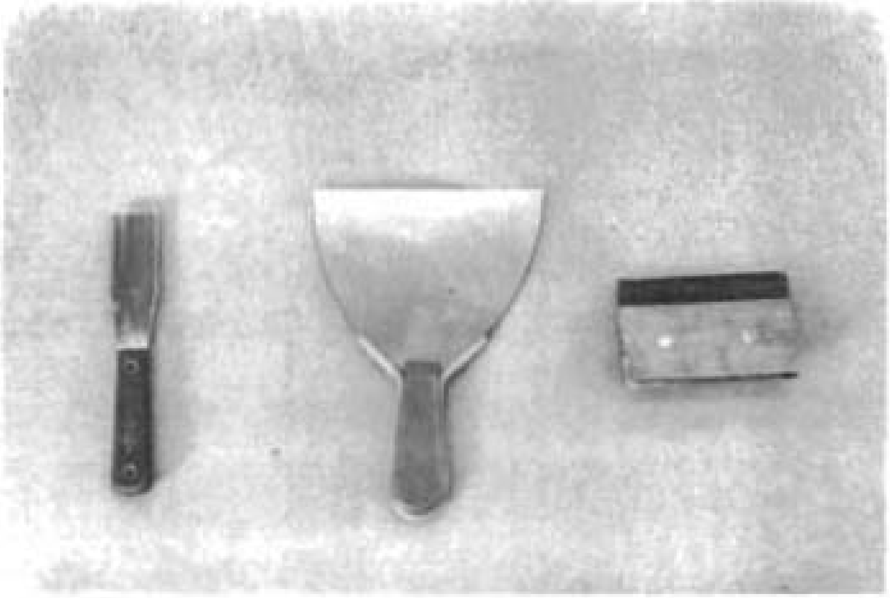
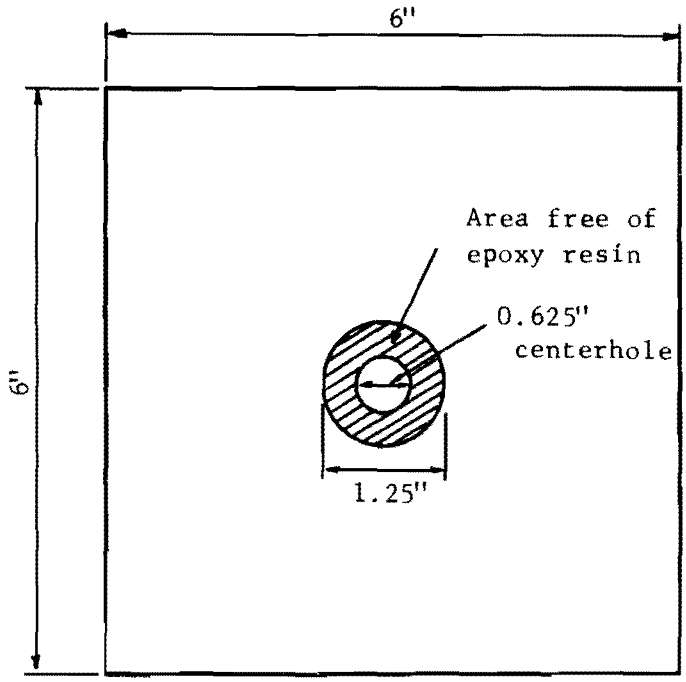


Fig. 2.2. Scrapers to apply the epoxy resin.



NOTE: Prestressing level = 70 psi

Fig. 2.3. Area free of epoxy resin at the jointing surface.

indicated that many of the properties such as pot life, viscosity, and sag characteristics could be easily altered once satisfactory bonding characteristics were obtained. However, a limited series of checks were made on epoxy resin physical characteristics. These included:

(a) Pot life
(b) Viscosity
(c) Tensile bond strength
(d) Suitability for application

2.4.2 Pot Life. Pot life of an epoxy resin is the period of time after mixing during which an adhesive remains suitable for use. It is generally considered as the time between mixing in the container and placing of the surfaces to be bonded in contact, although the primary test method (consistency) considers only the heat reinforcing characteristic case of pot life in the container. Contact time is equally important.

Two different tests for pot life of epoxy resins, as specified in ASTM D 1338-56,[9] are:

(a) Consistency Test
(b) Bond Strength Test

In carrying out the consistency test, 200ml of mixed epoxy resin were put into a 400ml heat resistant beaker. The method of test requires that consistency be checked by use of a viscosimeter at the start and end of the test. The material is then stirred by rotating a glass stirring rod (1/4 in. diameter and 7 in. long) five times at 10 min. intervals after mixing. The rotation of the stirring road was specified as one rotation per second by ASTM D 1338-56. This rotation was continued until the consistency of the epoxy resin was such that stirring at one rotation per second was impossible. The time at which the viscosity exceeded 3000 poises or the temperature of the mixture increased 30°F was noted and termed the pot life.

In carrying out the bond strength test, two tension bolt specimens were joined at 0, 30, 60, 90, and 120 min. after mixing was completed. They were tested after ten days, using the procedures outlined in Sec. 2.4.4. A graph of strength vs. jointing time after mixing was then plotted to determine the influence of pot life on the bond strength.

2.4.3 Viscosity. The viscosity of several epoxy resins was checked using a Brookfield RVT Viscosimeter (see Fig. 2.4). When used to determine pot life, viscosity was checked every 10 min. after mixing until the viscosity exceeded 300,000 cps.

2.4.4 Tensile Bond Strength. The heads of two bolts (1-1/4 in. diameter, 4-in. length) were joined together with the epoxy resin to test the epoxy resin tensile bond strength. To prevent eccentricity at the joints, the head of each bolt was machined to form a perfect circle (1-3/4 in. in diameter). Bolts were joined in a jig, as shown in Fig. 2.5. The correct alignment of the bolts was maintained by adjusting the plates vertically and horizontally prior to applying the epoxy resin on the heads of the bolts. Oil and grease on the bolt heads were completely removed with acetone prior to jointing. To keep the bolt heads from slipping until the epoxy resin hardened, excess adhesive was wiped off and the sides of the heads were taped.

To prevent damage to the threads of the tensile bolt specimens so that they could be reused in later tests, the specimens were coupled by nuts to other bolts which were then gripped by the testing machine (see Fig. 2.6). The loading test procedure followed ASTM D 2095-69.[10]

2.4.5 Suitability for Application. During all jointing operations in the hardened concrete test series, epoxy resins were observed and subjectively appraised regarding color, ease of mixing, ease of application, and tendency to sag.

## 2.5 Hardened Concrete Tests

2.5.1 General. Since the entire test program was focused on applications of epoxy resin jointing materials to jointing of precast concrete segments in post-tensioned bridges, test specimens for evaluating jointing of hardened concretes were desired which would be highly applicable to the actual use of the epoxy resins. As outlined in Sec. 1.2, sections of the prototype joints would cure under low levels of prestress and could be close to a zero axial stress condition when subjected to flexural and shear stresses. In design and analysis, it was obvious that under overload

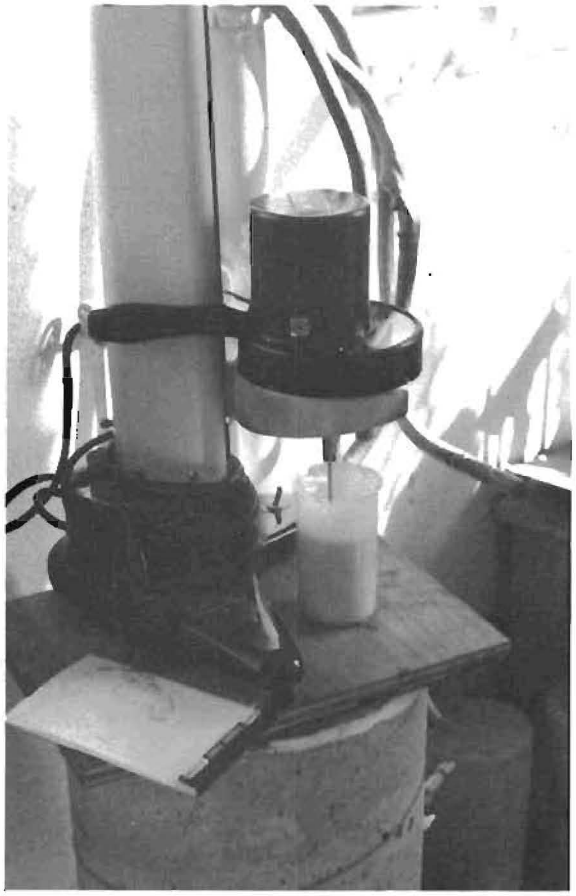


Fig. 2.4. Brookfield RVT Viscosimeter

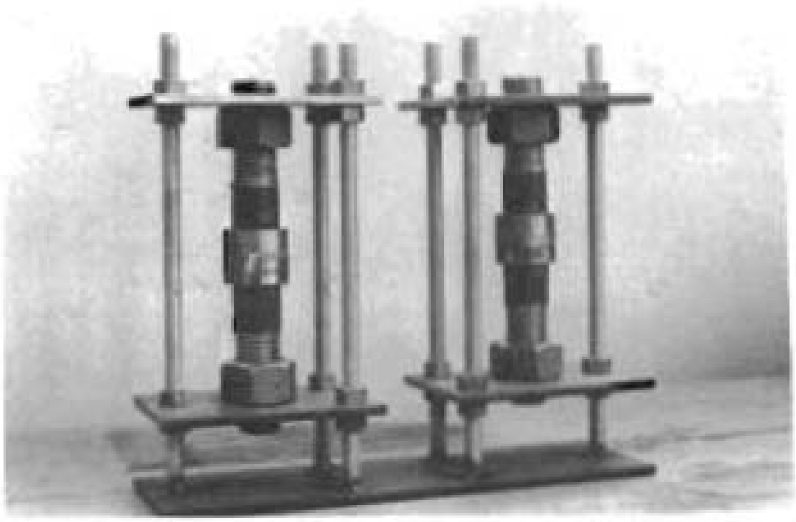


Fig. 2.5. Joining of tension test bolts.

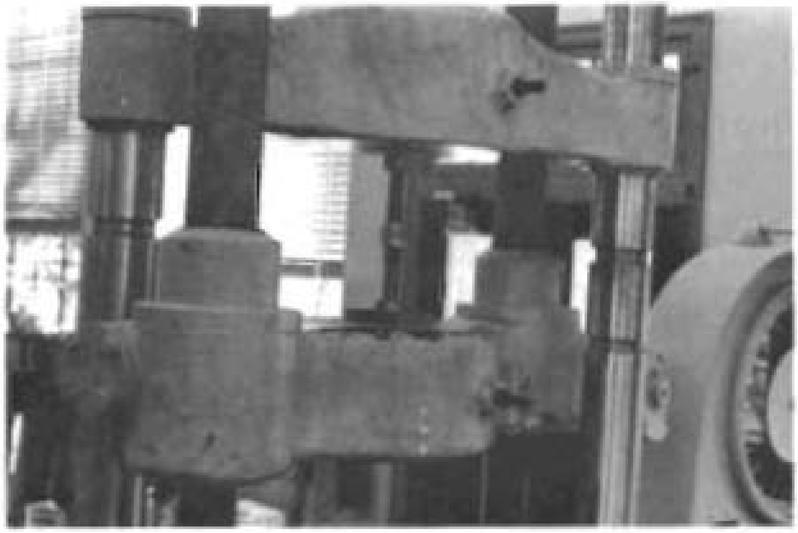


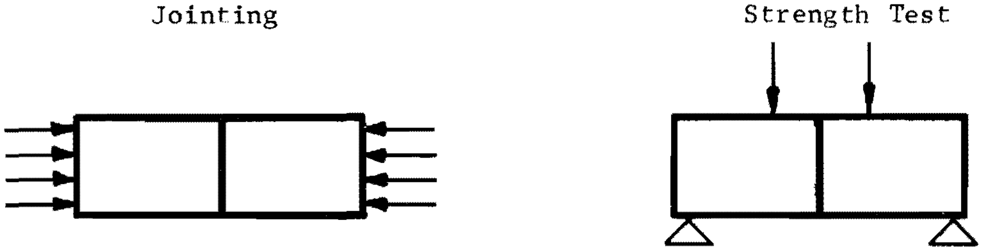
Fig. 2.6. Test setup for tension test.

conditions, substantial tensile and shear stresses could exist on portions of the prototype joint. Hence, it was decided to develop test specimens, as shown in Fig. 2.7(a) and (b), which would simulate low levels of prestress during adhesive curing but would be tested in flexure and shear without axial stress present. This would better simulate the jointing conditions and the critical loading conditions on the joint than inclined shear specimens such as shown in Fig. 2.7(c) and (d).

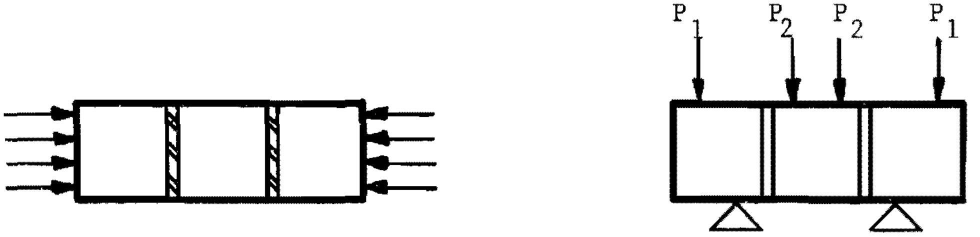
2.5.2 Flexure Test Specimen. Each specimen consists of two blocks, 6 x 6 x 11 in. (see Fig. 2.8). Steel forms for a modulus of rupture beam were used with steel plates inserted across the middle to make the two blocks 6 x 6 x 11 in. A 5/8 in. vinyl pipe covering a 1/2 in. steel rod was used to form the centerhole for the 3/8 in. prestressing strands. Since mold oil affects the bond strength of the epoxy resin and concrete, ordinary solid soap (1 part soap + 5 parts water) or a commercial bond breaking compound was put on the inside of the forms and jointing surface, except in a few tests where oil was deliberately used to evaluate degreasing procedures.

In early tests (Epoxy A and B) the specimen halves were cast simultaneously with the steel divider in place. In subsequent tests, segment (A) was cast first. The steel plate facing segment (B) was removed one day after casting and a liquid bond breaker (Thompson Bond Breaking Compound) was put on the surface, and segment (B) was cast directly against segment (A). One day after casting segment (B) the segments were easily separated. Figure 2.8 shows general form and casting details. Monolithic comparison specimens 6 in. x 6 in. x 22 in. were cast for control purposes.

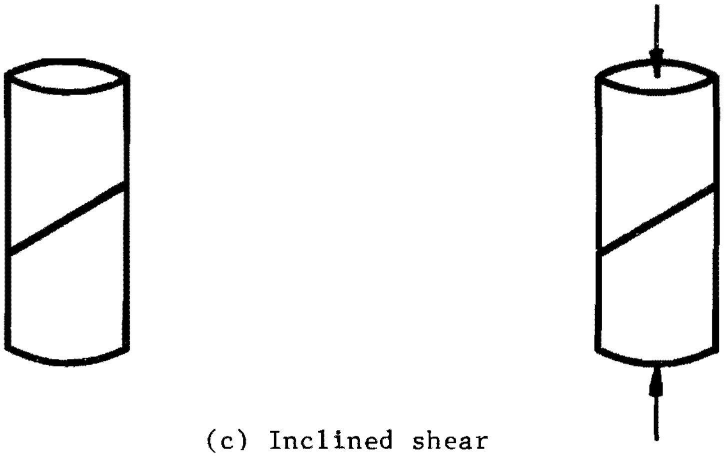
2.5.3 Flexure Test Jointing. After curing of the concrete, the jointing surfaces were cleaned with a wire brush to remove surface scale and simulate sand blasting, washed with water or steam cleaned, and wiped with acetone. Epoxy resin was applied to matching faces and the specimen was joined and prestressed. A high-strength bolt was inserted in the concentric duct and tensioned to produce a force equivalent to 70 psi axial compression on the cross section. End anchorage forces were applied



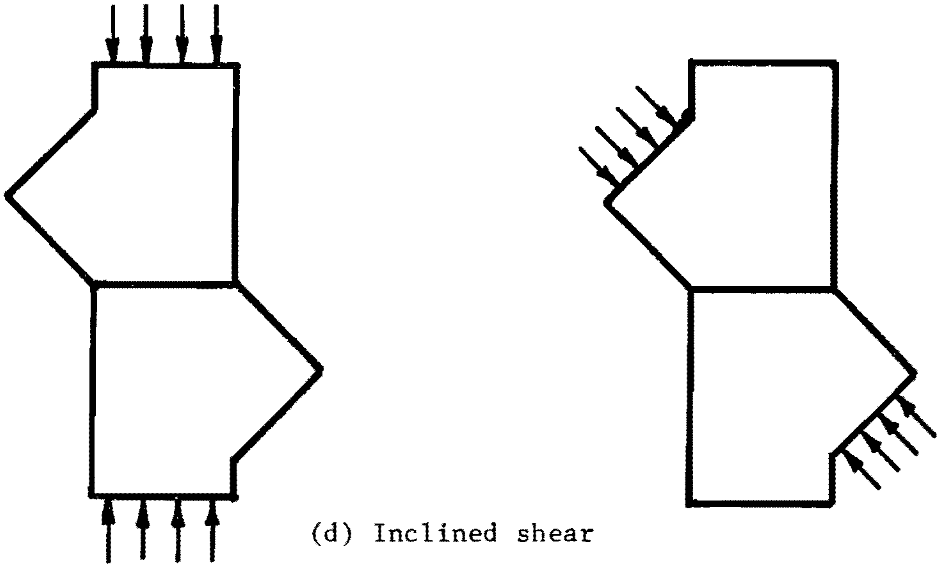
(a) Flexure



(b) Shear

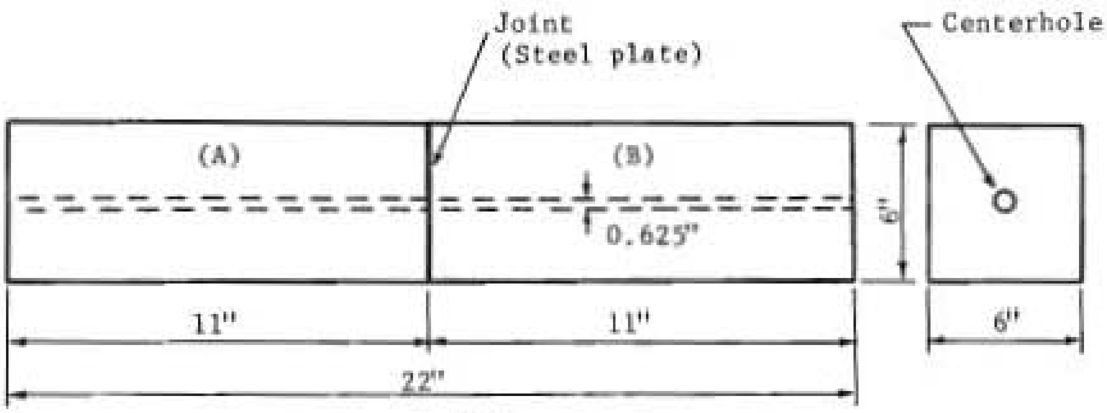


(c) Inclined shear

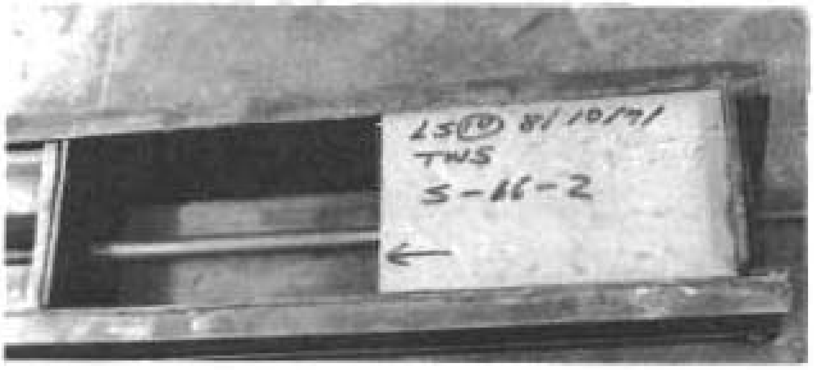


(d) Inclined shear

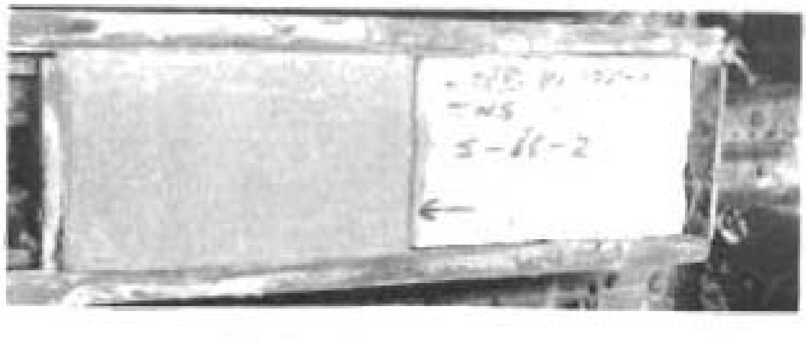
Fig. 2.7. Test specimen characteristics.



(a) Dimensions



(b) Form details



(c) Casting sequence

Fig. 2.8. Flexure test specimen.

through 4 in. x 4 in. x 1/2 in. end plates. Load levels were checked using an electronic load cell. The joined specimens were cured for ten days prior to loading tests.

2.5.4 Flexure Test Method. The prestressing tendon was removed from the specimen prior to loading. The load was applied at the third points of the specimen in accordance with ASTM C 78-64[11] (see Fig. 2.9). The bearing plates at the loading points were 3/4 in. wide, 1/4 in. thick, and 6 in. long.

The flexural strength was calculated by the equation:

$$\sigma = \frac{P\ell}{bd^2}$$

where $\sigma$ = ultimate flexural strength (psi)

$P$ = ultimate applied load indicated by the testing machine (lbs.)

$\ell$ = span length (in.)

$b$ = average width of specimen (in.)

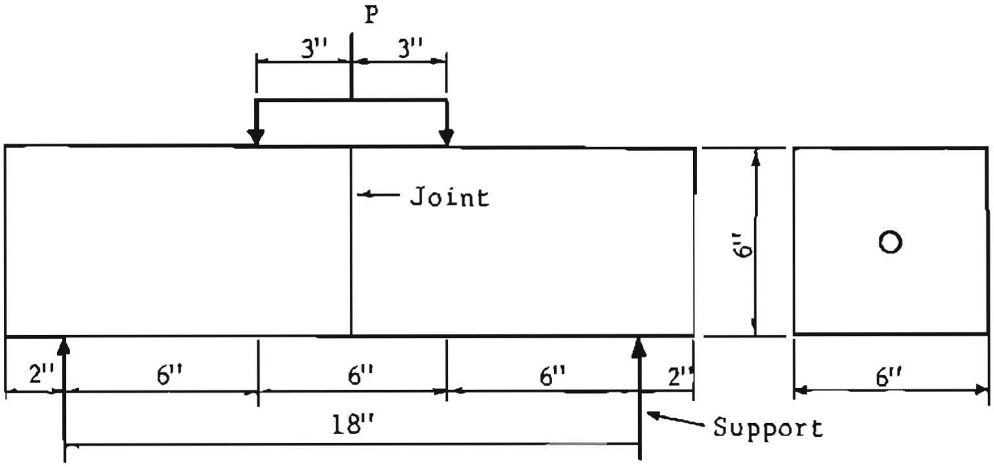
$d$ = average depth of specimen (in.)

2.5.5 Shear Test Specimen. Each specimen consisted of three blocks, 6 x 6 x 8 in., 6 x 6 x 6 in., and 6 x 6 x 8 in., as shown in Fig. 2.10. Steel forms for modulus of rupture beams with added interior steel plates were used to make three blocks as shown in Fig. 2.10(b) and (c). Other steps in the casting and joining procedures were the same as those previously described for flexure test specimens.

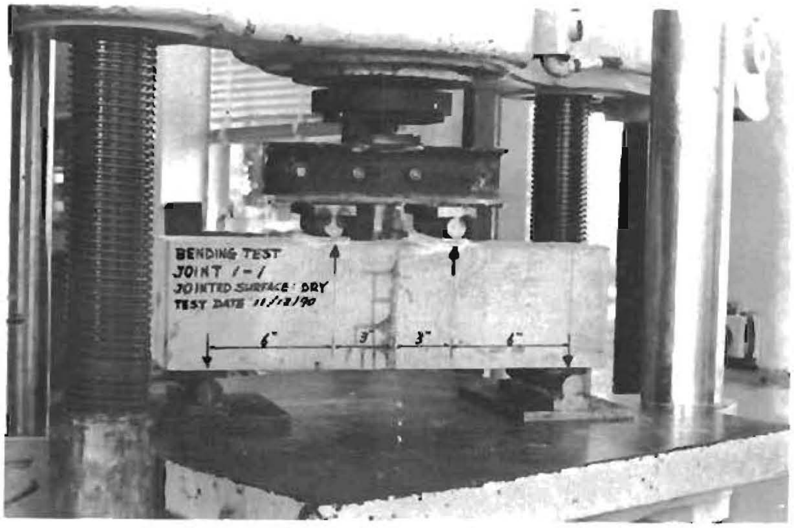
2.5.6 Shear Test Method. The prestressing tendon was removed prior to loading. Figure 2.11 shows the shear test setup.[1,8] In preliminary tests, several specimens without any joints were tested in order to determine the magnitude of lengths a, b, and c shown in Fig. 2.11. By setting a + b = 5 in., two cases which produced no moment at the joints were considered:

Case (1) a = 4 in., b = 1 in., c = 0.8 in.

Case (2) a = 4.5 in., b = 0.5 in., c = 0.45 in.

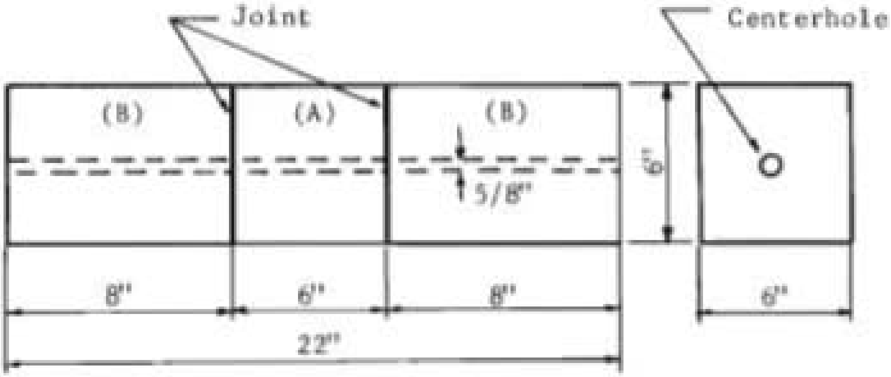


(a) Schematic



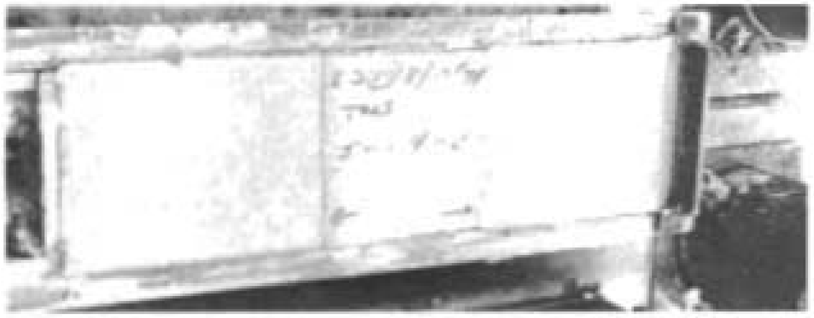
(b) Test setup

Fig. 2.9. Flexure test.



(a) Dimensions

(b) Form details



(c) Casting sequence

Fig. 2.10. Shear test specimen.

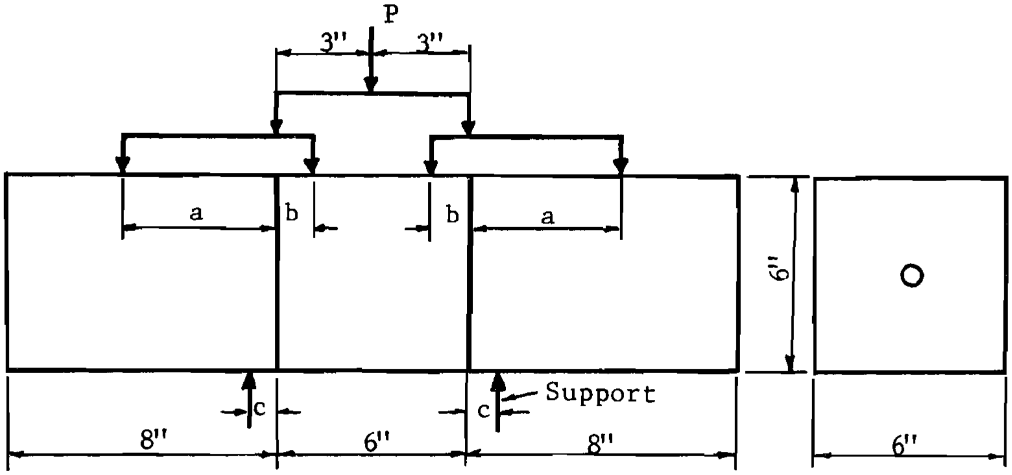


Fig. 2.11. Application of loads for shear test.

In Case (1), the specimen failed by flexure. Shear failure resulted in Case (2). Loads were applied as indicated in Case (2) for all other specimens, and the resulting shear and moment diagrams are shown in Fig. 2.12.

A load cell was used to check load distribution before the tests. The loads were applied through 1 in. diameter rollers to steel bearing plates embedded in plaster supports, because the surfaces were smooth. The bearing plates for the shear tests were 6 in. long and 1 x 1 in. (thick x wide) at the top surface and 1 x 0.9 in. at the supports. Fig. 2.13 gives a view of the test setup. The speed of loading was 0.095 in./min.

The shear strength was calculated by the equation:

$$\tau = \frac{V}{bd} = \frac{0.45P}{A}$$

where $\tau$ = ultimate shear strength (psi)
$V$ = shear force (lbs.)
$P$ = ultimate applied load indicated by the testing machine (lbs.)
$b$ = average width of specimen (in.)
$d$ = average depth of specimen (in.)
$A$ = average area of cross section of specimen (sq. in.)

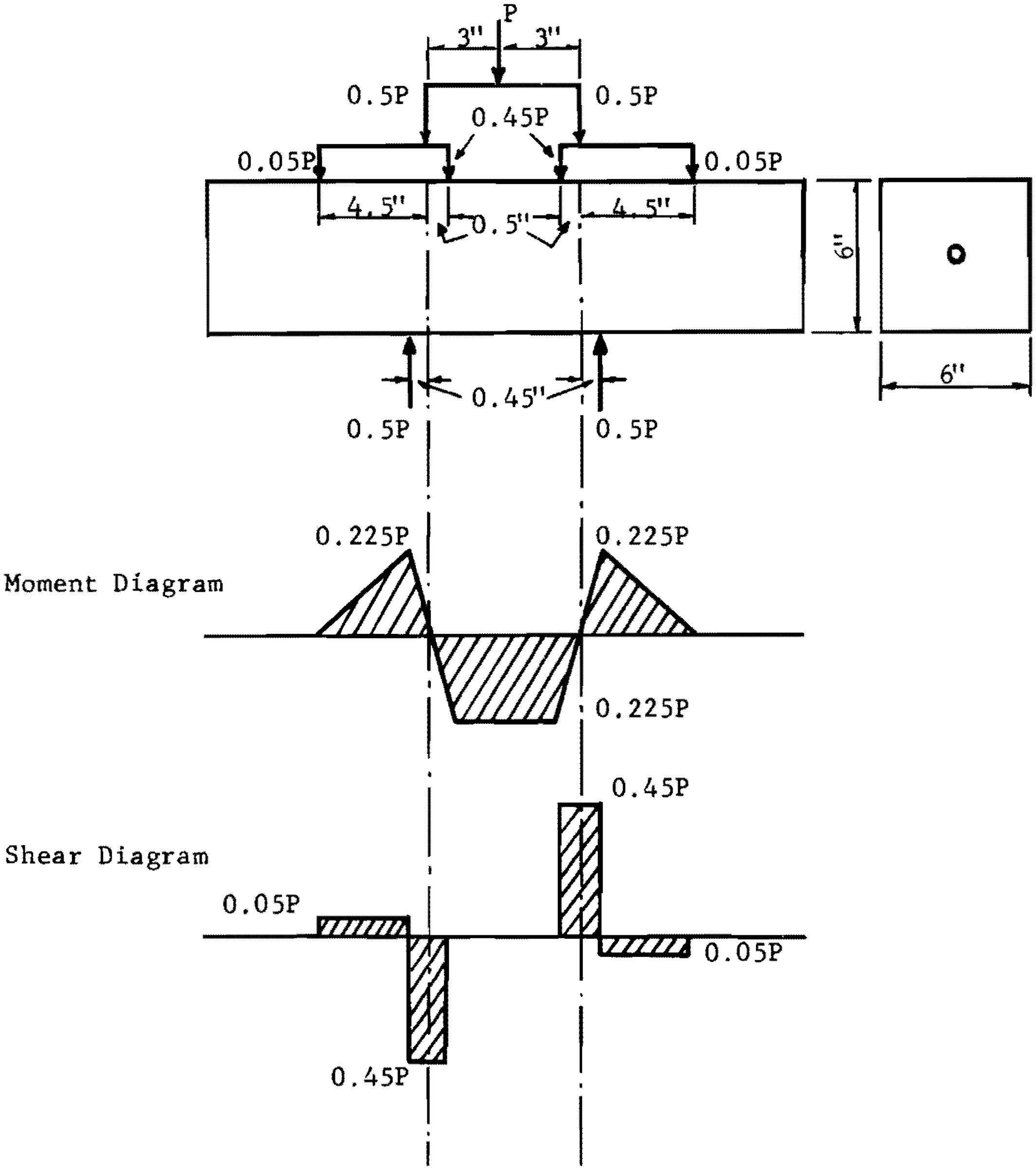


Fig. 2.12. Application of loads for shear test and moment and shear diagrams.

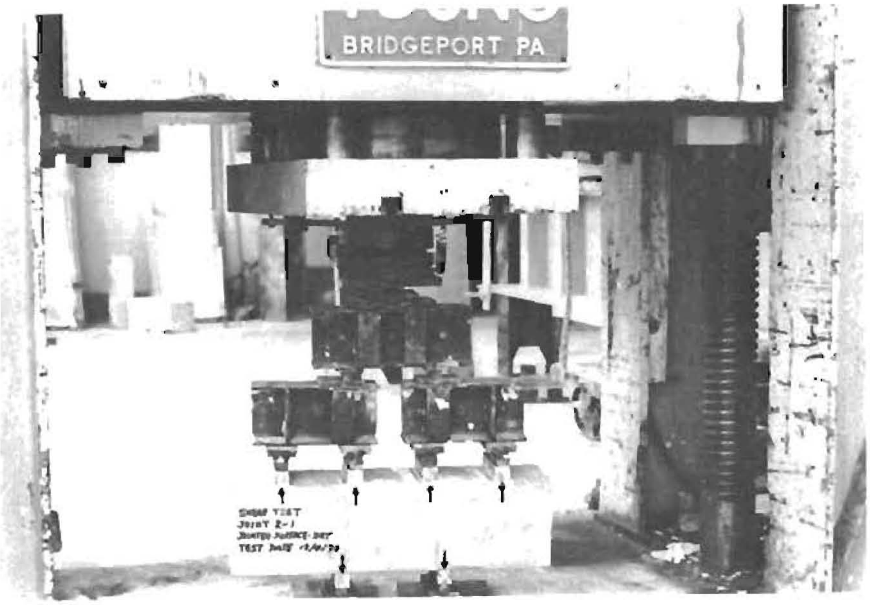


Fig. 2.13. Test setup for shear test.

2.5.7 Joint Surface Preparation. The importance of preparation of the surface to be joined has been pointed out in previous research.[4] Mold oil deposited on the jointing surface reduces the bond strength of epoxy resins. In addition the surface must be dry at the time of jointing because the strength of some epoxy resins is affected by the surface moisture.

Three different surface preparations[3,7] have been widely considered:

(a) Direct from the steel mold
(b) Wire brushed and cleaned or sand-blasted
(c) Chipping to remove the laitance and expose the aggregate

The usual surface preparation is "wire brushed and cleaned" or "sand-blasted". All joint surfaces in both the dried and wetted specimen series in these tests were wiped with acetone, wire brushed, and washed with water. In the practical usage of epoxy resins in segmental construction, several quite severe surface conditions are possible and even probable. These conditions include: (1) some bond releasing agent has to be used on the surface of the hardened concrete segment prior to casting a new segment against it, (2) oil or grease may be inadvertently put on some portions of the end form or on the segment faces prior or subsequent to casting, or (3) the precast segments may be wet at the time of construction due to rain or spray. These conditions were explored in selecting a proper epoxy resin.

Because of limited time and the large number of products submitted for evaluation, the number of tests run was minimized. The effect of oil and moisture conditions were evaluated by flexural tests only, since the effect of these variables on both flexural and shear strength was found to be essentially the same in the initial series.

Surface conditions at time of jointing used in the tests of hardened concrete were:

(1) Monolithic - No joint in specimens used for control reference in each series.

(2) Dry, soap - Soap was applied to the form end surface before casting segments (A) and (B). Specimens were dry at time of jointing.

(3) Saturated, soap - Same as (2) except specimens were put in a water bath for 24 hours and removed one hour prior to jointing.

(4) Dry, no oil - Bond breaking compound was put on the form prior to casting segment (A). The compound was also applied to the concrete surfaces of segment (A) which the concrete for segment (B) were cast against. Specimens were dry at time of jointing.

(5) Dry, oil - A light coat of machine oil was put on the form end surfaces prior to casting segment (A). Bond breaking compound was then applied to end surfaces of segment (A) after the forms were removed, and prior to casting of segment (B). Specimens were steam cleaned one to three days before jointing, but were dry at time of jointing.

(6) Saturated, no oil - Same as (4) except specimens were put in a water bath for 24 hours and removed one hour prior to jointing.

# CHAPTER 3

# TEST RESULTS

## 3.1 Epoxy Pot Life

Epoxy resin pot life was generally determined by consistency tests. It is not generally sufficient to define the pot life of epoxy resins at a constant temperature because the pot life can be greatly influenced by the temperature. However, since this program had an initial or exploratory character for selection of materials to be used in both a laboratory model and a field prototype where extreme temperatures were not expected, all pot life tests were performed under constant temperature ($75^o \pm 3^oF$).

Two different tests for pot life of epoxy resins are specified in ASTM D 1338-56[9] as

(1) Consistency Test
(2) Bond Strength Test

The consistency or viscosity tests tend to indicate the time required for stiffening of the material in the mixing container, while the bond strength test indicates the effective life of the material from tests of thin joints. Both are important concepts. However, the consistency test is simple and immediate, while the bond strength test does not yield available results for a period of ten days and, hence, is more complicated.

In the initial phase tests with Epoxies (A) and (B), pot life was compared on the basis of the beaker consistency tests with measurement of viscosity of the material at a series of time increments after mixing, and on the basis of tension bond strength tests. Results of the viscosity tests using the Brookfield Viscosimeter indicated the acceptable consistency at pot life is the simpler ASTM D 1338-56 test. In subsequent tests, epoxy resin was mixed in the beaker and consistency was checked by rotating the glass rod at prescribed intervals until the limit consistency was observed when regular rotation became almost impossible or the mixture temperature increased 30°F. Results of the pot life tests for all materials are given in Table 3.1.

TABLE 3.1. POT LIFE AS DETERMINED BY ASTM D 1338-56 CONSISTENCY TEST

| Epoxy | | Pot Life (Minutes) |
|---|---|---|
| A | | 110 |
| B | | 70 |
| C | | 85 |
| D | | 30 |
| E | | 60 |
| F | | 90 |
| G | | 75 |
| H | | 125 |
| I | | 40 |
| J | (@ 68°F) | 120 |
| THD Specification | (@ 68°F) | 90 |

Detailed comparisons with the pot life as indicated by the bond strength were made for Epoxies A and B. Results are shown in Fig. 3.1. From this plot it can be seen that both materials remained workable even though not joined until 120 minutes after mixing. Results from Table 3.1 for these two epoxies indicated pot lives as measured by the consistency tests of 110 and 70 minutes, respectively. Thus, the consistency test is a severe method of test for this type adhesive and the expected application. Further confirmation of this was experienced in construction of the one-sixth scale model in the laboratory. Epoxy E was used in this construction. Measured pot life in the consistency

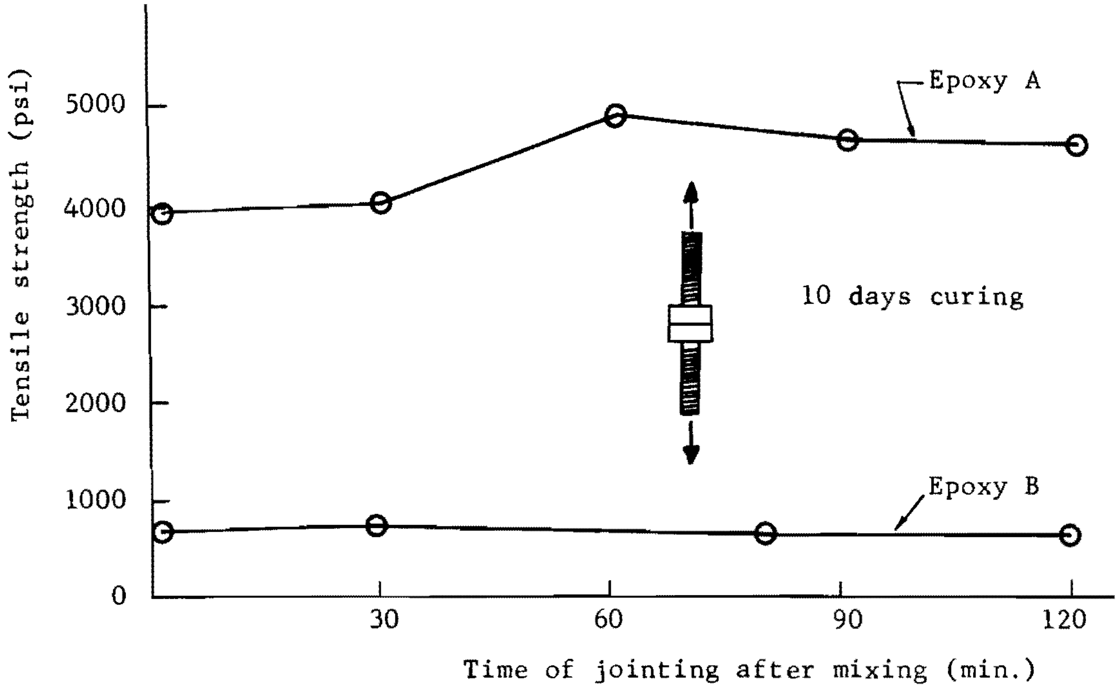


Fig. 3.1. Time after mixing vs. tensile strength.

test was 60 min. and it thus would not meet the specified 90 min. However, wide experience gained in the jointing of 84 segments indicated the material to be fully satisfactory in practical application at 75°F. These experiences indicate that the pot life requirement as measured by consistency could be relaxed.

Such a change is complicated by the fact that consistency and viscosity are affected by temperature in different ways. While the consistency test indicates practical stiffening in the container, viscosity is an important measure of workability. If the viscosity is high, the resin is difficult to spread evenly on the concrete jointing surface, and the resin does not penetrate well into small holes which are usually present on the jointing surface after surface preparation. If the temperature increases, the rate of reaction of resin and hardener (chemically from monomer to polymer) increases much faster than the viscosity decreases. These relationships are shown schematically in Fig. 3.2. Each epoxy resin has its own pot life vs. temperature relationship, but Fig. 3.2 indicates the trend which might be expected for changes in consistency and viscosity. At a particular temperature (b), the pot life (a) due to viscosity equals that due to consistency. This temperature (b) gives the longest pot life that satisfies both criteria.

Further study is required of pot life of typical epoxy resins for this application to document the relations among temperature, consistency, and viscosity, so that specifications may be improved. It is possible that different products may be required for extreme variations in temperature on the same project.

Experience obtained in the epoxy jointing tests indicated that from a practical workability basis, only Epoxies D and I had too short a pot life at 75°F, as measured by the consistency test. Thus, about 60 min. at 75°F would be a lower limit, assuming viscosity is acceptable. However, Fig. 3.2 indicates that a material which only has a pot life of 60 min. at 75°F would probably have substantially less pot life than 30 min. at 100°F. Operational requirements dictate an absolute minimum

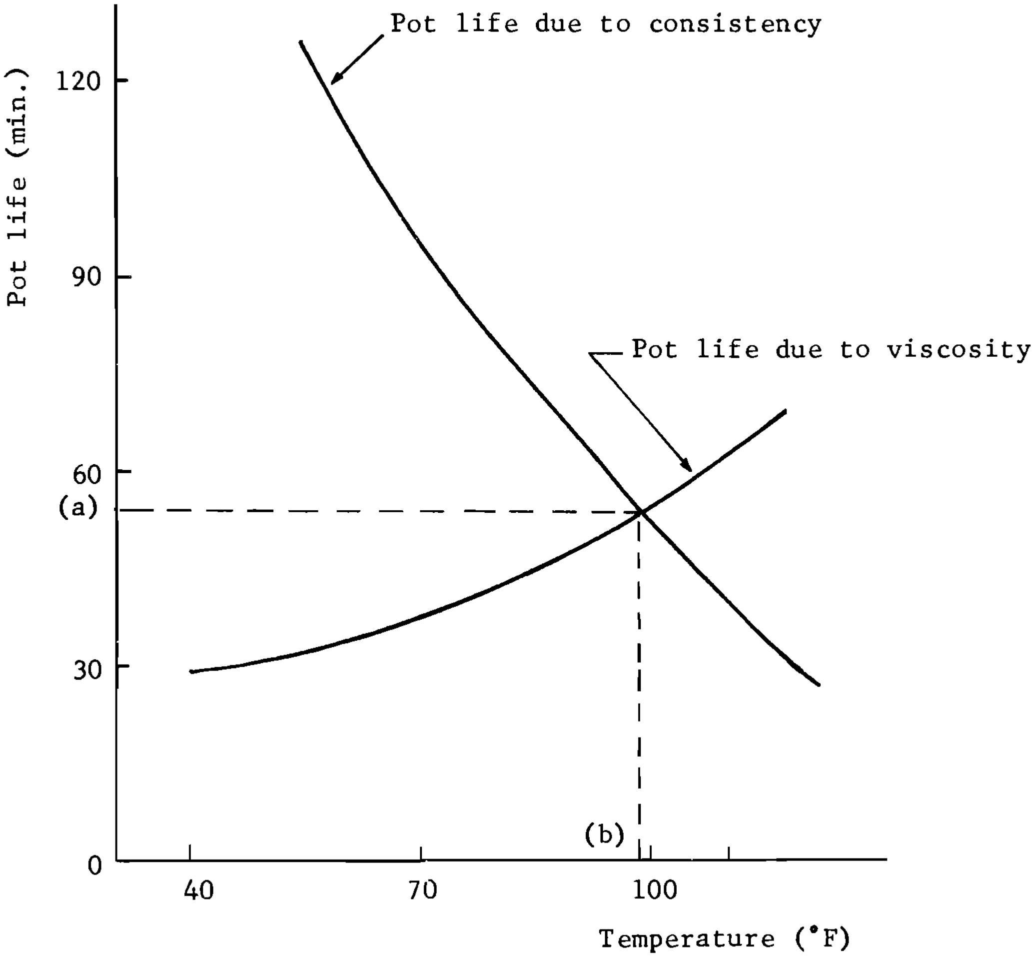


Fig. 3.2. Schematic diagram for pot life vs. temperature considering consistency and viscosity.

pot life of 30 min., so that an improved specification should list pot life requirements for at least two temperatures.

## 3.2 Epoxy Tensile Bond

The development of the tensile bond strength of the epoxy resin was checked for several of the products by the direct tension test using bonded bolts. Ten specimens were tested with each of three of the epoxy resins. These specimens were joined immediately after mixing the epoxy resins and tested after 1, 2, 4, 7, and 10 days. Test results are shown in Fig. 3.3. The tensile strength of Epoxy B was very low as compared to Epoxies A and E. It was noted that the color of Epoxy B between the bolt heads changed color from gray to red, while Epoxy B maintained its gray color when jointing concrete. This indicates the material may undergo a chemical reaction with steel and should not be used for jointing steel. Seventy percent of the full strength of Epoxy A was attained in one day, with essentially full strength reached in seven days. In contrast, Epoxy E was much slower in curing, with approximately five days required for development of 2000 psi minimum tensile strength. One of the desired benefits in use of epoxy resin joint for segmentally constructed precast prestressed concrete bridges is the rapid development of strength when compared to mortar joints. This helps speed up construction time. The rapid curing characteristics of Epoxy A are more suitable for this application than the slow curing characteristics of Epoxy E. Consideration of construction operations indicate that the specification should be changed to require that the minimum tensile strength of 2000 psi be achieved at 48 hours at 73°F.

## 3.3 Ease of Mixing and Application

All of the epoxy resins except Epoxy D were easy to mix because the viscosity of the resins and hardeners were generally similar. All of the resins when mixed were easy to apply to the concrete surfaces. When applied to vertical surfaces in a layer approximately 40 to 60 mils thick, the epoxy resins showed no sign of flow or sag.

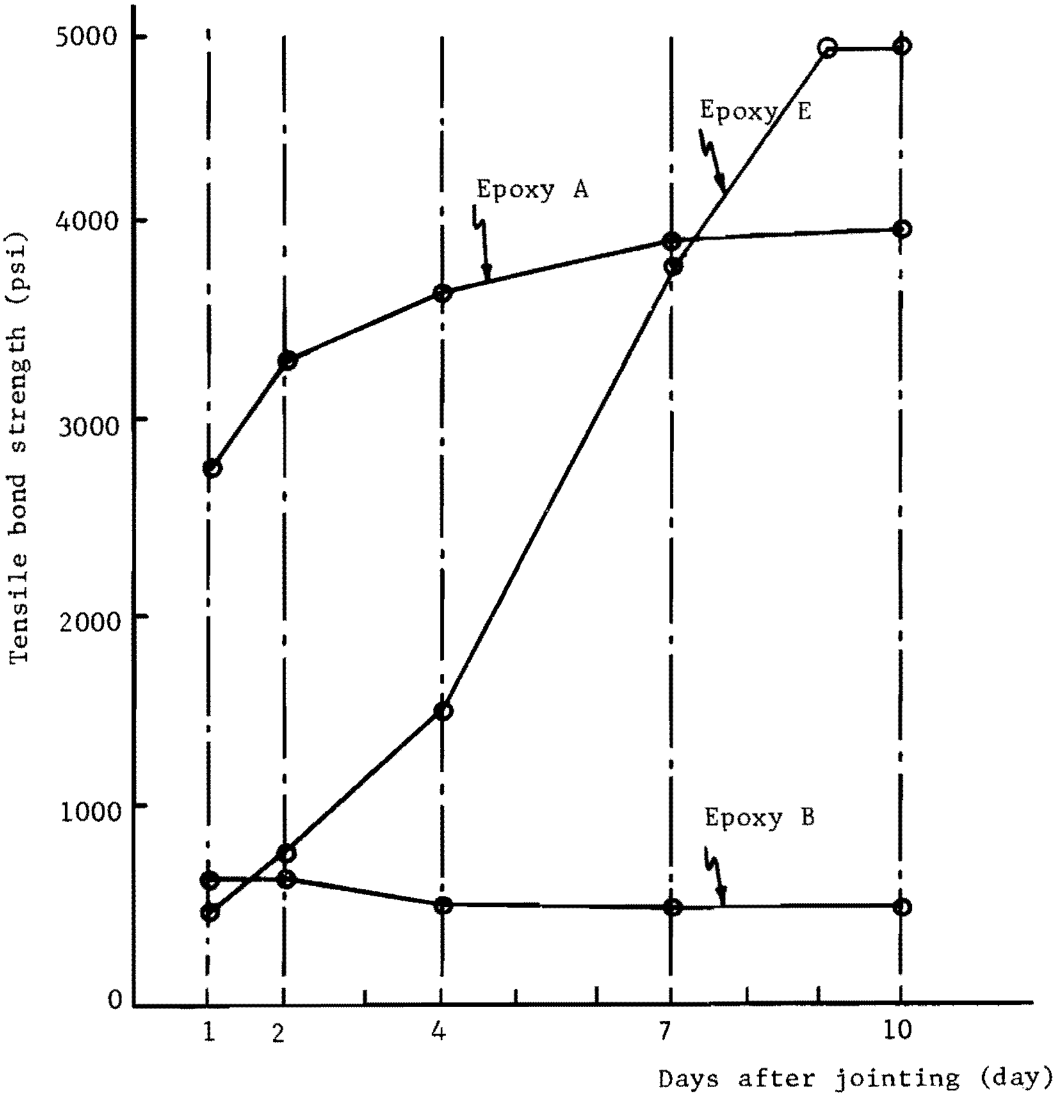


Fig. 3.3. Development of tensile bond strength of epoxy resins.

## 3.4 Color

Most of the materials submitted when mixed had a reasonable gray color which approximated that of concrete. Experience with several of the formulators which initially submitted products with objectionable light or dark colorations indicated that in most cases the color could be effectively altered to meet the specification without appreciable change in the product performance.

## 3.5 Flexure Test Results

Hardened concrete specimens were joined and tested in flexure as described in Sec. 2.5. Tests were carried out in duplicate or triplicate and all results are reported as averages of similar specimens. Standard deviations were about 5 percent for monolithic control specimens and 8 percent for jointed specimens. Test results for all flexure tests are reported in Table 3.2.

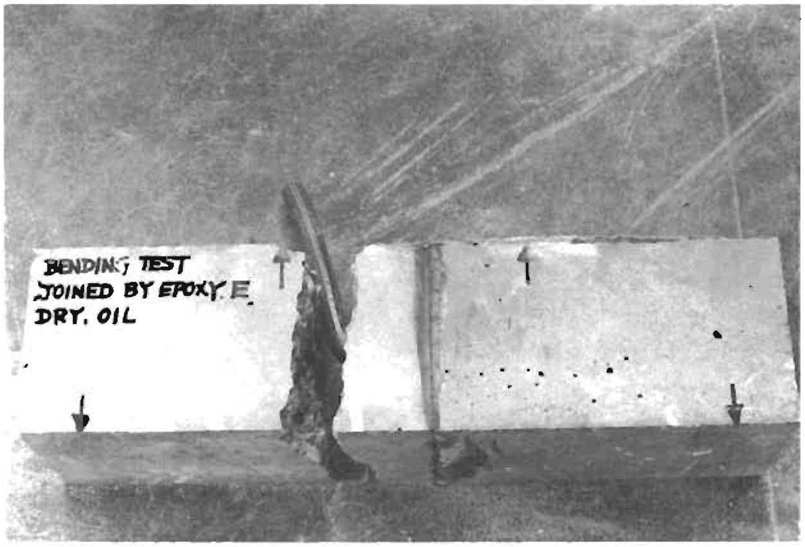
3.5.1 Failure Patterns. Three characteristic failure patterns were observed during testing and are indicated in Table 3.2. In the monolithic specimens and in some of the joined specimens, failure occurred as shown in Fig. 3.4 by rupture of the cross section away from the vicinity of the joint. This represents the ideal condition and shows the joint to be completely effective. In many of the joined specimens, failure occurred as shown in Fig. 3.5, by rupture in the concrete adjacent to the joint. Figure 3.5(b) indicates that failure was not in the adhesive because of the large amount of fractured aggregate and paste. The appearance of Figs. 3.4(b) and 3.5(b) are virtually identical. In contrast, Fig. 3.6 shows a bond failure at a joint. Note the smooth appearance of the epoxy surface and no signs of aggregate fracture.

3.5.2 Dry Surface Condition. The tabular data of Table 3.2 are shown in the bar charts of Fig. 3.7. Both the actual flexural strength and the flexural strength relative to the monolithically cast control specimens are shown. For the specimens which were dry at the time of jointing and where there had been no form oil on the jointing surfaces, the ultimate flexural strength of all epoxy resin specimens performed very well.

TABLE 3.2. FLEXURE TEST RESULTS

| Epoxy Resin | Surface Condition | Average Flexural Strength (psi) | $f'_c$ (psi) ($f_{sp}$) | Type of Failure* | Strength Relative to Monolithic Percent |
|---|---|---|---|---|---|
| | Monolithic | 636 | | 1 | 100 |
| A | Dry, soap | 614 | 7950 | 1 | 97 |
| | Saturated, soap | 403 | (558) | 2 | 63 |
| | Monolithic | 689 | 7900 | 1 | 100 |
| B | Dry, soap | 737 | (588) | 1 | 107 |
| | Saturated, soap | 80 | | 3 | 12 |
| | Monolithic | 729 | 6760 | 1 | 100 |
| C | Dry, no oil | 766 | (538) | 2 | 105 |
| | Dry, oil | 625 | | 2 | 86 |
| | Saturated, no oil | 133 | | 3 | 18 |
| | Monolithic | 729 | 6760 | 1 | 100 |
| D | Dry, no oil | 800 | (538) | 2 | 110 |
| | Dry, oil | 500 | | 2 | 69 |
| | Saturated, no oil | 50 | | 3 | 7 |
| | Monolithic | 729 | 6760 | 1 | 100 |
| E | Dry, no oil | 733 | (538) | 2 | 100 |
| | Dry, oil | 742 | | 1 | 102 |
| | Saturated, no oil | 467 | | 2 | 64 |
| | Monolithic | 729 | 6760 | 1 | 100 |
| F | Dry, no oil | 750 | (538) | 1 | 103 |
| | Dry, oil | 758 | | 1 | 104 |
| | Saturated, no oil | 175 | | 3 | 24 |
| | Monolithic | 729 | 6760 | 1 | 100 |
| G | Dry, no oil | 725 | (538) | 1 | 99 |
| | Dry, oil | 221 | | 3 | 30 |
| | Saturated, no oil | 183 | | 3 | 25 |
| | Monolithic | 760 | 7200 | 1 | 100 |
| H | Dry, no oil | 783 | (530) | 2 | 103 |
| | Dry, oil | No test | | - | - |
| | Saturated, no oil | 225 | | 3 | 30 |
| | Monolithic | 729 | 6760 | 1 | 100 |
| I | Dry, no oil | 683 | (538) | 2 | 94 |
| | Dry, oil | No test | | - | - |
| | Saturated, no oil | 107 | | 3 | 15 |

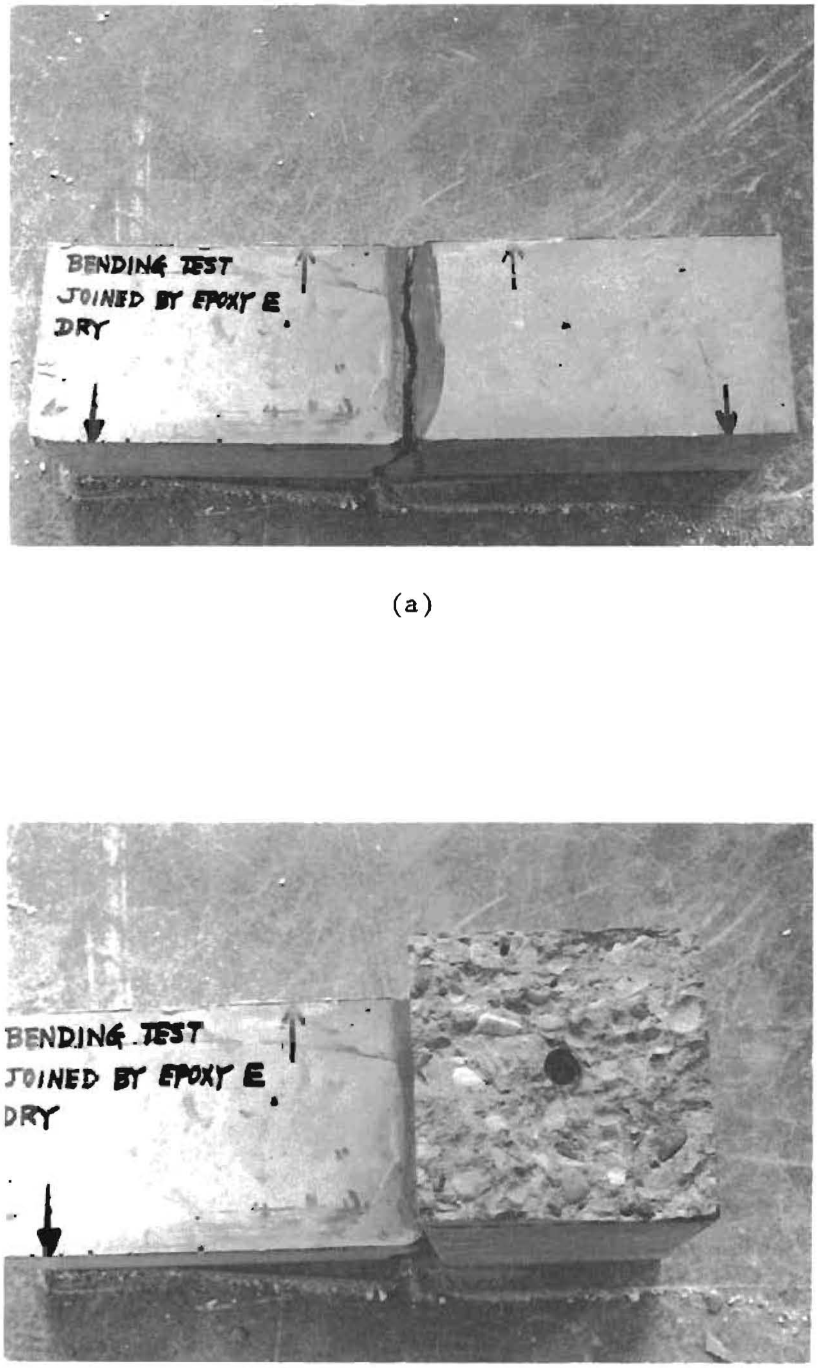
*1 - Away from joint
2 - Concrete adjacent to joint
3 - In epoxy joint



(a)

(b)

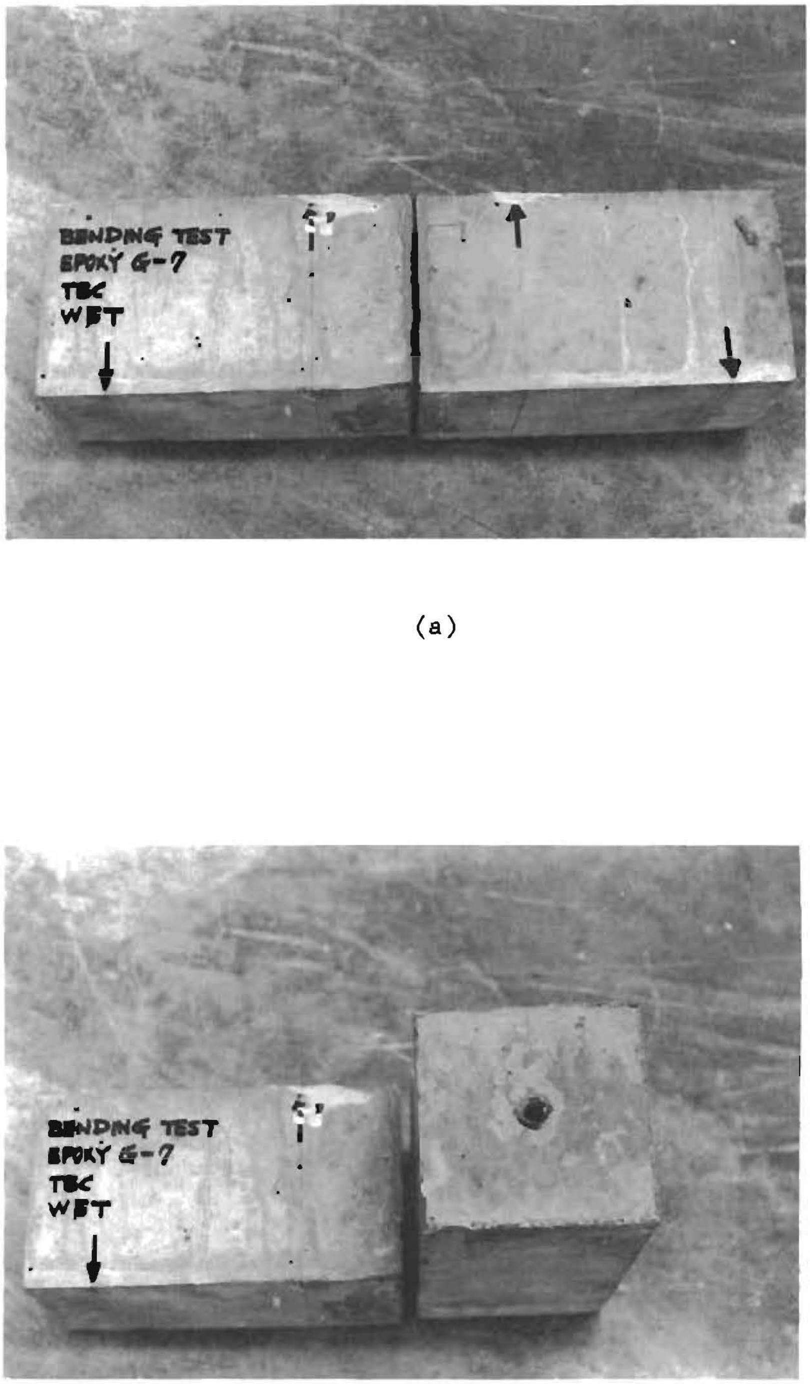
Fig. 3.4. Flexural failure away from joint.



(a)

(b)

Fig. 3.5. Flexural failure in concrete immediately adjacent to joint.



(a)

(b)

Fig. 3.6. Epoxy bonding failure at joint.

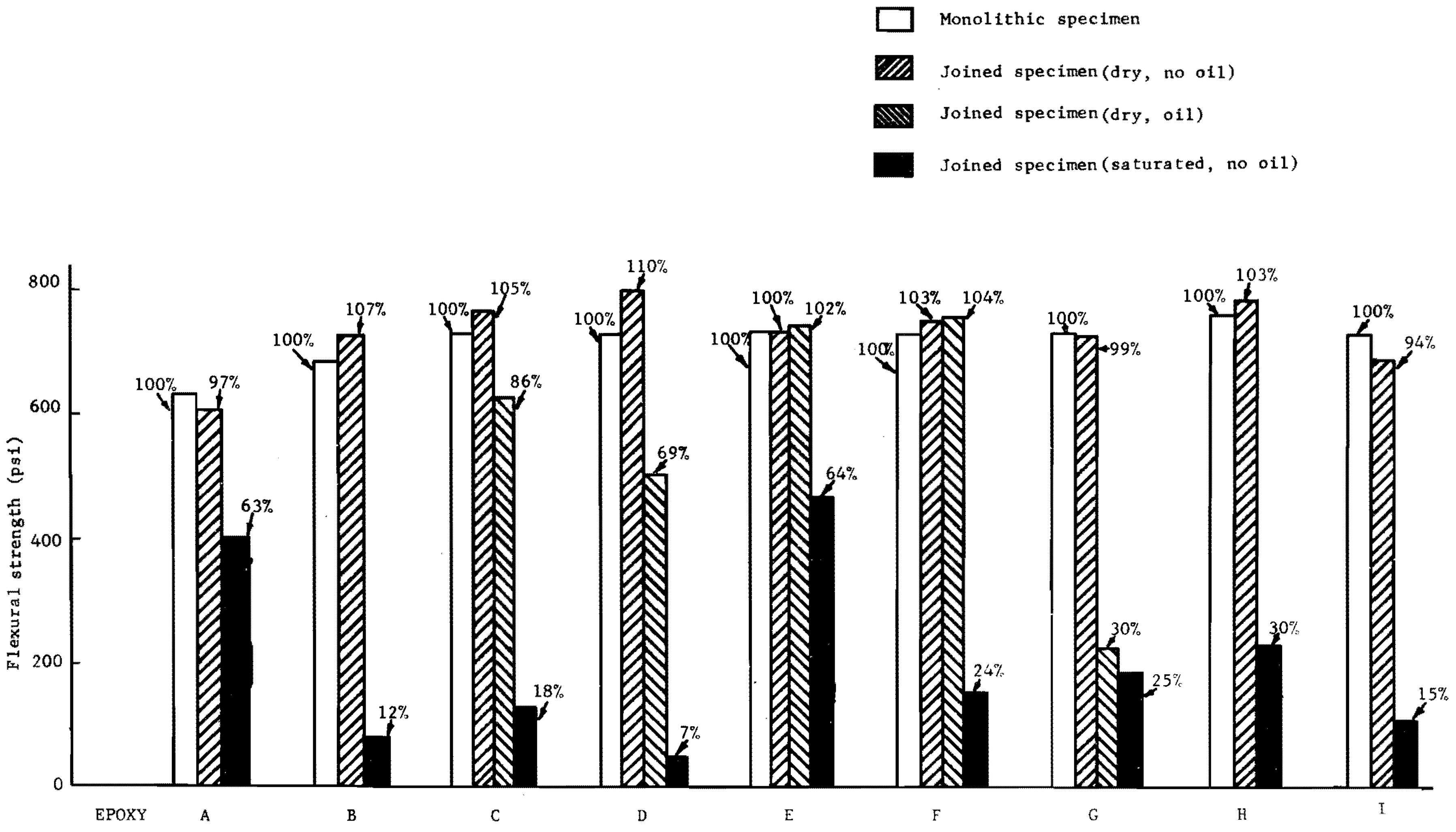


Fig. 3.7. Flexure test results of epoxy resins.

Only Epoxies A, G, and I carried less load than the monolithic reference specimens and in those cases the decrease was within the range of expected scatter. For all practical purposes all the dry joined specimens met the Texas Highway Department Item 2131 requirement that the joint material be able to develop 95 percent of the flexural tensile strength of a monolithic specimen.

3.5.3 Saturated Surface Condition. However, test results for the saturated condition were very unsatisfactory. Even though the faces were almost air dry at the time of jointing, only Epoxies A and E developed any substantial fraction of the dry joining condition, and they were only about two-thirds of the required 95 percent of flexural strength. This was the most severe shortcoming of the materials submitted and caused great concern in connection with construction of the prototype. However, the formulator of Epoxy F revised his formulation to take account of the poor performance in moist jointing and submitted samples designated Epoxy J to the Texas Highway Department Materials and Test Division for acceptance. Results of tensile tests on saturated mortar specimens indicated 100 percent breakage away from the joint and the material was accepted for use in the prototype structure at Corpus Christi. The superior performance of Epoxy E at the time of construction of the one-sixth scale model over other available epoxies led to its use in the construction of the model. (Epoxy A was not available in the United States.)

3.5.4 Oil Surface Condition. Several epoxies (C, D, E, F, and G) were evaluated for the dry, oil surface condition. All specimen joint faces were wire brushed, steam cleaned, and wiped with acetone prior to jointing. Epoxies C and D were appreciably affected by the presence of oil, while Epoxy G was greatly affected. No effect of oil on surfaces was noted with Epoxies E and F.

Additional specimens were tested using Epoxy E to investigate the efficiency of various types of degreasing procedures for surfaces inadvertently exposed to form oils. A series of flexural specimens was cast against oiled form surfaces and joined after various combinations of surface treatments. Results are shown in Fig. 3.8. Cleaning with acetone

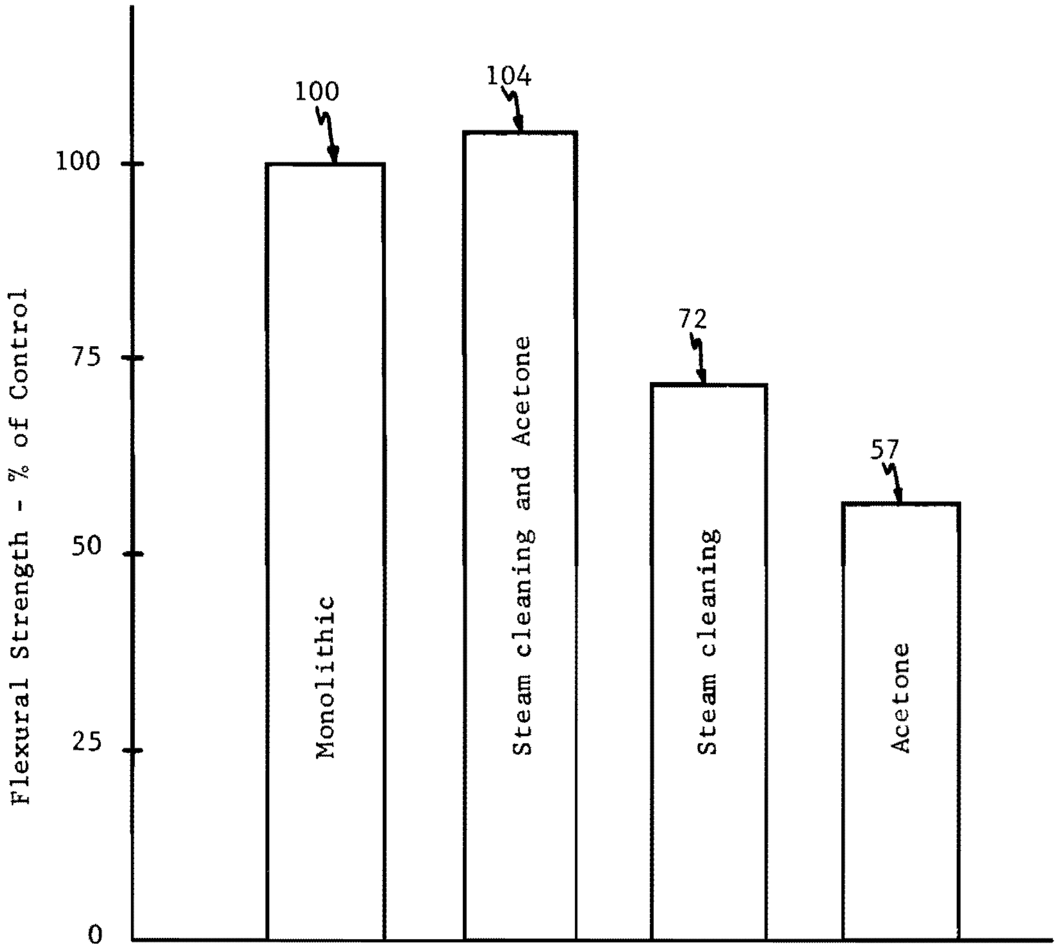


Fig. 3.8. Flexure test results for epoxy resins on surfaces cast against form oil.

or steam cleaning the surfaces is not fully effective, but combined steam cleaning and subsequent wiping with acetone just before joining was fully effective.

## 3.6 Shear Test Results

Hardened concrete specimens were joined and tested in shear as described in Sec. 2.5. Tests were carried out in duplicate or triplicate and all results are reported as averages of similar specimens. Standard deviations were about 10 percent for both the monolithic control specimens and the jointed specimens. Both of these values are increases in comparison to the results of the flexure test series, and indicate the higher scatter inherent in the shear test method with its more difficult loading method. Test results for all shear tests are reported in Table 3.3. The number of surface conditions tested was reduced, since saturated flexure tests indicated all materials A through I had failed the moist jointing requirement. Epoxy H was not tested in shear because of the late date of submission of the material.

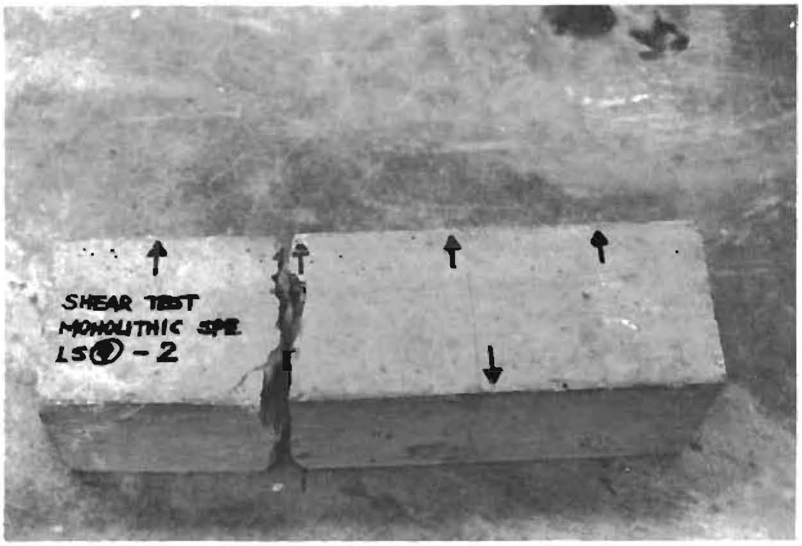
3.6.1 Failure Patterns. The characteristic failure patterns observed during shear tests were more complex than those observed in flexure tests because more combined failure cases occurred, as indicated in Table 3.3. In the monolithic control specimens fracture occurred both by wide scale rupture along a single failure plane, as shown in Fig. 3.9(a), and by simultaneous rupture along two failure planes through the specimen, as shown in Fig. 3.9(b). In some of the joined specimens, failure occurred in the concrete adjacent to the joint, with a marked fracturing of paste and aggregate, as shown in Fig. 3.10. However, in many cases only a part of the aggregate fractured and a portion of the failure occurred in the epoxy joint, as shown in Fig. 3.11(a), or total failure occurred in the bonding, as shown in Fig. 3.11(b).

3.6.2 Dry Surface Condition. The tabular data of Table 3.3 are shown in the bar charts of Fig. 3.12. Both the actual shear strength and the shear strength relative to the monolithically cast control specimens are shown. Because of the absence of aggregate interlock across the joint,

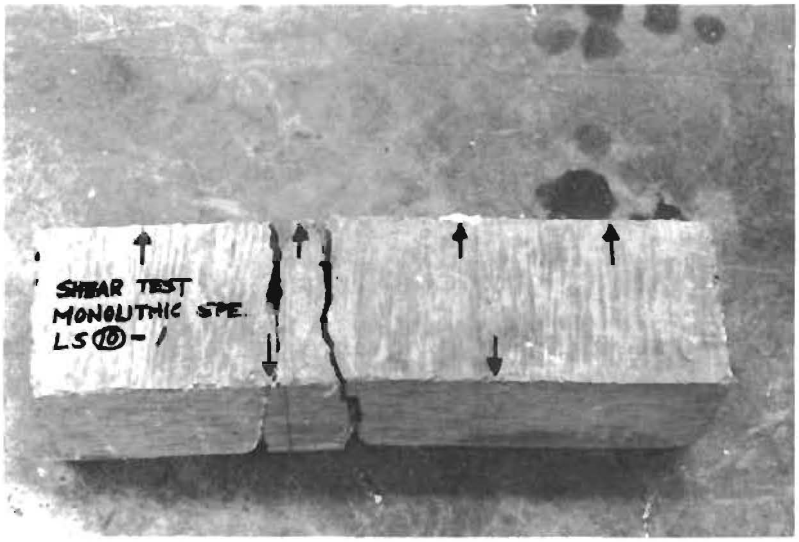
TABLE 3.3. SHEAR TEST RESULTS

| Epoxy Resin | Surface Condition | Average Shear Strength (psi) | $f'_c$ (psi) ($f_{sp}$) | Type of Failure* | Strength Relative to Monolithic Percent |
|---|---|---|---|---|---|
| | Monolithic | 717 | 7740 | 1 | 100 |
| A | Dry, soap | 501 | (576) | 2 | 70 |
| | Saturated, soap | 240 | | 3 | 34 |
| | Monolithic | 764 | 8330 | 1 | 100 |
| B | Dry, soap | 456 | (595) | 3 | 60 |
| | Saturated, soap | 92 | | 3 | 12 |
| | Monolithic | 753 | 6760 | 1 | 100 |
| C | Dry, no oil | 775 | (538) | 2 | 103 |
| | Dry, oil | No test | | | |
| | Saturated, no oil | No test | | | |
| | Monolithic | 753 | 6760 | 1 | 100 |
| D | Dry, no oil | 727 | (538) | 2-3 | 97 |
| | Dry, oil | No test | | | |
| | Saturated, no oil | No test | | | |
| | Monolithic | 753 | 6760 | 1 | 100 |
| E | Dry, no oil | 571 | (538) | 2-3 | 76 |
| | Dry, oil | 369 | | 3 | 49 |
| | Saturated, no oil | 260 | | 3 | 34 |
| | Monolithic | 753 | 6760 | 1 | 100 |
| F | Dry, no oil | 608 | (538) | 2-3 | 81 |
| | Dry, oil | No test | | | |
| | Saturated, no oil | No test | | | |
| | Monolithic | 753 | 6760 | 1 | 100 |
| G | Dry, no oil | 328 | (538) | 3 | 44 |
| | Dry, oil | 378 | | 3 | 50 |
| | Saturated, no oil | 246 | | 3 | 33 |
| H | No tests | | | | |
| | Monolithic | 753 | 6760 | 1 | 100 |
| I | Dry, no oil | 359 | (538) | 3 | 48 |
| | Dry, oil | 331 | | 3 | 44 |
| | Saturated, no oil | No test | | | |

*1 - In concrete
2 - Concrete adjacent to joint
3 - In epoxy joint

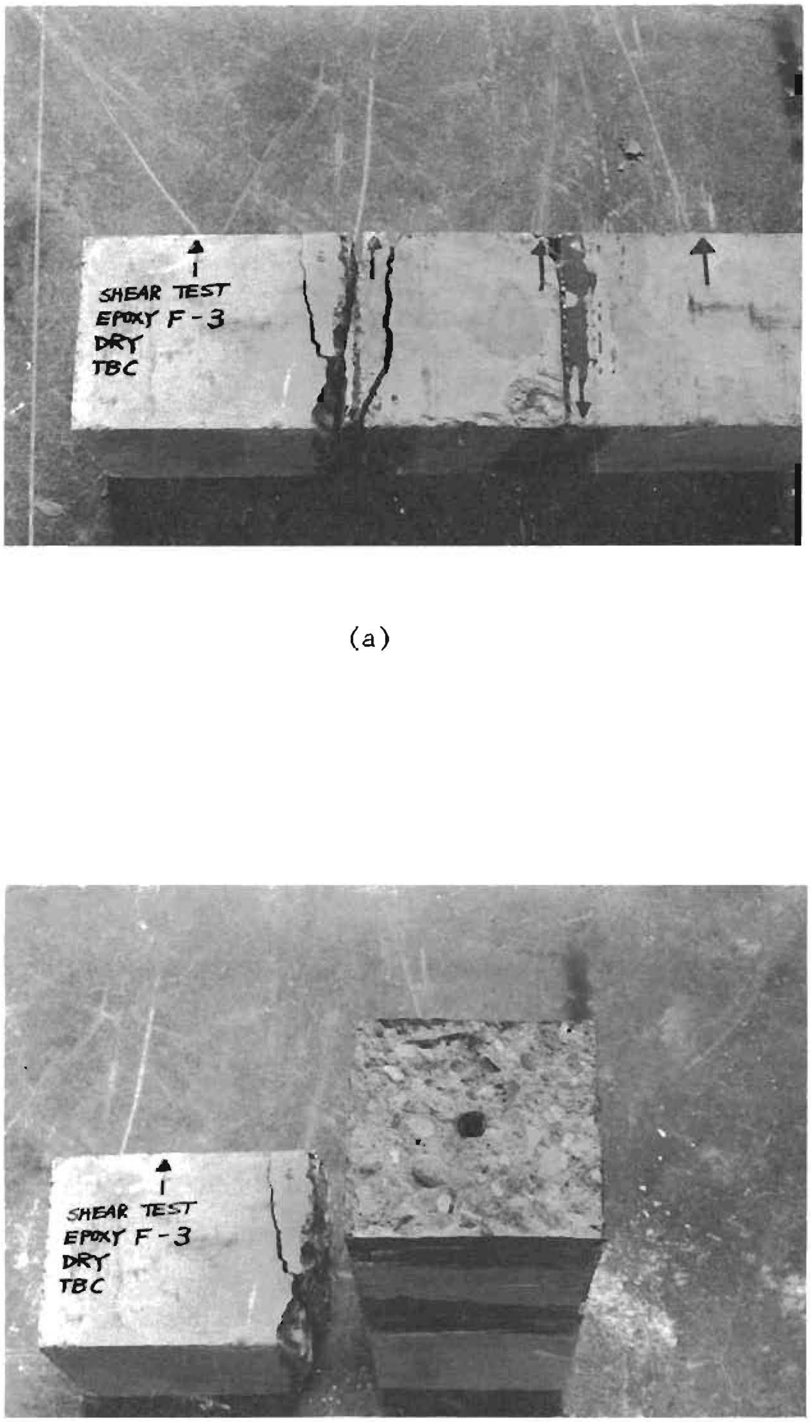


(a) Single fracture



(b) Double fracture

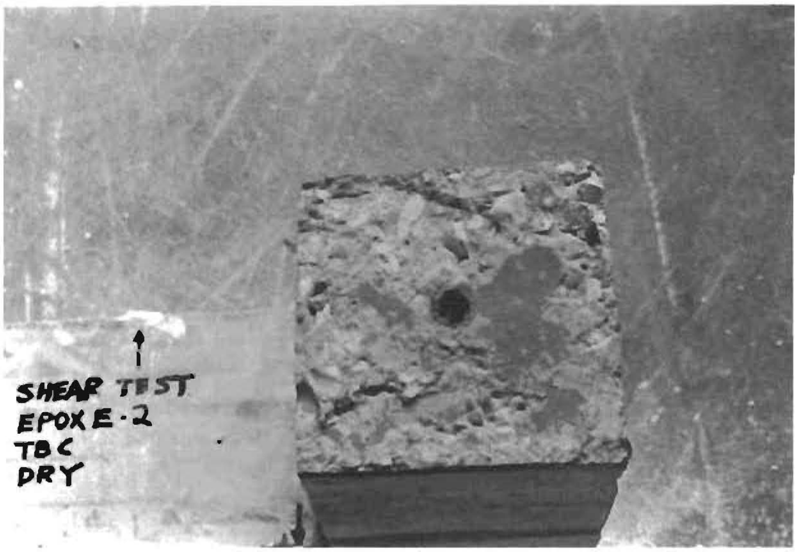
Fig. 3.9. Typical shear failures in monolithic specimens.



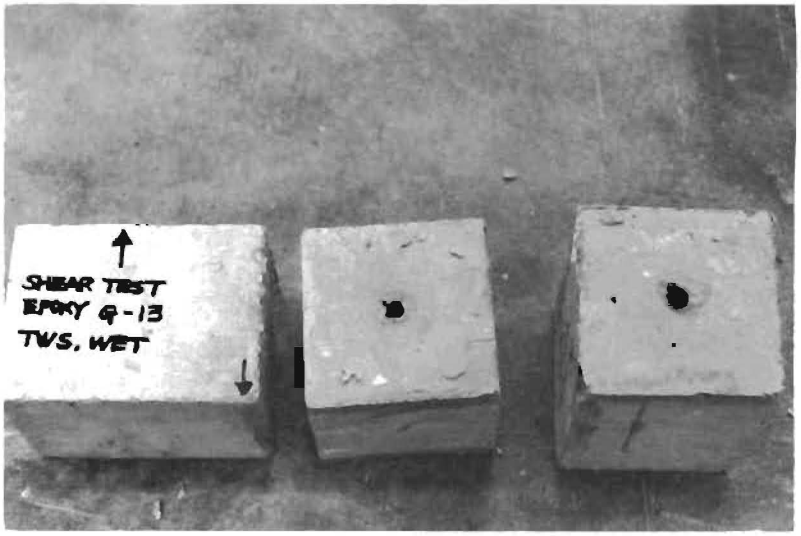
(a)

(b)

Fig. 3.10. Shear fracture in concrete immediately adjacent to joint.



(a) Partial failure



(b) Total failure

Fig. 3.11. Epoxy joint failures.

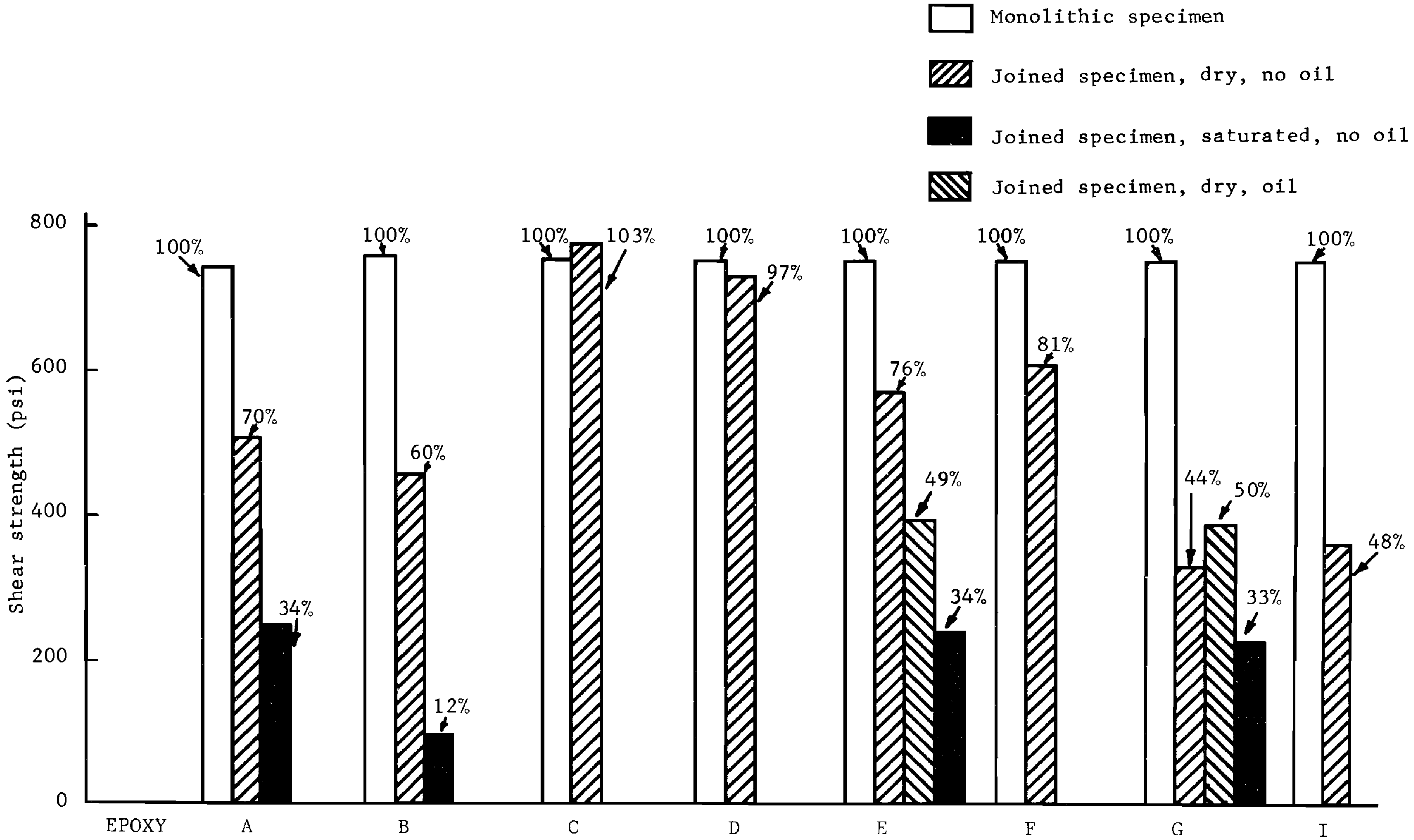


Fig. 3.12. Shear test results of epoxy resins.

performance of the joined specimens was expected to be less than that of monolithic specimens, and the Texas Highway Department Item 2131 requirement was that the joint material be able to develop 70 percent of the shear strength of a monolithic specimen. For the specimens which were dry at the time of jointing and where there had been no form oil on the jointing surfaces, the ultimate shear strength varied widely. Epoxies C and D developed the full shear strength in spite of the absence of aggregate interlock. Epoxies A, E, and F met or exceeded the requirement of 70 percent, while Epoxies B, G, and I failed the requirement even in the dry, no oil joint condition.

3.6.3 Saturated Surface Condition. Since all epoxies tested in the main program had failed the moist joining test when flexural specimens were joined, only a few epoxies were checked for moisture effects on shear strength. Epoxies A, E, and G developed about one-half of the required 70 percent of companion shear strength. Epoxy B developed far less than that. No consistent pattern was noted between dry and saturated performances in flexure and in shear. Results of these tests were extremely disappointing.

3.6.4 Oil Surface Condition. Epoxies E and G were evaluated in shear for the dry, oil surface conditions. As in the flexure series, all specimen joint faces were wire brushed, steam cleaned, and wiped with acetone prior to jointing. Epoxy E showed a substantial decrease in strength for this condition, although the flexure tests had not indicated adverse effects when exposed to oils. Epoxy G showed no effect of oil surface exposure, although the flexure specimen had been very adversely affected.

## 3.7 Segmental Bridge Model

An excellent check on the performance of two of the epoxy resins was afforded by their utilization with the major testing program of one-sixth scale models of the segmental box girder bridge erected at Corpus Christi, Texas. Complete details of the model test program have been reported by Kashima[12] and will be included in further reports in the present series. However, a brief summary of the findings is included because of the confirmation of the performance of these epoxy resins in this type construction.

A very detailed one-sixth scale segmentally cast and cantilever erected model of the three-span post-tensioned box girder bridge planned for Corpus Christi, Texas, was constructed and loaded to failure in the Civil Engineering Structures Research Laboratory at Balcones Research Center (see Fig. 3.13). Epoxy E was used for all joints in the construction of this model and proved to have pot life, consistency, and workability suitable for this type of construction. The model structure was loaded at service dead load plus live load levels with no cracking evident in the structure. Load was then increased until the design ultimate dead load and substantial increments of ultimate design live load were applied. When cracking occurred, the cracks tended to form at random locations between the joints and propagated through the webs of the sections. Typical development of cracks in the negative and positive moment regions during loading to failure are shown in Figs. 3.14 and 3.15. This indicated that the epoxy joints in the structure did not present a plane of weakness. Final complete failure took place with rupture of the tendons near the middle of the center span. At this time wide cracking appeared adjacent to one of the epoxy joints, but in the concrete section rather than in the epoxy joint. The maximum shear at the time of this final flexural failure was approximately 75 percent of the calculated shear capacity and indicates very successful jointing. Slip measurements at the joints indicated no slip tendency during loadings.

After failure of the bridge model in the longitudinal loading test, a series of punching shear tests was performed using typical HS20 wheel loads. Punching tests directly across the joints showed that there was no weakness of the joints under punching shear conditions in the top slab and strengths substantially higher than the value calculated by the equation for two-way shear in the ACI Building Code were developed. From these tests it was concluded that the epoxy resin joint did not constitute a plane of weakness for punching resistance.

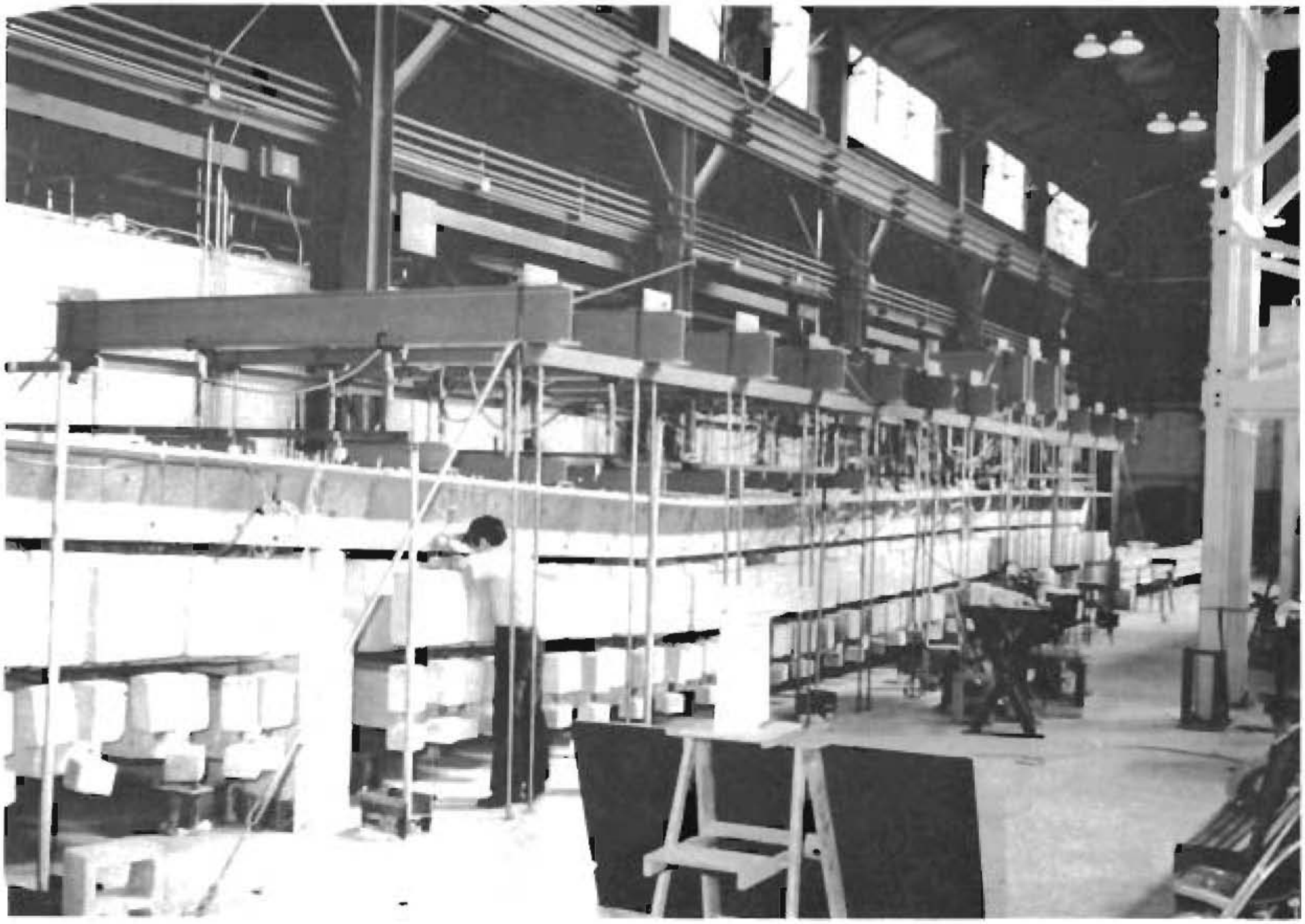
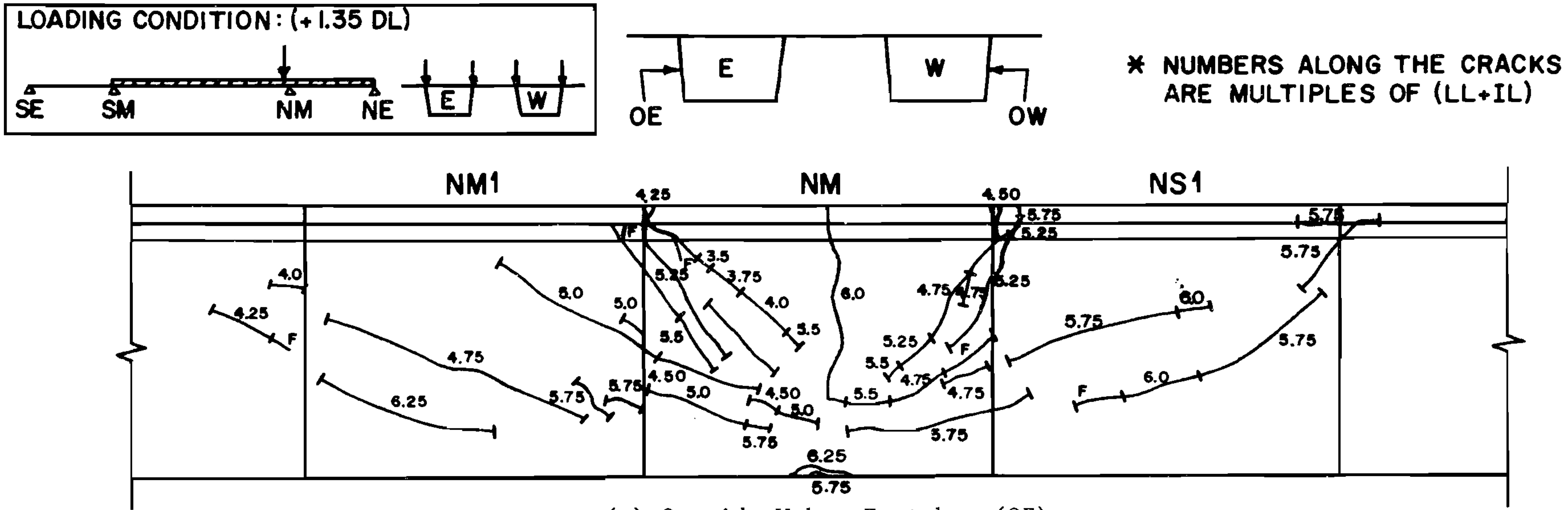
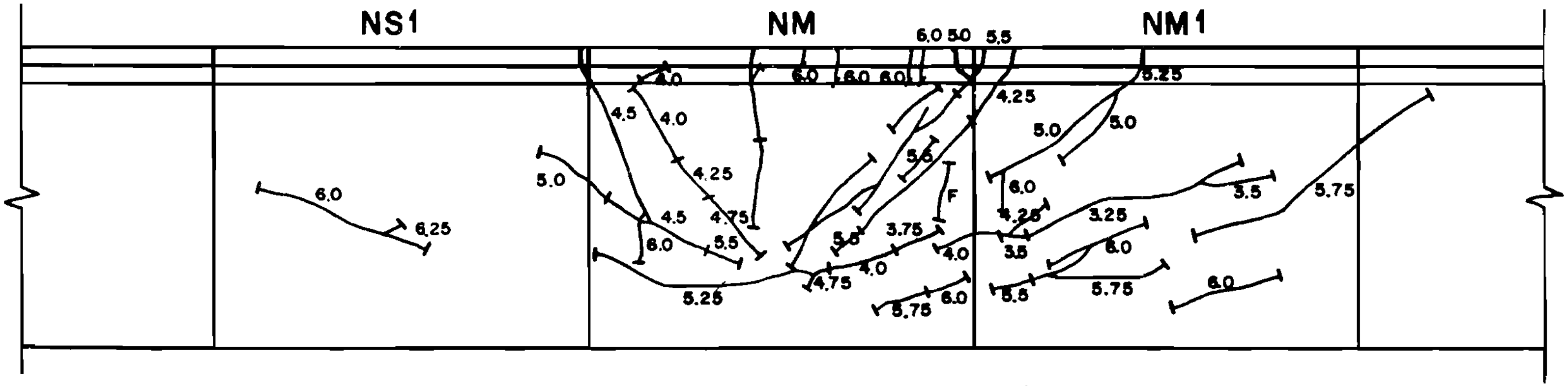


Fig. 3.13. Ultimate load testing of one-sixth scale model of Corpus Christi bridge.

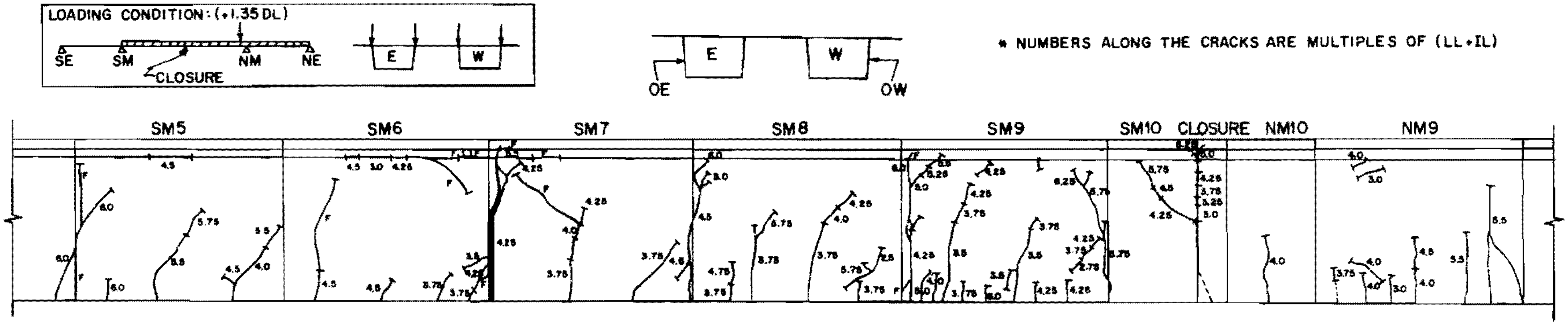


(a) Outside Web - East box (OE)

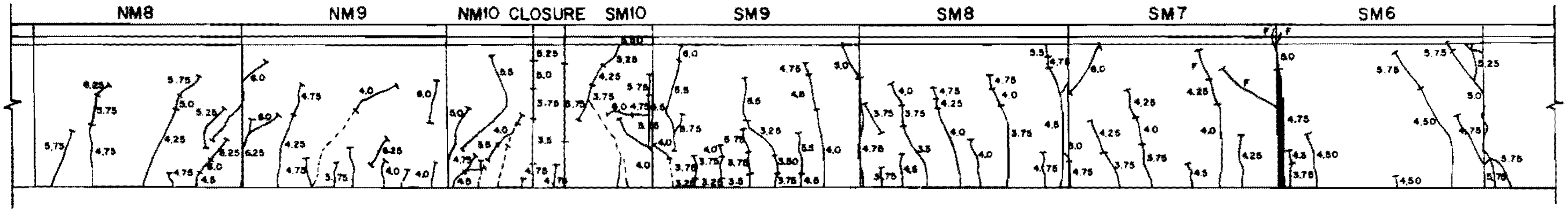


(b) Outside Web - West box (OW)

Fig. 3.14. Development of cracks around NM pier during loading to failure.



(a) Outside Web - East box (OE)



(b) Outside Web - West box (OW)

Fig. 3.15. Development of cracks around the center of main span during loading to failure.

An additional check was made possible when a second one-sixth scale model test was undertaken to evaluate the shear capacity of the Corpus Christi bridge cross section with some changes in tendon anchorages and web reinforcement. In this model (shown in Fig. 3.16) Epoxy J was used for jointing. This test specimen was taken to complete shear failure. Diagonal cracks formed and completely crossed the joint, propagating from one segment to the next as if no joint were present. The final failure load was very close to that predicted by ordinary prestressed concrete shear design equations. At final failure some separation along the joint occurred. It was concluded that the epoxy joint system did not induce any discernible weakness in this type construction.

## 3.8 Summary

While none of the materials tested in the main program met the original specifications proposed by the authors for use by the Texas Highway Department in construction of the Corpus Christi bridge, valuable information was obtained which suggests modification in some of the specification requirements. Epoxy pot life does not appear as critical as first believed, since the bond contact life of the resins was generally longer than the pot life. Only Epoxies A, F, H, and J met the specified 90 min. minimum pot life. However, at 70 to $75^{\circ}$F, all epoxies tested with the exception of D and I had sufficient pot life to allow normal jointing to take place.

For specimens in a dry condition, Epoxies A, C, D, E, and F developed the required flexural and shear capacities of bonded concrete specimens. However, in the presence of moisture represented by saturated, surface dry specimens, none of the materials tested in the main series could develop the required strengths. The shear strength under the moist jointing conditions was particularly weak. Subsequent to the main test series, one of the products was changed and resubmitted for Texas Highway Department evaluation (Epoxy J). This material apparently can develop full strength in both the dry and moist conditions. Additional tests are required to verify the applicability of this and other recently developed materials over a full range of surface and temperature conditions.

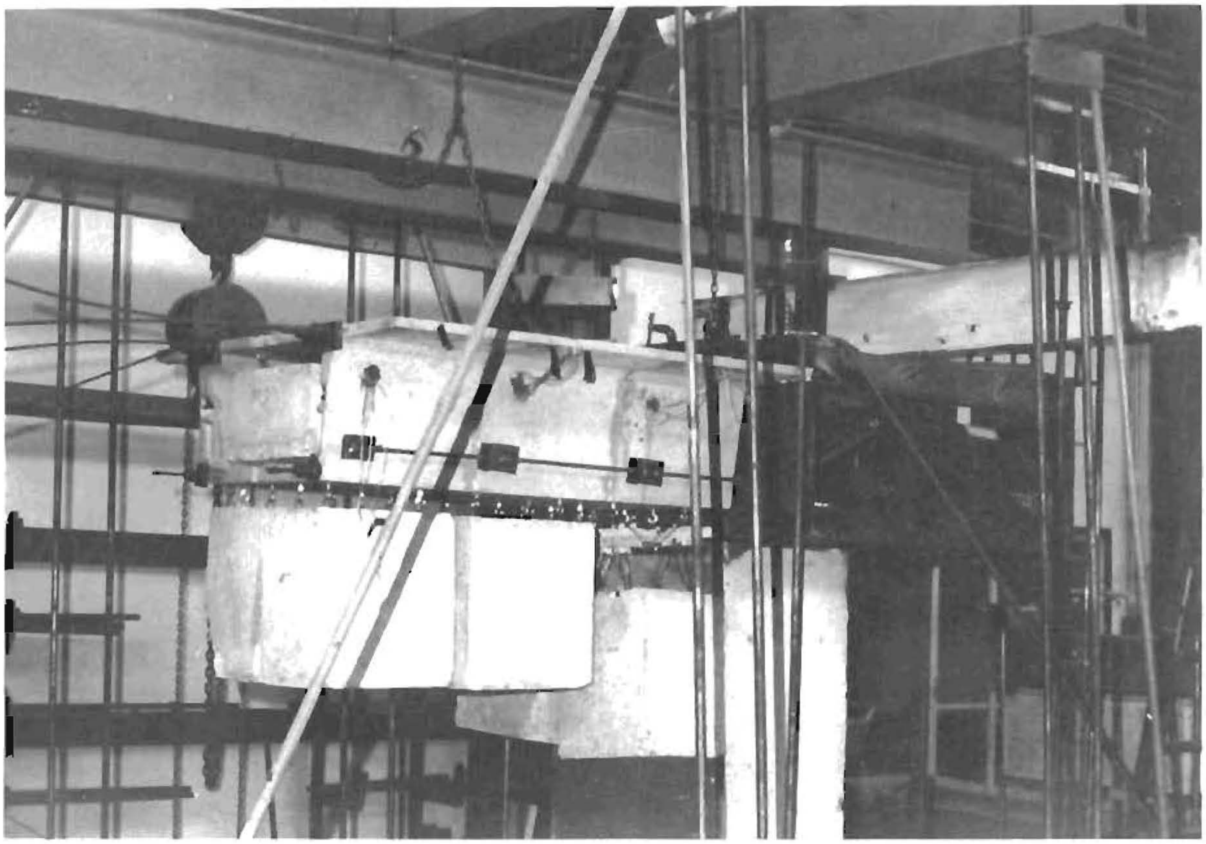


Fig. 3.16. Ultimate shear test of one-sixth scale partial model.

# CHAPTER 4

## RECOMMENDATIONS

### 4.1 General

This study was primarily concerned with development of reasonable specifications for jointing with epoxy resin materials in segmentally precast, cantilever-erected, prestressed concrete bridges. The results of the testing program, as outlined in Chapter 3, the experience obtained from construction of the one-sixth scale model structures described in Sec. 3.7, and the experience obtained from construction of the prototype structure in Corpus Christi, Texas, during 1972-73 have been used to develop guidelines for similar applications. Recent recommendations of ACI Committee 503[13] for use of epoxy compounds with concrete and of successful practices[14] used to control epoxy resin jointing in several foreign projects have also been considered. As the volume of this type of construction increases, epoxy resin suppliers should become more interested in this application and it is anticipated that products and procedures successfully used abroad[14] will enter the U.S. markets.

In subsequent sections, desirable guidelines for each facet of material and joint performance are discussed. A complete guideline based on these sections but without explanation or commentary is included as Sec. 4.2, in a form suitable for inclusion in a project document. It is recommended that this revised specification be used with construction of this nature during normal ranges of temperature in moderate and warm climatic regions such as Texas. Specific recommendations are made for colder climate applications in Sec. 4.3.11.

## 4.2 Recommended Special Specification - Epoxy Bonding Agent

1. DESCRIPTION. This item shall govern for the furnishing and application of epoxy material for use as an adhesive on the jointing faces of precast concrete segments, as required by the plans.

2. MATERIALS. The epoxy bonding agent shall be of two components, a resin and a hardener. The two components shall be distinctly pigmented so that mixing produces a third color and shall be packaged in pre-proportioned, labeled, ready for use containers. The epoxy material shall meet the following requirements:

   a. Pot Life - Minimum of 60 minutes at 73°F and 30 minutes at 90°F (Use ASTM 1338 with a viscosity limit of 3000 poises and temperature increase limit of 30°F).
   b. Contact Time - Minimum of 120 minutes at 73°F and 60 minutes at 90°F. (Use ASTM D 1338 Bond Strength Test with epoxy spread into a 1/16 inch [70 mil] thick layer 15 minutes after initial mixing.)
   c. Compressive Strength - Minimum of 2000 psi at 24 hours and 6000 psi at 48 hours at 73°F (ASTM D 695).
   d. Tensile Strength (Direct or Flexural) - Minimum of 1000 psi at 24 hours and 2000 psi at 48 hours at 73°F (ASTM D 638)
   e. Color - Concrete gray, after mixing and curing.
   f. Resistance to flow on vertical surface - Thin layers of adhesive approximately 1/16 inch thick (70 mils) applied to steel panels in a vertical position shall show no sag or flow when maintained at 73°F and at 100°F. (Similar to ASTM D2730.)
   g. Viscosity of the individual components at 77°F
      Poises 250 Minimum
      1250 Maximum

   The material shall have chemical resistance, weather resistance, and coefficient of thermal expansion compatible with that of concrete.

   The epoxy bonding agent shall be able to bond hardened concrete prism specimens under the following conditions:

   a. Temperature Range 50°F to 100°F
   b. Surface Conditions Dry and Moist
      (Moist is defined as one hour air drying at 73°F and 50% RH after complete saturation for at least 24 hours.)
   c. Prism specimens shall be made of concrete having a minimum compressive strength of 6000 psi.
   d. Contact pressure during curing shall be 50 to 100 psi.
   e. The joint material shall be able to develop 95 percent of the flexural tensile strength and 70 percent of the shear strength of companion monolithic test specimens after a 7 days cure at 73°F. Specimens shall be tested for both dry and moist surface conditions at time of jointing.

The Contractor shall furnish the Engineer a sample of the material for testing, and a certification from a reputable laboratory indicating that the material complies with the above requirements.

3. CONSTRUCTION METHODS. Surfaces to which the epoxy material is to be applied shall be free from all oil, laitance, form release agent, or any other material that would prevent the material from bonding to the concrete surface. All laitance and other contaminants shall be removed by light sandblasting or by steam cleaning and wire brushing or grinding. Surfaces contaminated with oils shall also be cleaned with an approved solvent such as acetone. Wet surfaces should be dried with a heater or gas flame before applying epoxy.

Mixing of the resin and hardener components shall be in accordance with the manufacturer's instructions. Mixing shall continue until the epoxy is thoroughly mixed and of uniform color. Use of a proper sized mechanical mixer operating at no more than 600 RPM will be required. Contents of damaged or previously opened containers shall not be used. Mixing shall not start until the segment is prepared for installation.

The epoxy material shall be applied to all surfaces to be joined within the first half of the pot life, as shown on the containers.

The coating shall be smooth and uniform and shall cover the entire surfaces to be joined with a maximum thickness of 1/16 inch. Epoxy should not be placed within 3/8 inch of prestressing ducts to minimize flow into the ducts. The units shall be joined within 45 minutes after application of the epoxy material and a minimum temporary prestress of 50 psi should be applied within the contact time of the epoxy material.

The joint shall be checked immediately after erection to ascertain uniform bearing and fit. Excess epoxy from the joint should be removed where accessible. All tendon ducts shall be swabbed immediately after stressing, while the epoxy is still plastic, to remove or smooth out any epoxy in the conduit and to seal any pockets or air bubble holes that have formed at the joint.

No jointing operations shall be performed when the ambient temperature is below 50°F or above 100°F. When the temperature is above 85°F the epoxy coated surfaces shall be shaded from direct sunlight.

If the jointing is not completed within 45 minutes after application of the epoxy material, the operation shall be terminated and the epoxy bonding agent shall be completely removed from the surfaces. The surfaces must be prepared again and fresh epoxy shall be applied to the surfaces before resuming jointing operations.

4. MEASUREMENT AND PAYMENT. No direct measurement or payment will be made for the materials, work to be done, or equipment to be furnished under this item, but it shall be considered subsidiary to the particular items required by the plans and the contract.

## 4.3 Commentary on Recommended Special Specification - Epoxy Bonding Agent

4.3.1 General. Detailed comparison with the similar special specification used for the Corpus Christi bridge and included as Appendix B will indicate that, while the general form has been maintained, several important changes have been made. The major changes are:

(a) More specific packaging and color requirements are included.
(b) Pot life has been revised and specified for two temperatures.
(c) Contact time has been included.
(d) Mechanical strengths are specified for given curing times and conditions.
(e) Sag requirements are clarified.
(f) Certain physical characteristics of the epoxy components and mix have been deleted.
(g) Laboratory test certification requirements have been clarified.
(h) Mixing and application procedures are amplified.
(i) Specific requirements for temporary prestressing are included.

4.3.2 Packaging and Color Requirements. Increased quality control and simplified batching can be obtained if the epoxy components are preproportioned by the manufacturer in clearly labeled containers. If the resin and the hardener are distinctly pigmented (for instance, white and black), it is easy to check that thorough and proper mixing has been obtained by simply checking the uniform gray color of the final mixture. Blending of two incorrect material containers will yield the wrong color and inadequate mixing will show up by uneven coloration and streaking of the mixture.

4.3.3 Pot Life. In the original specification, a minimum pot life of 90 minutes at 68°F was specified, as measured by ASTM D 1338. This pot life is longer than required for practical application and should have a specified value at elevated temperatures. Since all experience with Epoxy E indicated that its pot life of 60 minutes at 75°F was completely acceptable, the specification has been changed to 60 minutes at 73°F (the standard temperature in the ASTM D 1338 test). Furthermore, because of the possible use of segmental construction in warm months of the year in Texas, a minimum requirement of 30 minutes at 90°F has been added. In both cases the method of test is clarified as the Consistency Test in ASTM D 1338 with viscosity and temperature increase limits specified.

4.3.4 Contact Time. In order to amplify the intent of the original pot life requirements, a new section has been included to specify the open or contact time. This represents the practical application of pot life requirements for epoxies in this jointing application. Because the heat reinforcement characteristics are so different when spread into a thin layer, the requirement specifies that a 1/16 inch (70 mil) thick film of epoxy spread 15 minutes after initial mixing shall have a minimum contact time of 120 minutes at 73°F and 60 minutes at 90°F (measured from time of spreading). Contact time can be evaluated by bonding tensile or shear lap specimens at the indicated time and testing efficiency of bonding. This allows 75 minutes for total jointing at elevated temperatures, which should be fully adequate for an organized construction crew. Inclusion of this requirement is the major justification for relaxation of the pot life requirement in Sec. 4.3.3.

4.3.5 Curing Conditions for Mechanical Strengths. As shown in Fig. 3.3, Epoxies A and E developed the same bond strength in seven days, but at very different rates. Epoxy A developed most of its strength within two days, while Epoxy E was much slower in curing. In the original specifications no time requirements were given for development of such mechanical strengths. In view of the rapid timetable for construction generally desired in precast segmental construction, minimum epoxy mechanical strengths should be developed in 24 and 48 hours at normal curing temperatures. Tests of the joined concrete prisms are to show the required percentages of the monolithic companion specimen strengths after seven days' curing at standard temperatures. Meeting these requirements should ensure rapid cure epoxies suitable for the construction method.

4.3.6 Sag Requirements. A specific test procedure for determining resistance to flow on vertical surfaces is specified similar to ASTM D2730.[15] The material can show no sag at either standard temperature or at the upper range of temperatures allowed for jointing.

4.3.7 Deletion of Certain Physical Requirements. In order to meet the thixotropic requirements imposed by the sag test, the originally specified viscosity limits had to be changed upward.* Although Epoxy J did not quite meet these revised limits, it was still felt as acceptable for use. A viscosity limit on the mixed material was deleted, and viscosity limits on the components included. Similarly, Fig. 3.6 of Ref. 13 indicates that it is impractical to specify a termal expansion coefficient for an epoxy system to be within 10 percent of the termal coefficient of concrete. In the thin joint application in segmental bridges, a difference in thermal coefficient is not significant. Accordingly, this requirement was also dropped.* Other items in the original specifications, such as specific gravity, rate of absorption, and rate of shrinkage, which seemed either undefinable or not germane, were also dropped from the revised specification.

4.3.8 Laboratory Test Certification. In the original specifications, the contractor was required to furnish the engineer a certification

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*See Note, p. 74.

from a reputable laboratory indicating that the material complies with the basic mechanical strength requirements. However, this statement was placed before any mention of the requirements for performance in jointing hardened concrete specimens. As a result, a great deal of time and effort was spent in testing material which was certified to have proper compressive and tensile strength, but which had never been evaluated for ability to join hardened concrete under the surface conditions specified in the prism test series. As can be seen from the results in Chapter 3, almost all of these materials failed to meet the full requirements. In order to control the number of ill-qualified materials which can be submitted for testing, the specification has been revised so that the contractor must furnish a certificate indicating that tests have been run on hardened concrete specimens as well as basic epoxy properties.

4.3.9 Mixing and Application Procedures. Detailed requirements for surface preparation have been revised to emphasize the need for keeping the surfaces free of oily substances. The proper procedures for removing a contaminant and surface treatment for wet surfaces has been amplified. General mixing precautions have been clarified. Experience with the flow of epoxy during prestressing indicates that immediate steps should be taken to clean the excess from all interior joints and to check for and remove any epoxy which gets into the duct systems at the stressed joint before insertion of a tendon or hardening of the epoxy.

4.3.10 Temporary Prestressing Requirements. In order to give the contractor guidance as to the minimum level of temporary prestressing to be used to secure effective jointing and to provide the epoxy supplier with a general level of minimum prestress which he can use for developing contact pressure between test segments, a value of 50 psi has been specified. This represents the general lower level design condition in the Corpus Christi bridge and is also representative of minimum contact pressures that have been used successfully in several foreign applications.

4.3.11 Cold Weather Provisions. It is anticipated that this type of construction will also take place during cold weather. It will generally be necessary to amplify the specifications to provide for alternate materials for cold and moderate or warm weather jointing. ACI Committee 503[13] has designated the following classes of epoxy compounds:

Class A - for use below 40°F
Class B - for use between 40° and 60°F
Class C - for use between 60° and 100°F

The temperatures indicated for each class refer to the temperature of the concrete substrate.

It would seem inappropriate to attempt to use a Class A epoxy compound for this application. The guideline specification given in Sec. 4.2 would be generally appropriate for Class C. Specifications for Class B for general use between 40° and 60°F could use the specification of Sec. 4.2 altered as follows. Pot life requirements should be set at a minimum of 75 minutes at 40°F and 30 minutes at 60°F. The contact time should be modified to specify a minimum of 120 minutes at 40°F and 60 minutes at 60°F. The requirements for epoxy compressive and tensile strength should be developed after 48 hours of curing at 40°F. The requirements for concrete prism strength should be required after seven days at 40°F.

When working in cold weather, the construction method provisions should be amplified to require that the joint be protected from extreme cold temperatures and heated to develop proper curing. In severe cases, temperature records of concrete temperatures at the joint should be kept to provide a curing history. Obviously, considerably more information and testing of hardened specimens at various temperatures and curing conditions are needed before further specific recommendations can be spelled out.

## 4.4 Inspection

In addition to the material acceptance tests, which should be initially performed by a neutral testing laboratory and then checked by the owners' organization, the owners' inspector should make regular checks of the epoxy jointing procedures. Data such as the weather, ambient temperature, concrete surface temperature, adhesive batch number, and the jointing time should be noted. The inspector should frequently sample and record data such as the observed pot life of the epoxy resin, the surface conditions of the segments being joined, the adequacy of coverage of the adhesive, the amount of material being squeezed from the joints, and the approximate contact time of the epoxy. A crude determination of the contact time can be noted from behavior of lap joint samples spread on small cement-asbestos boards. This procedure has been used very successfully in Montreal in connection with construction of the Velodrome being prepared for the 1976 Olympics.

## 4.5 Epoxy Hazards

Comprehensive recommendations concerning handling precautions for epoxies used in connection with concrete are contained in Chapter 9 of ACI Committee 503's report.[13] Chief among the problems is skin irritation and skin sensitization due to working with the epoxy material. To minimize danger to personnel, it is recommended that working areas be well-ventilated, disposable rubber or plastic gloves should be used and discarded after each use, and careful attention should be paid to personal cleanliness and protection. In particular, safety eyeglasses or goggles are strongly recommended when handling epoxy compounds. Experience at Corpus Christi indicates that epoxy will quickly spread via workers' clothing to elevators, doorways, hatches, ladders, etc. Vigorous measures should be taken to confine the spread of epoxy to prevent health hazards. Use of proper disposable equipment, such as aprons and gloves, and immediate cleaning of tools and excess epoxy from interior surfaces can be helpful. Provision should be made for access to soap and water to remove excess epoxy compound from skin and eyes. Other solvents should not be used to remove epoxy products from the skin. All workers should be thoroughly educated in safety precautions.

## 4.6 Conclusions and Recommendations

Based on the exploratory test program outlined in this study, experience in construction of the one-sixth scale laboratory models, and experience gained in construction of the prototype bridge at Corpus Christi, a revised set of specifications for epoxy jointing of precast concrete segmental box girder bridges, as contained in Sec. 4.2, is recommended for general usage in moderate and warm climates such as that of Texas. For cold weather applications, the specification needs to be modified, as outlined in Sec. 4.3.11.

Experience with the nine materials submitted for exploratory testing in connection with usage in the laboratory model and the Corpus Christi bridge indicates that no fully satisfactory material which met all of the original specifications was found in the programs. However, a number of promising materials were identified which could be used with waiver of some parts of the specifications. Continued development by manufacturers indicates promise that the revised specification can be met by one or more American formulators.

The critical test condition in evaluation of the jointing capacity of the epoxy resin was the moist surface condition. In preliminary evaluations, testing can be limited to pot life, contact time, and moist surface condition flexural concrete prism specimens to quickly determine potential adequacy. If the material passes these tests, a full series of evaluation testing could then be undertaken.

Because of the limited scope of this study, the results are not totally conclusive. Further detailed examination of important variables such as the effect of temperature on pot life, contact time, and rate of curing needs to be undertaken in subsequent investigations. In addition, complete development of the specification for this application should consider some methods of testing for long term resistance to weathering, temperature stability, and creep.

# REFERENCES

1. Prestressed Concrete Institute, Japan, Construction Manual for Precast Concrete Segmental Construction, December 1968.

2. Prestressed Concrete Institute, Japan, Tentative Standard for Epoxy Resin for Precast Concrete Segmental Construction, April 1968.

3. Sims, F. A., and Woodhead, S., "Rawcliffe Bridge in Yorkshire," Civil Engineering and Public Works Review, April 1968.

4. Johnson, R. P., "Glued Joints for Structural Concrete," The Structural Engineer, Vol. 41, No. 10 (October 1963), pp. 313-321.

5. American Concrete Institute, "Guide for Use of Epoxy Compound with Concrete (ACI 403)," Journal of the American Concrete Institute, August 1962.

6. American Concrete Institute, "Epoxy Glues Pontoons Together to Make a Floating Bridge," Journal of the American Concrete Institute, May 1962, pp. 732.

7. CIBA Products, Ltd., "Araldite in Segmental Concrete Construction," Technical Note, September 1969.

8. Base, G. D., "Shearing Tests on Thin Epoxy-Resin Joints between Precast Concrete Units," Concrete and Construction Engineering, Vol. 58, No. 7 (July 1963), pp. 273-277.

9. American Society for Testing and Materials, "Standard Method of Test for Working Life of Liquid or Paste by Consistency and Bond Strength (ASTM D 1338-56)," ASTM Standard, Part 22, November 1974.

10. American Society for Testing and Materials, "Standard Method of Test for Tensile Strength of Adhesives by means of Bar and Road Specimens (ASTM D 2095-72)," ASTM Standard, Part 22, November 1974.

11. American Society for Testing and Materials, "Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)(ASTM C 78-64)," ASTM Standard, Part 14, November 1974.

12. Kashima, Satoshi, "Construction and Load Tests of a Segmental Precast Box Girder Bridge Model," Ph.D. dissertation, The University of Texas at Austin, January 1974.

13. ACI Committee 503, "Use of Epoxy Compounds with Concrete (ACI 503-73)," Journal of the American Concrete Institute, Vol. 70, No. 9, September 1973.

14. Hugenschmidt, F., "Epoxy Adhesives in Precast Prestressed Concrete Construction," Journal of the Prestressed Concrete Institute, Vol. 19, No. 2 (March-April 1974), pp. 112-124.

15. American Society for Testing and Materials, "Standard Method of Test for Sag Flow of Highly Viscous Resins" (ASTM D2730-68), ASTM Standard, Part 36, April 1974.

# APPENDIX A

## Main Requirements of the Japanese Standard - Tentative Standard for Epoxy Resin for Precast Concrete Segmental Construction

## Tentative Standard for Epoxy Resin for Precast Concrete Segmental Construction

| Item | Specified Value | Test Method |
|---|---|---|
| Mixing Ratio<br>Resin Component/<br>Hardener Component (pbw) | None | |
| Density | 1.1-1.9 g/cm$^3$<br>(0.040-0.069 lb./cu.in.) | JIS Z 8804, 2 |
| Viscosity | 1.0-5.0x10$^4$ cps at<br>20$^\circ$ ± 1$^\circ$C(68$^\circ$ ± 2$^\circ$F) | By BH Rotary Viscosimeter |
| Pot Life | 2-4 hrs. at 20$^\circ$ ± 1$^\circ$C<br>(68$^\circ$ ± 2$^\circ$F) | By Gardner dried hour testing machine |
| Bending Tensile Strength | 7 days $\geq$ 100 kg/cm$^2$<br>(1425 psi) | JIS K 6911 - 5.17 |
| Tensile Strength | 7 days $\geq$ 100 kg/cm$^2$<br>(1425 psi) | JIS K 6911 - 5.18 |
| Compressive Strength | 7 days $\geq$ 500 kg/cm$^2$<br>(7120 psi) | JIS K 6911 - 5.19 |
| Impact Strength | More than 2 cm kg/cm$^2$<br>(11.4 in. psi) at 0$^\circ$C<br>(32$^\circ$F) | JIS K 6911 - 5.20 |
| Elastic Coefficient of Compression | 1-4.5x10$^4$kg/cm$^2$<br>(14.3-64.3x10$^4$ psi) | By 2x2x2 cm<br>(3/4x3/4x3/4 in.) |
| Coefficient of Thermal Expansion | Same value as concrete | JIS K 6911 - 5.25 |
| Rate of Absorption | Same value or less than concrete | JIS K 6911 - 5.26 |
| Rate of Shrinkage | Same value or less than concrete | JIS K 6911 - 5.7 |
| Degree of Hardness | 7 days, shore scale<br>100 + 10 at 20$^\circ$ + 5$^\circ$C<br>(68$^\circ$ + 9$^\circ$F) | ASTM D 530 - 50T |

| Item | Specified Value | Test Method |
|---|---|---|
| Heat Resistance | No change in appearance and decrease of compression strength less than 10% at 200°C x 2 hrs. (392°F x 2 hrs.) | Use 2x2x2 cm (3/4x3/4x3/4 in.) JIS K 6911 - 5.19 |
| Chemical Resistance | Same value or more than concrete at 20° + 5°C (68° + 9°F) | JIS K 6911 - 5 |
| Resistance for Weather | Same value or more than concrete | ASTM D 795 - 57 |
| Flowing | Not to have less thickness than 0.25 mm (0.01 in.) at 20°C + 5°C (68° + 9°F) | The thickness is measured after hardening. Epoxy resin of 0.5-2 mm (0.02-0.08 in.) is applied on the vertical surface of concrete with section 15x15 cm (6x6 in.) |
| Color of Mixing Material | $A_1$ - 1004 - 1006 | By color sample of Japan Paint Institute |

# APPENDIX B

## Specifications for the Epoxy Bonding Agent Used for the Corpus Christi, Texas, Segmental Bridge Project

# TEXAS HIGHWAY DEPARTMENT

## SPECIAL SPECIFICATION

## ITEM 2131

## EPOXY BONDING AGENT

1. DESCRIPTION. This item shall govern for the furnishing and application of epoxy material for use in the joint between precast concrete units, as required by the plans.

2. MATERIALS. The epoxy material shall be of two components, a resin and a hardener (1 to 1 ratio), meeting the following requirements:

| | | |
|---|---|---|
| a. | Pot Life Min. 90 minutes at 68°F (ASTM D1338) | |
| b. | Compressive Strength | 6,000 psi min. |
| c. | Tensile Strength (Direct or Bending) | 2,000 psi min. |
| d. | Specific Gravity | 70 to 120 lbs./cu.ft. |
| e. | Viscosity at 68°F | 10,000 to 50,000 cps* |
| f. | Coefficient of Thermal Expansion | Within 10% of that for concrete* |

The material shall have a rate of absorption, rate of shrinkage, chemical resistance and weather resistance compatible with concrete and a consistency such that it will not flow appreciably when applied to a vertical concrete surface. The color shall be concrete gray.

The Contractor shall furnish the Engineer a sample of the material for testing, and a certification from a reputable laboratory indicating that the material complies with the above requirements.

The sample of the material submitted will be tested additionally for the following:

a. Ability to join test specimen under the following conditions

| | |
|---|---|
| Temperature Range | 50°F to 100°F |
| Surface Conditions | Dry to Moist |

(Moist is defined as "one hour drying after complete saturation".)

b. The joint material shall be able to develop 95 percent of the flexural tensile strength and 70 percent of the shear strength of a monolithic test specimen.

The test specimen shall be made of concrete having a minimum compressive strength of 6,000 psi. The specimen will be tested with both dry and moist surface conditions.

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*See Note, p. 74.

3. CONSTRUCTION METHODS. Surfaces to which the epoxy material is to be applied shall be free from all oil, laitance or any other material that would prevent the material from bonding to the concrete surface. All laitance shall be removed by sanding or by washing and wire brushing.

Mixing of the resin and hardener components shall be in accordance with the manufacturer's instruction. Use of a proper sized mechanical mixer will be required.

The epoxy material shall be applied to all surfaces to be joined within the first half of the pot life as shown on the containers.

The coating shall be smooth and uniform and shall cover the entire surfaces to be joined with a maximum thickness of 1/16 inch. The units shall be joined within 45 minutes after application of the epoxy material.

No jointing operations shall be performed when the ambient temperature is below 50°F or above 100°F. When the temperature is above 85°F the epoxy coated surfaces shall be shaded from direct sunlight.

If the jointing is not completed within 45 minutes after application of the epoxy material the operation shall be stopped and the epoxy material shall be completely removed from the surfaces. Fresh material shall be applied to the surfaces before resuming jointing operations.

4. MEASUREMENT AND PAYMENT. No direct measurement or payment will be made for the materials, work to be done or equipment to be furnished under this item, but it shall be considered subsidiary to the particular items required by the plans and the contract.

Note: In October, 1972, Special Specification Item 2131 was modified as follows at the request of the contractor and with Texas Highway Department approval.

2(e) Viscosity at 68°F - 90,000 to 120,000 cps.
Viscosity was changed to increase the thixotrophy for use on vertical surfaces.

2(f) Coefficient of thermal expansion. No requirement.
Requirement deleted as impractical to fulfill.