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Development Of A Rebar Dowel Anchorage System For Attaching The California Type 25 Concrete Barrier To Existing Bridges

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7. AUTHOR(S)
J.P. Dusel, Jr., J.R. Stoker, E.F. Nordlin

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This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration for the project title "Development of a Rebar Dowel Anchorage System for Attaching the California Type 25 Concrete Barrier to Existing Bridges".

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The objective of this research was to develop a satisfactory anchorage system for attaching New Jersey-shaped concrete bridge replacement barrier onto existing concrete decks.

Initially dynamic pullout tests of rebar dowels bonded in shallow drilled holes in a reinforced concrete slab were conducted to develop methods which would maximize pullout strengths. Important test parameters included rebar diameter, hole depth, and type of bonding material. Ultimate pullout loads ranging from 25.0 kips to 34.8 kips were attained with individual #6 rebar dowels bonded in 6-inch-deep holes.

Secondly, static load tests were performed on standard California Type 25 Concrete Barrier and replacement barriers constructed on a typical concrete bridge deck to determine maximum horizontal loads which could be resisted. In preliminary tests, two 3-foot lengths of replacement barrier, attached with grouted #6 rebar dowels, withstood higher horizontal loads than did the standard Type 25 Concrete Barrier. A 16-foot-long replacement barrier, tested subsequently and anchored using #6 grouted rebar dowels, withstood a maximum static horizontal load of 93 kips applied to a concentrated area about 26 inches above the deck surface.

Recommendations are made to use a drill-and-bond procedure for attaching replacement barrier to existing bridge decks.

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Bridge rails, barriers, barrier types, replacements, anchor rods reinforcing steel, dowels, grouting

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

June 1979

FHWA No. D-4-149
TL No. 636871

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

DEVELOPMENT OF A REBAR DOWEL ANCHORAGE SYSTEM FOR ATTACHING THE CALIFORNIA TYPE 25 CONCRETE BARRIER TO EXISTING BRIDGES

Study made by .... Structural Materials Branch

Under the Supervision of ..... E. F. Nordlin, P.E.

Principal Investigator .... J. R. Stoker, P.E.

Co-Investigator .... J. P. Dusel, Jr., P.E.

Report Prepared by .... J. P. Dusel, Jr., P.E.

Very truly yours,

Neal Andersen

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

JPD:db

Attachment

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Leonard A. Nordman George K. Oki	Fabrication of Fixtures
Albert Sequeira Richard L. Johnson William A. Ng	Instrumentation
David A. Wong Donald R. Smith	Concrete and Grout Cylinder Testing
Darla Bailey Kathy Raymond	Typing
Elmer Wigginton	Drafting

The authors also wish to thank Mr. Ralph Bishop of the Office of Structures for providing valuable technical consultation.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph)	.4470	metres per second (m/s)
	feet per second(fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs)	4.448	newtons(N)
	kips (1000 lbs)	4.448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1.356	joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs)	.1130	newton-metres (Nm)
	foot-pounds(ft-lbs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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1. INTRODUCTION

One extremely important safety feature of California's current highway network is the extensive barrier system which protects errant automobiles from fixed roadside objects and other dangerous exposures, properly redirects them with the normal traffic flow and minimizes injuries to the occupants. Some of the most important barriers are positioned along the edges of bridges to provide protection from the serious consequences of a vehicle falling from a bridge.

Many improvements and changes have been made in bridge barriers since the construction of the first wooden bridge railings in the early history of California transportation. These changes have come about as a result of (1) changes in mode of transportation, (2) vehicle type, design, size and speed, (3) highway alignment and geometry, (4) traffic volume, and (5) increasing concern for the safety of the traveling public.

Concrete or steel baluster-type bridge railings were popular until the 1950's. These railings were adequate for the early era of the automobile. However, as the speed, size and weight of vehicles and the traffic volumes increased in the second half of this century, some undesirable features developed and became apparent in this type of bridge railing. Impacting vehicles sometimes became snagged or "trapped" on the vertical posts that support the horizontal rail. Also these types of rails were not always structurally adequate to retain larger and/or higher speed vehicles under severe impact conditions.

Early in the 1950's, the California Division of Highways (currently the California Department of Transportation or Caltrans) initiated a program to develop more effective bridge barriers for larger, higher speed vehicles. Over the succeeding years, various types of new bridge barriers were developed, tested, and used, including California Types 1, 2, 8, 9, 15 and 20. In 1973, Caltrans developed and began to use a bridge barrier design designated as "Concrete Barrier Type 25", shown in Appendix A, which has a New Jersey profile as did the earlier tested Type 20 Concrete Bridge Barrier. The Type 25 Concrete Bridge Barrier is a 32-inch-high, reinforced concrete barrier and, unlike the Type 20 Barrier, does not utilize a secondary metal top rail system.

The overall performance of the Type 25 Concrete Bridge Barrier has proven to be superior to other types of bridge barriers tested and used in California to date. It effectively redirects impacting vehicles and, at shallow impact angles, collisions with the barrier result in minimal damage to impacting vehicles and occupants. The extremely low maintenance costs of this type of bridge barrier also make its continued use very attractive.

Currently, an estimated 7,000,000 linear feet of the older style baluster-type bridge railing exist along the edges of bridges in California. In an effort to upgrade safety features of older bridges, Caltrans is replacing previously constructed bridge railings with the Type 25 Concrete Bridge Barrier.

Normally, the Type 25 Concrete Bridge Barrier is anchored to concrete deck overhangs of new bridges using reinforcing bars cast in the concrete when the deck slab is poured. The purpose of this research was to develop a sufficiently strong yet economical method of attaching replacement barriers to existing concrete bridge decks where the older style baluster-type railing has been removed. In this research, a successful attachment procedure using rebar dowels bonded in shallow drilled holes was tested. By using this drill-and-bond anchorage method, the costly process of removing and recasting the outer portion of the bridge deck overhang with new cast-in-place anchorage reinforcement could be avoided. The word "bond" is used throughout this report in its broadest sense to mean "to secure or to cause to adhere firmly". Its employment is not intended to imply the usage of any one particular type of adhesive.

At the beginning of this project, an investigation was performed to determine dynamic pullout strengths of #5 and #6 rebar dowels bonded in shallow drilled holes and to perfect an installation procedure for developing optimum pullout strengths of the bonded rebar dowels.

Following the development of a satisfactory bonding procedure for anchoring rebar dowels, six full-scale sections of bridge barrier, attached using various rebar anchorage systems, were constructed on a simulated bridge deck. The full-scale barrier sections were tested by applying static horizontal loads to determine how strengths of replacement barriers anchored using grouted rebar dowels compared with that of the conventional or standard Type 25 Concrete Bridge Barrier. Results of dynamic pullout tests of rebar dowels and static load tests performed on the various barrier sections are discussed in this report.

2. OBSERVATIONS AND CONCLUSIONS

2.1 Discussion of Rebar Pullout Tests

A complete listing of the rebar dynamic pullout strength test data is presented in Table 4, Section 5.1 of this report. The load-deflection curves, shown in Appendix B, were drawn from actual plots made during pullout tests in a 7-inch-thick reinforced concrete slab. It should be mentioned that important factors such as different curing times and temperatures of bonding materials and, in the first phase of pullout tests, tensile failure in the reduced threaded sections at the top end of many #6 rebars may have somewhat affected the shapes of the load-deflection curves. After analyzing the data, the following conclusions about the important parameters have been made.

2.1.1 Rebar Pullout Strength

A summary of average dynamic pullout strengths of bonded rebar dowels calculated from results in Table 4, page 73 of this report is shown in the following Table 1. As seen, average pullout strengths for #5 and #6 rebars bonded in 5-inch-deep holes with Type II Modified portland cement grout are 22.6 kips and 21.3 kips respectively. For the same grout type, pullout strengths increase to 29.1 and 29.8 kips for #5 and #6 rebars respectively by increasing the embedment depth of 6 inches. In general, dynamic pullout strengths obtained from rebars embedded in holes 6 inches deep and bonded with the other materials tested are about the same as those obtained with the Type II Modified portland cement grout. At the 5-inch embedment depth, pullout strengths of rebars bonded using the other bonding materials are slightly lower than those bonded with the portland cement grout.

Table 1. Average ultimate pullout strengths of individual rebar dowels bonded in shallow holes.

Average ultimate pullout strengths (kips) of individual rebar dowels, bonded with various materials

Embedment depth, inches	Rebar size	Type II Modified portland cement grout	Wil-X shrinkage compensating cement grout	Epoxy mortar (Specification No. 8040-61J-03)	Bostik-275 quick-set mortar
5	#5	22.6	-	18.9	-
	#6	21.3	16.5	20.1	-
6	#5	29.1	-	26.2	-
	#6	29.8	28.2	30.0	30.2

Notes: 1. Dashed line (-) indicates no tests were conducted.

2. Each result shown above is an average of two identical tests.

3. For further information about tests, refer to Table 4, Section 5.1 of this report.

2.1.2 Rebar Size (#5 and #6 rebar tested)

In general, especially at embedment depths of more than 5 inches, the use of #6 rebar resulted in larger average dynamic pullout strengths than were obtained with #5 rebar, most likely due to greater bond area.

2.1.3 Embedment Depth (5 and 6 inches tested)

5 inches:

° As expected at such a shallow embedment depth, results of pullout strengths were somewhat erratic with pullout loads attained with some #5 rebars exceeding those of the #6 rebars.

° Both #5 and #6 rebars bonded with Type II Modified portland cement grout at this embedment depth, gave the most consistent results and generally provided a constant or slightly increasing tensile load resistance beyond the yield point of the system (see Appendix B-1).

° Rebars bonded with epoxy mortar, on the other hand, seemed to provide decreasing load resistance beyond the system yield point and inconsistent results (see Appendix B-2).

6 inches:

° In general, for all systems tested at a 6-inch embedment depth, pullout strength results seemed to be more consistent and follow a more logical pattern than for systems where a 5-inch depth was used. Average pullout strengths of rebars embedded 6 inches into the concrete slab were approximately 40 percent higher than those at the 5-inch embedment depth.

- Highest pullout resistance was achieved using Bostik-275 mortar.

- Load-deflection curves of rebar specimens bonded with Type II Modified portland cement grout were the most consistent and uniform.

- #6 rebars provided consistently higher pullout strengths than did the #5 rebars.

- Average pullout strengths of rebar specimens bonded with either epoxy mortar or Type II Modified portland cement grout were almost identical.

2.1.4 Hole Diameter, Drilling Method, and cleaning procedures

- A criterion of requiring the hole diameter to be 1/4 inch greater than the nominal rebar diameter worked well.

- The impact drill equipped with a carbide-tipped bit worked well and produced a rough-sided hole, desirable for good mechanical bond of grouting materials, provided the holes were blown clean with compressed air.

- Pullout strengths of rebars bonded in rough-sided holes were increased considerably by additionally cleaning holes thoroughly with a brush and water after drilling operations had been completed (3).

- At a minimum embedment depth of 6 inches, pullout strengths of rebars bonded in smooth-sided holes, produced using a diamond-impregnated core bit, were high. The maximum pullout strengths were about equivalent to those obtained in tests run where rough-sided holes were made using a carbide-tipped bit with rotary impact hammer and blown clean with compressed air only.

2.1.5 Choice of Bonding Materials

- Initial material costs of the four different bonding materials tested, (1) Type II Modified portland cement grout, (2) epoxy mortar, (3) Wil-X cement grout, and (4) Bostik-275 mortar, have been summarized in Appendix F. Type II Modified portland cement grout is obviously the most economical and probably the easiest to use. Epoxy mortar is the least economical.

- Although the ultimate pullout strengths of rebar bonded with Type II Modified portland cement grout and epoxy mortar are comparable, epoxy mortar requires more thorough mixing and critical measuring of the components than any other bonding material tested.

Some of the additional limitations and potential problems with using epoxy bonding material should be pointed out. These include:

(1) The potential danger of severe dermatitis if epoxy is allowed to come in contact with the skin or eyes.

(2) Possible problems with obtaining satisfactory bond and pullout strength if the epoxy mortar is applied in damp or wet holes.

(3) The uncertainty of the effects of age or shelf life of the epoxy on its strength.

- Neither Wil-X cement nor Bostik-275 cement are as common or readily available as either portland cement or epoxy. Furthermore, the ultimate pullout strengths of rebar bonded with these proprietary cements were not significantly different from the pullout strengths obtained with rebar bonded with portland cement grouts or epoxy resin to strongly recommend their use.

2.1.6 Barrier Design and Rebar Dowel Installation Criteria

° Because relatively high ultimate pullout strengths were achieved in most tests where used, #6 rebar having an embedment depth of 6 inches appears to be the most reliable and should be the minimum rebar size and embedment depth specified for post-bonded rebar dowel systems attaching replacement barrier to bridge decks. This is provided the deck thickness is sufficient to permit this embedment depth to be attained.

° A pullout movement or deflection of 0.01 inch seems to be a good overall approximation of an average deflection where "system yield" of the post-bonded rebar dowel occurs from the drilled hole.

It should be fully understood that the results obtained from these controlled rebar pullout tests should be considered as optimum. In order to achieve good results from actual field installations of post-bonded rebar dowels for anchoring barriers, all important installation details and procedures used in this research and recommended in this report should be clearly explained in the special provisions or specifications, and understood by inspectors and construction workers. The most important factors to be stressed include:

(1) Drilling dowel holes to the proper diameter (1/4 inch larger than nominal rebar size) using a method that will not damage adjacent concrete.

(2) Cleaning holes thoroughly to remove dust and other deleterious material prior to grouting.

(3) Soaking holes thoroughly with water (in instances where portland cement grout is used) and then removing excess water just prior to grouting.

(4) Mixing the bonding material using proper proportions.

(5) Not allowing more water to be added than is originally specified, in order to make the grout more pourable (in the case of portland cement grout).

(6) Adequate curing of the Type II Modified portland cement grout used to bond the rebar dowels.

2.2 Discussion of Barrier Tests

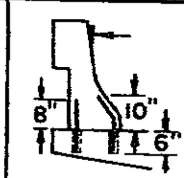
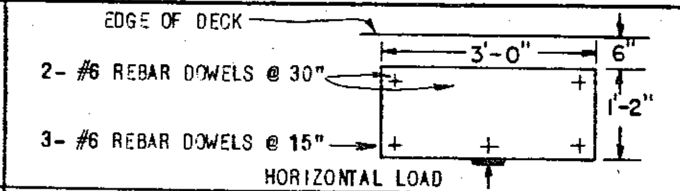
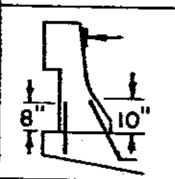
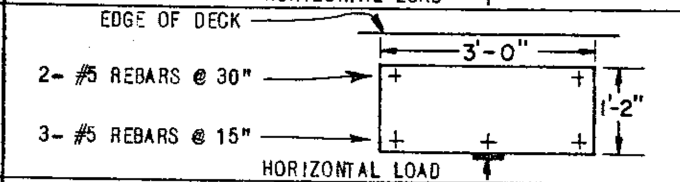
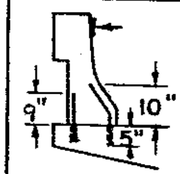
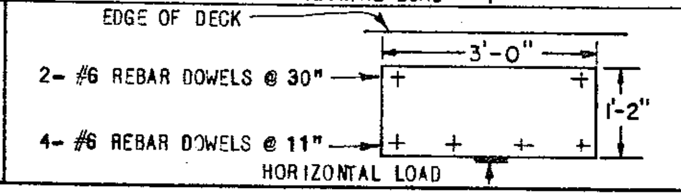
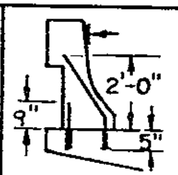
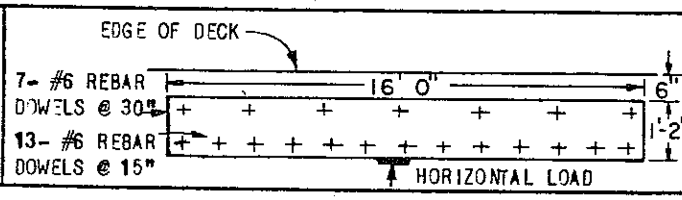
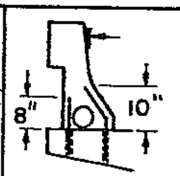
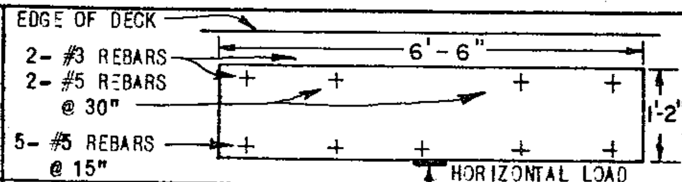
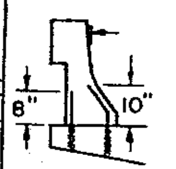
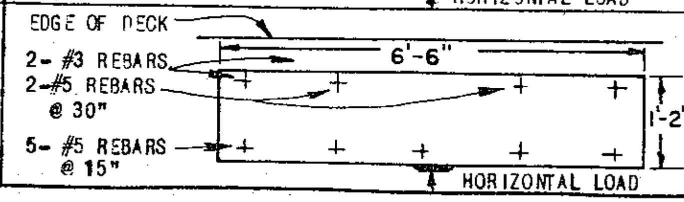
2.2.1 General Comments

In the various sections of barriers evaluated in Test Series I and II, the static horizontal load resistance of the barriers anchored to the bridge deck with grouted rebar dowels proved to be superior to the static overturning load resistance provided by the standard Type 25 Concrete Bridge Barrier. Test Series III was conducted to confirm the design standards for a Modified Type 25 Concrete Barrier containing 6-inch-diameter utility duct. A summary of the six barrier tests conducted in Series I, II and III is shown in Table 2.

2.2.2 Series I Tests: Three 3-Foot-Long Barriers

The two 3-foot-long replacement barrier test sections attached to the bridge deck with portland cement-grouted #6 rebar dowels withstood higher horizontal loads than did the standard Type 25 Concrete Bridge Barrier section having cast-in-place

Table 2. Summary of results from Series I, II, and III static load tests on bridge barriers.

SERIES - TEST NO.	TYPE & LENGTH OF BARRIER	DESCRIPTION OF REBARS USED TO ANCHOR BARRIER SECTIONS: GENERAL DESCRIPTION OF ANCHORING REBARS	CROSS SECTION SHOWING REBAR EMBEDMENT	PLAN VIEW OF BARRIER BASE SHOWING LOCATIONS OF ANCHORING REBARS	MAXIMUM HORIZONTAL LOAD, kips
I-1	Type 25 Replacement Barrier, 3 feet long	#6 REBAR DOWELS, BONDED WITH TYPE II MODIFIED PORTLAND CEMENT GROUT IN HOLES 6 INCHES DEEP			41.2
I-2	Standard Type 25 Concrete Barrier, 3 feet long	#5 REBARS, CAST-IN-PLACE			28.7
I-3	Type 25 Replacement Barrier, 3 feet long	#6 REBAR DOWELS, BONDED WITH TYPE II MODIFIED PORTLAND CEMENT GROUT IN HOLES 5 INCHES DEEP			34.3
II-1	Type 25 Replacement Barrier, 16 feet long	#6 REBAR DOWELS, BONDED WITH TYPE II MODIFIED PORTLAND CEMENT GROUT IN HOLES 5 INCHES DEEP			93.0
III-1	Modified Type 25 Concrete Barrier w/6"Ø conduit 6½ feet long	#3 AND #5 REBAR DOWELS, EMBEDDED DEEPLY INTO THE DECK OVERHANG TO SIMULATE CAST-IN-PLACE REBARS OF A STANDARD TYPE 25 BARRIER			34.9
III-2	Standard Type 25 Concrete Barrier, 6½ feet long	#3 AND #5 REBAR DOWELS, EMBEDDED DEEPLY INTO THE DECK OVERHANG TO SIMULATE CAST-IN-PLACE REBARS OF A STANDARD TYPE 25 BARRIER			44.5

#5 rebars anchoring the barrier to the bridge deck (see Table 2). The barrier section (Test No. 1) with rebar dowels grouted in 6-inch-deep holes withstood a horizontal load of 41.2 kips, about 20 percent higher than the barrier with #6 rebars grouted in 5-inch-deep holes (34.3 kips) anchoring the barrier to the deck, and over 40 percent higher than the standard type 25 Concrete Bridge Barrier anchored with cast-in-place #5 rebars (28.7 kips).

Thus, the drill-and-bond rebar dowel method used to anchor the two 3-foot-long barrier test sections to the bridge deck provides at least as much overturning resistance as the anchorage system utilizing #5 cast-in-place rebars for standard Type 25 Concrete Barriers installed on new bridges.

A weak point observed in the rebar designs of each of the 3-foot-long barrier segments tested was the minimal length of the upper tails of the rebar dowels along the front face of the barrier. These tails extended only 10 inches above the deck surface into the barrier. Failure of two of the three short barriers resulted because of lack of bond of these upper tails of anchoring rebars.

2.2.3 Series II Test: One 16-Foot-Long Barrier

The scheme used to anchor the 16-foot-long replacement barrier to the bridge deck in Test Series II was comprised of thirteen #6 rebar dowels along the front face of the barrier spaced at 15 inches and seven #6 rebars spaced at 30 inches along the edge-of-deck side of the barrier. All rebar dowels were bonded with Type II Modified portland cement grout and installed in drilled holes 5 inches deep (see Table 2). This anchoring rebar configuration, considered to be the minimal acceptable design which would be used on older bridges with thin bridge decks, was found to provide a horizontal load resistance of 93 kips. This anchorage system was deemed to provide protection equal to that of a standard Type 25 Concrete Bridge Barrier and thus ample resistance to contain a 4500-pound passenger car traveling at 60 mph at a 25° impact angle.

2.2.4 Series III Tests: Two 6 1/2-Foot-Long Barriers

In Barrier Test Series III, two 6 1/2-foot-long barrier sections were tested. The first 6 1/2-foot-long barrier section tested contained a 6-inch-diameter utility conduit in the center of its lower base portion (see Figure 11, page 43). This test section withstood a maximum horizontal load of 34.9 kips.

The second section, having an anchorage reinforcement scheme similar to that of a standard Type 25 Concrete Bridge Barrier, withstood a maximum horizontal load of 44.5 kips before failure, approximately 27 percent higher than the maximum load withheld by the barrier with the conduit. The failure mode observed was similar to that of the three foot long standard barrier section which withheld a maximum horizontal load of 28.7 kips (Test No. 2) which was tested in Series I. In this second Series III test, a horizontal crack in the concrete was initiated in the face of the standard barrier just above the top tails of the front row of #5 anchoring rebar dowels and extended diagonally through the barrier section (see Figure 38, page 96). The crack was caused by a lack of vertical steel reinforcement, needed to carry the high tensile loads in the concrete near the surface of the barrier face.

Thus the strength of the modified barrier containing the 6-inch-diameter conduit is not considered to be equivalent to that of a standard Type 25 Concrete Barrier. However, even though this relatively short 6 1/2-foot-long section of barrier with conduit proved to be somewhat weaker under a static load than a comparable short length of standard concrete barrier without conduit, a longer length, say 10 to 12 feet, of the barrier containing the conduit tested dynamically might prove to meet requirements for barriers in the Transportation Research Circular Number 191(3).

3. RECOMMENDATIONS AND IMPLEMENTATION

3.1 Recommendations

On the basis of the results of the dynamic pullout tests conducted on rebar dowels bonded in shallow drilled holes in a reinforced concrete slab and various static horizontal load tests performed on sections of bridge barrier during this research study, the following recommendations are made:

3.1.1 Rebar Size

It is recommended that #6, ASTM Designation A615, Grade 60 rebars be used for all anchoring dowels to be bonded in drilled holes.

3.1.2 Hole Depth or Rebar Embedment Lengths

Wherever possible, a minimum embedment or hole depth of 6 inches should be required for the rebar dowels installed along the traffic side of the barrier. For these dowels, hole depths of slightly less than 6 inches should only be allowed in special cases where deeper holes are not possible and where the strength of the deck concrete is adequate. Rebar embedment lengths of less than 5 inches should not be allowed in any case. For the row of rebar dowels installed at the barrier base and adjacent to the edge of the bridge deck, a minimum embedment depth of 5 inches is satisfactory. It should be emphasized that such small hole depths recommended above will only provide acceptable pullout strengths if rebars are installed with similar bonding materials and following the detailed installation procedures used in this research study and outlined in Section 3.1.3 of this report.

3.1.3 Rebar Dowel Bonding Procedures

From results obtained while performing rebar pullout tests, it is recommended that current specifications concerning the installation of bonded rebar dowels in drilled holes, namely, Caltrans Standard Special Provision B51.61 and Caltrans 1978 Standard Specification, Section 51-1.13, be revised. It is felt that such specifications are incomplete when requiring the installation of post-grouted dowels for critical structural applications, especially where high pullout strengths of bonded rebar dowels installed in extremely shallow holes, 5 and 6 inches deep, are required. It is recommended that these current specifications be modified to include the following minimal information:

DRILL AND BOND DOWELS--Requirements for drilling and bonding rebar dowels shall conform to the details shown on the plans, and the provisions in Section 51-1.13, "Bonding" of the Standard Specifications and these special provisions.

The reinforcing steel dowels shall conform to the provisions in "Reinforcement" of these special provisions.

General Procedures

Rebar dowels shall be installed using the following procedures:

(1) Where dowels are to be bonded in holes drilled into existing concrete, the holes shall be drilled by methods that will not shatter or damage the concrete adjacent to the holes.

(2) The diameter of the drilled holes shall be 1/4 inch larger than the nominal rebar dowel size, unless otherwise specified.

(3) Holes shall be thoroughly cleaned of dust and other deleterious material.

(4) Either a Type II Modified portland cement grout or an epoxy mortar shall be used for bonding rebar dowels into drilled holes. Specific instructions for use of each bonding material are to be followed carefully as described below:

Type II Modified portland cement grout:

a. The grout shall consist of a neat cement paste, made from water mixed with a Type II Modified portland cement meeting the requirements of Section 90-2.01 of the Caltrans Standard Specifications. The mixing ratio shall be 4 gallons of water/94 pounds of cement. No change in this mixing ratio shall be permitted unless approved by the Engineer.

b. Clean holes shall then be saturated thoroughly with water for a minimum of 5 minutes prior to placing grout. Immediately prior to grouting, all free water shall be removed from holes.

c. Only as much grout shall be mixed as can be used in a reasonable amount of time.

d. After the initial mixing, thinning or retempering of grout with extra water shall not be allowed. Hardened or set grout which has become too stiff or dry to provide a good bond shall be discarded.

e. Dowels shall not be installed if the mean air or grout temperatures are less than 45°F. Furthermore, after placing, the fresh grout shall be maintained at a temperature of not less than 45°F for 72 hours, and at not less than 40°F for an additional 4 days.

f. The temperature of the mixed grout, immediately before placing, shall be not less than 50°F nor more than 90°F.

g. The cement grout shall be cured continuously with either wet rags or a satisfactory curing compound for a minimum period of 3 days without disturbing the dowels.

Epoxy Mortar:

(1) The epoxy mortar shall consist of a mixture of epoxy conforming to State Specification 8040-61J-03, described in Section 95-2.01 of the 1978 Caltrans Standard Specifications, and an equal volume of 16x30 mesh sand.

(2) The epoxy shall further conform to all general requirements in Caltrans Standard Specification 95-1.

(3) Some of the more important requirements contained in the specifications are that:

a. Temperature of epoxy components shall be between 60°F and 85°F at the time of mixing,

b. holes shall be clean before placing epoxy mortar,

c. concrete surfaces of the drilled holes shall be primed with a coat of epoxy resin just before placing the mortar.

3.1.4 General Reinforcing of Barrier

With respect to reinforcement requirements for Type 25 Replacement Barrier attached to existing concrete bridge decks using rebar dowels bonded in drilled holes for anchorage, it is recommended that the reinforcement scheme shown in Appendix C be adopted for use. If deviations from this suggested plan are necessary, results and recommendations contained in this report should first be considered, then sound engineering judgment should be applied.

3.1.5 Further Research

It is also recommended that full-scale dynamic testing of bridge barriers which are significantly different from the standard Type 25 Concrete Bridge Barrier, such as the barrier containing a 6-inch-diameter duct and tested with static loading in this study, be carried out before such barriers are used on bridges where impact by heavy vehicles at high speeds and large angles is likely.

3.2 Implementation

Results of this research study have already been utilized in a number of contracts where older baluster type bridge railing has been successfully replaced by a Type 25 Replacement Barrier attached to bridge decks with bonded rebar dowels. It has been estimated that a savings of at least $75 per foot of Type 25 Replacement Barrier installed using doweled rebar anchors will be realized. A large portion of this saving results from eliminating the labor and material costs associated with removal and replacement of the concrete deck overhang, tasks formerly necessary to install cast-in-place rebars which anchor the standard Type 25 Concrete Bridge Barrier to the deck overhangs.

The satisfactory bonding procedure for anchoring rebar dowels, developed in this project, will no doubt be applied to other critical structural applications in the future.

4. DESCRIPTION OF EXPERIMENTAL PROGRAM

4.1 Testing Program - General Discussion

In order to develop a satisfactory, economical method of attaching a Type 25 Concrete Bridge Barrier onto an existing concrete bridge deck overhang, the scope of the project was divided into a preliminary testing phase to determine maximum dynamic pullout loads attainable for bonded rebar dowels and three series of full-scale static horizontal load tests on barrier sections. These series of tests on barrier sections are further described as follows:

Series I ° Horizontal or lateral load tests on two short 3-foot-long prototype sections of replacement barrier to compare the static strength of the standard Type 25 Concrete Bridge Barrier installed on new bridge decks to that of replacement barrier prototypes attached to the existing concrete deck with promising rebar doweling installation methods developed in preliminary phase tests.

Series II ° A horizontal lateral load test on a 16-foot-long replacement barrier prototype, anchored with rebar dowels in drilled holes at the previously established minimum spacing embedment depth in order to determine the amount of horizontal load resistance offered by a longer continuous section of concrete bridge replacement barrier.

Series III ° Horizontal or lateral load tests on two 6 1/2-foot-long sections of Type 25 Concrete Bridge Barrier to compare the affect of placing a 6-inch-diameter steel conduit, centered in the bottom portion of the concrete barrier. The conduit would serve as a utility duct. See Figure 11A, page 43.

4.1.1 Construction of the Simulated Bridge Deck

In order to carry out the planned barrier load tests, a 24-foot-long reinforced concrete simulated bridge deck overhang test section was constructed. The dimensions and reinforcing steel sizes and spacings were typical of older bridges built in California. A large beam section was formed adjacent to and continuous with the deck overhang section in order to stabilize the overhang while performing horizontal load tests on various planned replacement barrier prototype test sections and to simulate continuity provided by an exterior reinforced concrete bridge girder. A large earth-supported concrete slab section was built adjacent to and continuous with the deck overhang. This slab, having a thickness of 7 inches and a reinforcing steel pattern similar to that of a typical bridge deck, provided a suitable concrete section to conduct pullout tests on bonded rebar dowels. Figure 1 shows a plan view of the test site and a structural cross section indicating concrete dimensions, as well as size and position of reinforcing steel.

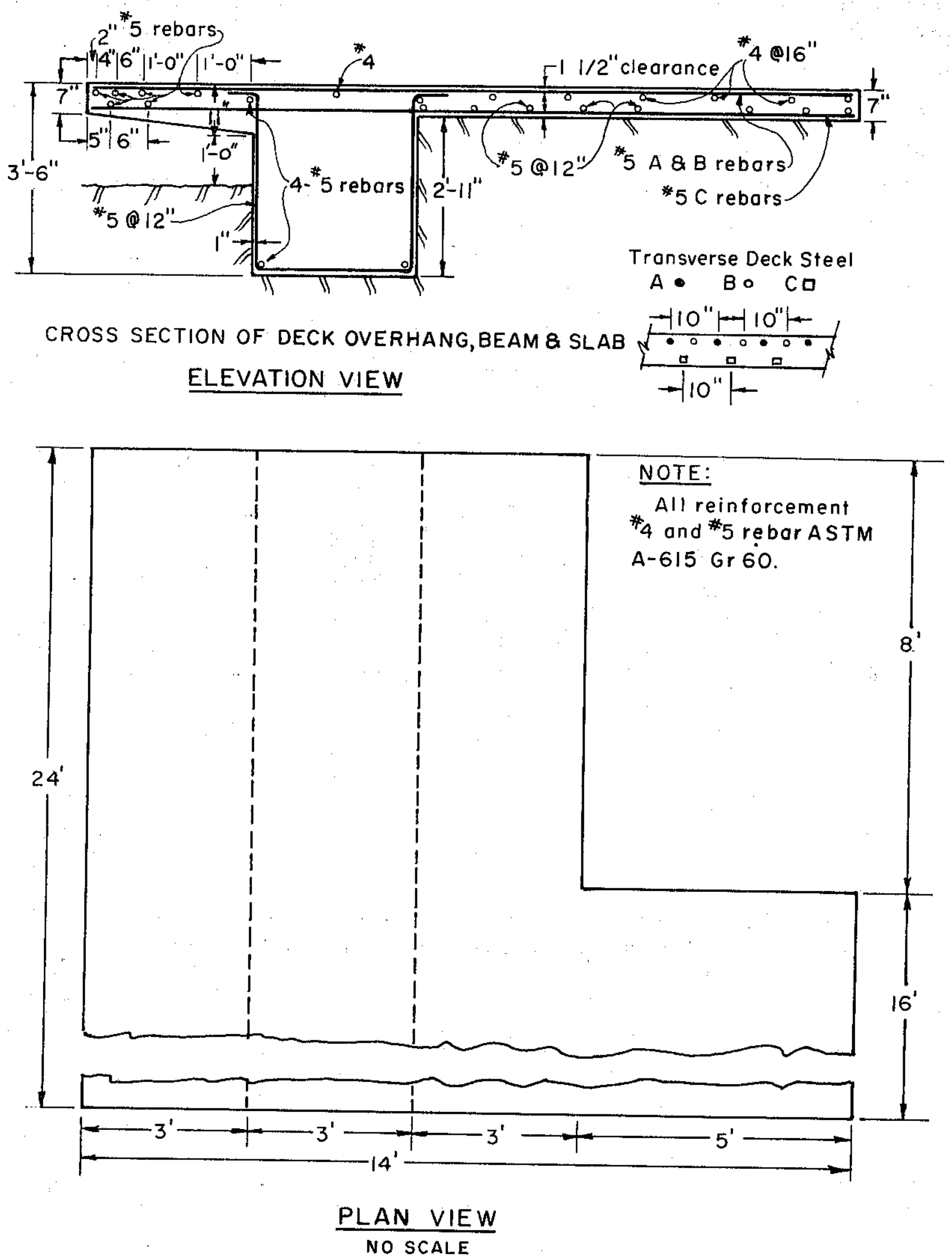


Figure 1. Plan view of simulated bridge deck.

4.1.1.1 Reinforcing steel placement

The reinforcing steel used in the concrete slab, beam, and deck overhang conformed to requirements in ASTM Designation: A615, Grade 60 (see Figure 2). The rebar size and spacing used were similar to those in the Bridge Planning and Design Manual, dated May 1970 (Figure 3). Reinforcing in the deck overhang was positioned as for a typical Type 25 Concrete Bridge Barrier; details are shown in Drawing BO-5, page 85 of the 1975 Caltrans Standard Plans (Figure 4).

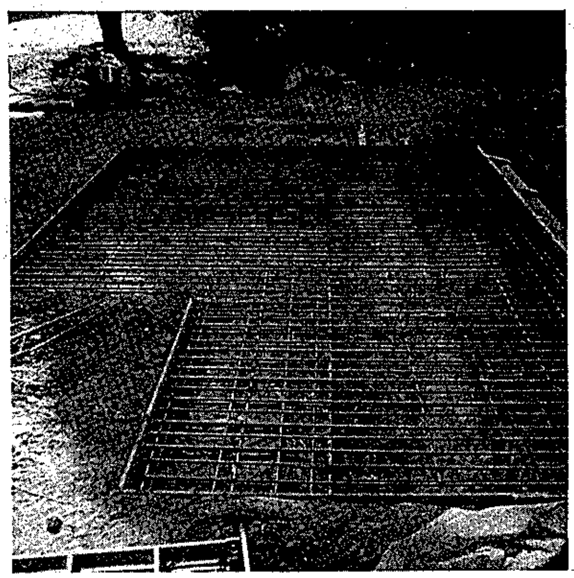
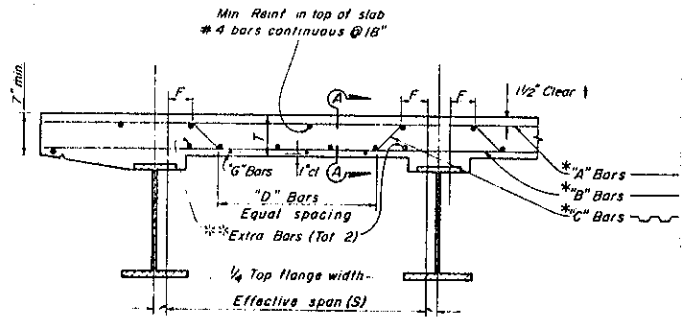
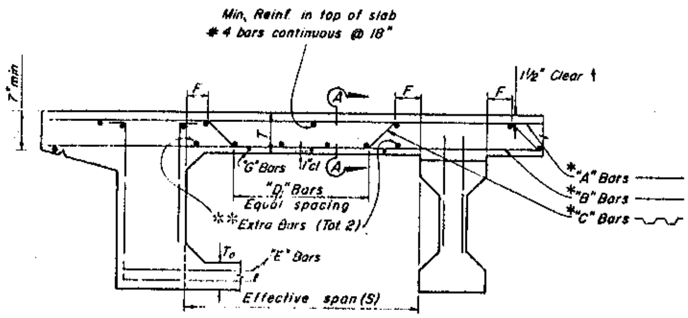


Figure 2. Overall view of test site prior to placing concrete for simulated bridge deck.

SLABS
WITH
TRANSVERSE REINFORCEMENT



SLAB ON STEEL BEAMS



SLAB ON CONCRETE GIRDER

** Add extra "D" bars for S = 11' or greater.

* For curved structures place radially and space along ℄ between edges of deck.

For skews 20° or less place parallel to abutments and bents and space along ℄ structure.

For skews greater than 20° place reinforcement perpendicular to girders. Use A and B bars at acute corners at ½ the given spacing.

† Increase cover over "A" bars and adjust slab thickness in freeze-thaw or marine environments. See Vol. I Sec. 6-4

†† Conventional RC Box Girders. For prestressed box girders use #5 bars of equivalent area.

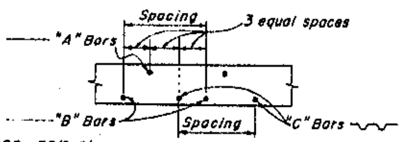
Design Stresses:
f_s = 20,000 lbs. per sq. in.
f_c = 1200 lbs. per sq. in
n = 10

D.L. $M^{lk} = \frac{wS^2}{10}$

L.L. + Imp $M^{lk} = \frac{P(S+2)}{32} \times 1.30 \times 0.80 = .52(S+2)$

w = Weight per lin ft. per ft. width of slab.
S = Effective span
Impact factor 1.30
Continuity factor 0.80
P = Wheel load = 16ᵏ

Distribution Reinforcement:
$220/\sqrt{S}$, max = 67%



SECTION A-A

Notes: Impact factor 30% for all spans
For "slab on concrete girder" spans greater than 10'-6", note the requirements of Article 6-7.2, Vol. I.
For culverts or bridge slabs supporting fill, note provisions of Article 3-2.5, Vol I.
Design based on decks having 3 or more girders. For 2 girder decks a special design is required.

DESIGN DATA

Effect. Span	"T" † Top Slab Thick.	Dim. "F"	ABC Bars Size	ABC Bars Spacing	D Bars No. of #5 Bars	G Bars No. of #4 Bars	"To" Bot Slab Thick. Min.	"E" †† Bars Bot. Slab
4'-0"	6"	6"	5	13"	4	2	5½"	#4@14"
4'-3"	6⅛"	7"		13"	4	2		
4'-6"	6⅛"	7"		12"	4	2		
4'-9"	6¼"	7"		12"	4	3		
5'-0"	6⅜"	8"		12"	4			
5'-3"	6⅜"	8"		12"	4			
5'-6"	6½"	9"		11"	4			
5'-9"	6⅝"	9"		11"	4			
6'-0"	6⅝"	9"		11"	4			
6'-3"	6¾"	10"		11"	4			
6'-6"	6⅞"	10"		11"	4			
6'-9"	6⅞"	11"		10"	5			
7'-0"	7"	11"		10"	5			
7'-3"	7⅛"	11"		10"	5			
7'-6"	7⅛"	1'-0"		10"	6		5⅞"	#4@14"
7'-9"	7¼"	1'-0"		10"	6	3	5½"	#4@13"
8'-0"	7½"	1'-1"	5	10"	6	4	6"	#4@13"
8'-3"	7½"	1'-1"	6	13"	6		6¼"	#4@12"
8'-6"	7⅝"	1'-1"		13"	7		6⅜"	#4@12"
8'-9"	7¾"	1'-2"		13"	7		6⅝"	#4@12"
9'-0"	7¾"	1'-2"		13"	8		6¾"	#4@12"
9'-3"	7⅞"	1'-2"		13"	8		7"	#4@11"
9'-6"	8"	1'-3"		12"	9		7⅛"	#4@11"
9'-9"	8"	1'-3"		12"	9		7⅜"	#4@11"
10'-0"	8⅛"	1'-4"		12"	9		7½"	#4@10"
10'-3"	8¼"	1'-4"		12"	10			
10'-6"	8¼"	1'-4"		12"	10			
10'-9"	8⅜"	1'-5"		12"	10			
11'-0"	8⅜"	1'-5"		12"	11			
11'-3"	8½"	1'-6"		11"	11	4		
11'-6"	8⅝"	1'-6"		11"	12	5		
11'-9"	8⅝"	1'-6"		11"	12			
12'-0"	8¾"	1'-7"		11"	12			
12'-3"	8⅞"	1'-7"		11"	13			
12'-6"	8⅞"	1'-7"		11"	13			
12'-9"	9"	1'-8"		11"	13			
13'-0"	9"	1'-8"		11"	14			
13'-3"	9⅛"	1'-9"		10"	14			
13'-6"	9¼"	1'-9"		10"	15			
13'-9"	9¼"	1'-9"		10"	15			
14'-0"	9⅜"	1'-10"		10"	15			
14'-3"	9½"	1'-10"		10"	16			
14'-6"	9½"	1'-11"		10"	16			
14'-9"	9⅝"	1'-11"		10"	16			
15'-0"	9¾"	1'-11"		10"	17	5		
15'-3"	9¾"	2'-0"	6	10"	17	6		
15'-6"	9⅞"	2'-0"	7	13"	17			
15'-9"	10"	2'-1"		13"	17			
16'-0"	10"	2'-1"		13"	18			
16'-3"	10⅛"	2'-1"		13"	18			
16'-6"	10¼"	2'-2"		13"	19			
16'-9"	10¼"	2'-2"		12"	19			
17'-0"	10⅜"	2'-3"		12"	19			
17'-3"	10½"	2'-3"		12"	20			
17'-6"	10½"	2'-3"		12"	20			
17'-9"	10⅝"	2'-4"		12"	20			
18'-0"	10¾"	2'-4"		12"	21	6		
18'-3"	10¾"	2'-4"		12"	21	7		
18'-6"	10⅞"	2'-5"		12"	21			
18'-9"	10⅞"	2'-5"		11"	22			
19'-0"	11"	2'-6"		11"	23			
19'-3"	11⅛"	2'-6"		11"	23			
19'-6"	11¼"	2'-6"		11"	23			
19'-9"	11¼"	2'-7"		11"	23			
20'-0"	11⅜"	2'-7"	7	11"	24	7		

Figure 3. Size and position of reinforcing steel in a typical bridge deck.

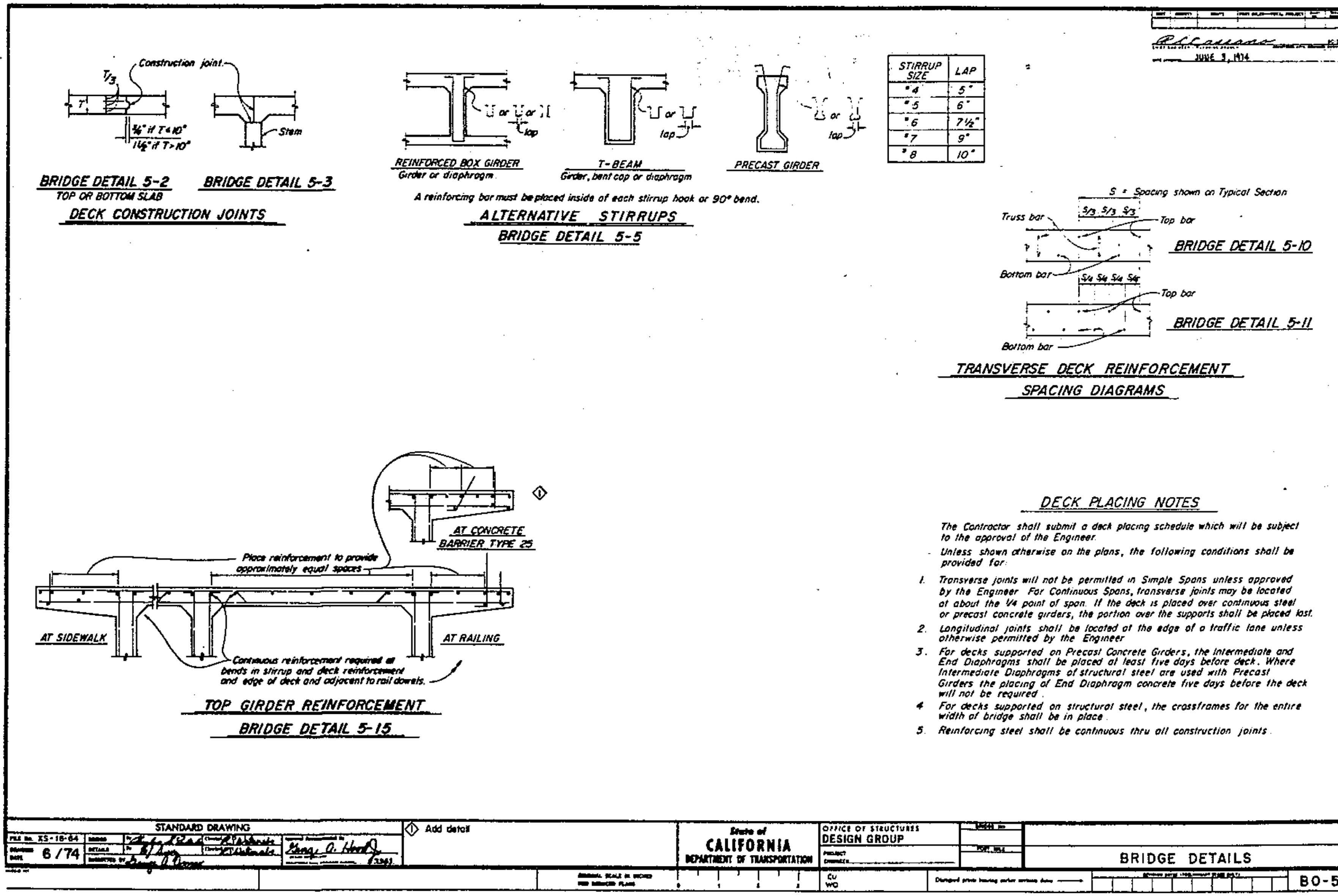


Figure 4. Position of reinforcing steel in a bridge deck overhang beneath a Type 25 Concrete Bridge Barrier.

4.1.1.2 Concrete design and placement

A class "A" concrete mix design, conforming to California Department of Transportation 1978 Standard Specifications(8) was used in the slab, beam, and deck overhang. A concrete mix having a maximum coarse aggregate size of 1 1/2 inches and a consistency not exceeding 2 inches of ball penetration was used to simulate typical concrete used in bridge decks.

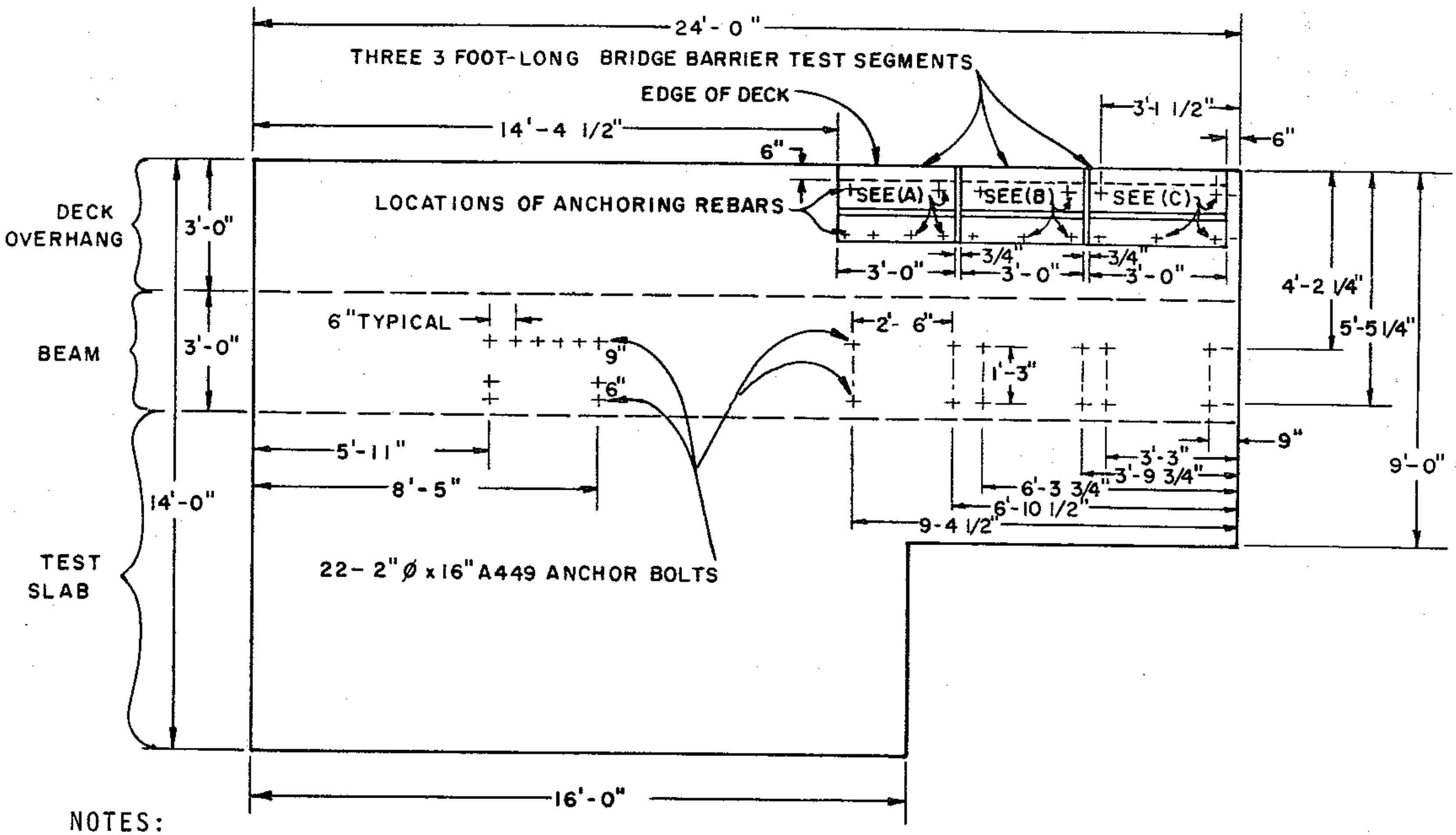
The surface finish of the concrete was performed according to Section 51-1.17, Finishing Bridge Decks, of the 1978 Caltrans Standard Specifications(8). The surface was struck off, floated longitudinally, and scoured transversely with a stiff bristled broom. Eight 6-inch-diameter by 12-inch-high concrete cylinders were made to determine the compressive strength of the deck concrete at the time the rebar pullout tests and barrier load tests were performed.

Curing - The surface of the concrete was water cured for seven days. An automatic sprinkler system adjacent to the site was used for this purpose.

At the end of the curing period, the wooden forms were removed from under the deck overhang to eliminate any additional support they might provide while conducting horizontal loading tests on the barrier sections.

4.1.1.3 Placement of anchor bolts for barrier loading fixture

In order to anchor a heavy loading fixture (see Figures 22 and 23, page 66) so that a horizontal load could be applied to the various sections of concrete barrier, twenty-two high strength anchor bolts were cast in the concrete deck and ballast beam. These bolts were 2 inches in diameter by 16 inches long, and conformed to Specifications in ASTM Designation: A449. Ten of the bolts were installed so that a specially designed fixture could be attached to the concrete deck and beam section for loading the 16-foot-long barrier test section. The remaining twelve bolts were installed within the deck and beam section, four each in three adjacent locations, for loading the three short 3-foot-long barrier test sections. A plan view showing the location and pattern of the anchor bolts is attached (see Figure 5).



NOTES:

(A) Replacement Barrier anchored to concrete deck with #6 rebar dowels, embedded 5 inches, and bonded with Type II Modified portland cement grout.

(B) Replacement Barrier anchored to concrete deck with #6 rebar dowels, embedded 6 inches, and bonded with Type II Modified portland cement grout.

(C) Standard Type 25 Concrete Barrier anchored to concrete deck with #5 rebars cast-in-place.

Figure 5. Plan view of test site showing locations of short barrier sections, and anchor bolts for attaching loading fixture.

4.1.2 Preliminary Testing - Rebar Dowel Pullout Strengths

A total of twenty-three dynamic pullout tests were performed in the preliminary phase tests (Phase A and B) on #5 and #6 rebar dowels shallowly embedded in holes drilled in the 7-inch-thick simulated bridge deck slab. The rebars were bonded in the holes using various grouts and mortars.

Variables in these tests included rebar size (#5 and #6) hole depth (5 and 6 inches), and the following types of bonding material:

- Type II Modified portland cement grout.
- Epoxy mortar.
- Wil-X cement grout.
- Bostik-275 quick set mortar.

A further description of these bonding materials is presented in Section 4.2.2 of this report.

The following parameters in this preliminary test phase were held constant.

- type of rebar: Grade 60 (ASTM A615)
- hole diameter: 1/4" larger than nominal bar diameter
- drilling method: carbide-tipped drill w/rotary impact hammer
- strength of concrete slab: 5100 ± psi.

The discussion which follows details how the preliminary pullout tests were conducted:

4.1.2.1 Hole preparation

A rotary impact hammer with carbide-tipped bits was used to drill all holes. This method produced rough-sided holes which provided for good mechanical interlock and keying action of the grout to the concrete.

Proper depths of holes were easily controlled by measuring the shaft of the bit and placing a band of tape around the bit at the desired point. The depths of finished holes were again checked with a metal scale.

In order to maintain a hole axis normal to the surface of the concrete slab, a 2-inch-diameter pipe stub three inches long was placed so the pipe axis was perpendicular to the concrete slab surface and the outside edges of the pipe were spaced at an equal distance from the desired center of the hole; while drilling, the carbide bit was kept centered in the top of the pipe stub. To minimize the shrinkage of bonding materials and thus improve rebar pullout strengths, the volume of bonding material was kept at a minimum by drilling holes only 1/4 inch larger in diameter than the nominal rebar size. One of the holes in which the Bostik-275 mortar was placed, however, was drilled 3/8 inch larger in diameter than the nominal rebar diameter because of the high viscosity of the first batch of Bostik-275 mortar.

4.1.2.2 Preparation of rebar dowels

#6 rebar dowels for Phase A Tests: In order to attach the #6 rebar dowels to a pulling rod, two inches of the top end of all rebar dowels were machined with a 5/8-18 UNF thread prior to grouting.

Initial tension tests were performed in the laboratory on similar threaded #6 ASTM A615 Grade 60 rebar dowels to determine maximum steel strengths in the reduced threaded region; these tensile strengths yielded average ultimate strengths of 28.5 kips. Even though the required miminum ultimate strength for an unthreaded Grade 60 #6 rebar is 39.6 kips, it was felt that an ultimate pullout load of grouted rebar embedded six inches into a concrete slab would be less than 25 kips.

Prior to grouting, the rebar dowels were cleaned by immersion in a trichloroethane bath to remove any oil film.

<u>#5 and #6 rebar dowels for Phase B Tests</u>: Because many of the threaded #6 rebar dowels in Phase A failed in the reduced threaded area, the root area of all rebars (both #5 and #6) used in Phase B tests was increased at the coupler junction by welding a threaded #8 rebar stub to the top of each dowel.

Tension tests, conducted in the laboratory to determine ultimate strengths of rebar dowels welded to #8 rebar stubs, produced average tensile strengths of 32.9 kips and 45.4 kips for the #5 and #6 rebars respectively. The required minimum ultimate strengths for #5 and #6 ASTM Designation: A615 grade 60 rebar are 27.9 kips and 39.6 kips respectively.

Again, to remove any oil film from the rebars prior to grouting, the dowels were washed with trichloroethane.

4.1.2.3 Temperature variation during curing of bonded rebar specimens

After grouting, rebar specimens for Phase A tests were cured for 28 days (November 9, 1976 through December 9, 1976). The average mean high and low temperatures during this 28 day curing period were 62°F and 43°F respectively. During the initial 7 day curing period of specimens for the Phase A pullout tests, the temperatures were the highest of any during the total curing period, the mean high and low for the first week being 68°F and 54°F respectively. These high initial temperatures during the most critical period of the curing cycle undoubtedly contributed to the excellent pullout strengths recorded in the Phase A tests.

In Phase B, the rebar dowels bonded with epoxy mortar were cured for a total of 14 days. The mean high and low temperatures for this period (December 13, 1976 through December 27, 1976) were 59°F and 32°F respectively. The test specimens bonded with Type II Modified portland cement grout and Wil-X cement grout were cured 28 days (December 13, 1976 through January 11, 1977). The mean high and low temperatures for this period were 66°F and 39°F respectively. During the first seven days of the curing period for grouted rebar specimens of the Phase B tests, temperatures were considerably colder than were those of the initial curing period for Phase A specimens, the mean high and low being 62°F and 33°F respectively. The colder weather during the initial curing period for Phase B specimens certainly affected the rate of strength gain of the bonding materials.

4.1.3 Full-Scale Static Load Tests on Barrier Sections, Test Series I, II and III

Following the completion of the pullout tests of the rebar dowels, in which a successful procedure for anchoring bonded rebar dowels in shallow holes was developed, horizontal load tests were performed on a total of six barrier sections in three series of tests.

4.1.3.1 Test Series I: Three 3-foot-long barrier tests

The purpose of conducting the Series I tests was to determine if the resistance to shear and overturning of concrete replacement barriers attached to a concrete bridge deck with a grouted #6 rebar dowel system developed in the preliminary pullout tests would be equivalent to those of a standard Type 25 Concrete Bridge Barrier attached to the deck with cast-in-place #5 rebars.

Three 3-foot-long sections of concrete bridge barrier were constructed. Each section had the same shape and exterior cross section dimensions as a standard Type 25 Concrete Bridge Barrier, shown in Appendix A.

To prevent possible concrete barrier failure in the neck region, and to purposely concentrate load on the anchoring rebars at the base of the barrier sections, additional "hair pin" reinforcement, consisting of four #6 rebars, was included in the "neck" regions of each barrier section as shown in Figures 6, 7, and 8.

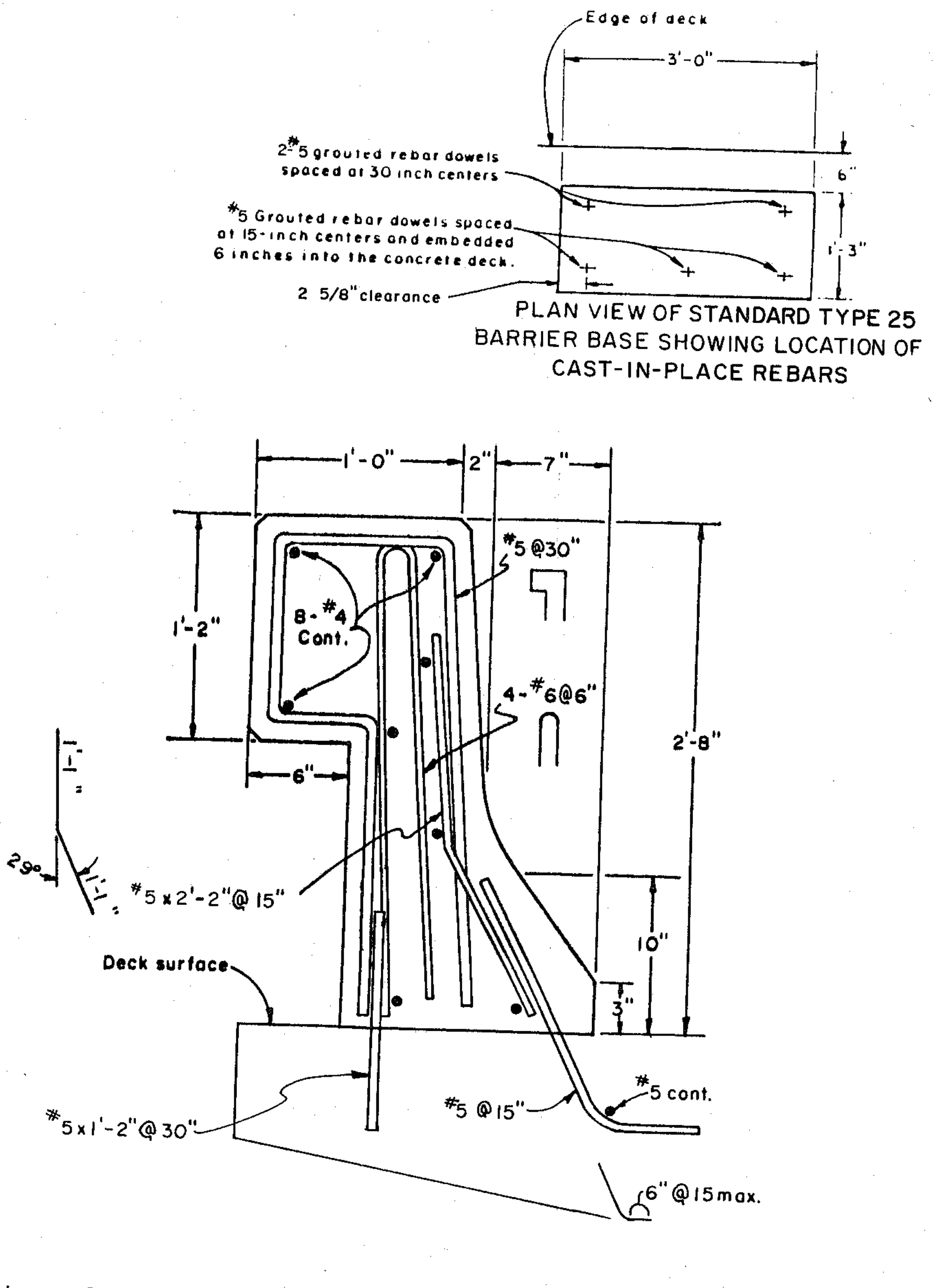


Figure 6. Steel reinforcement in the standard Type 25 Concrete Bridge Barrier section, anchored with #5 cast-in-place rebars - Series I, Test Number 2.

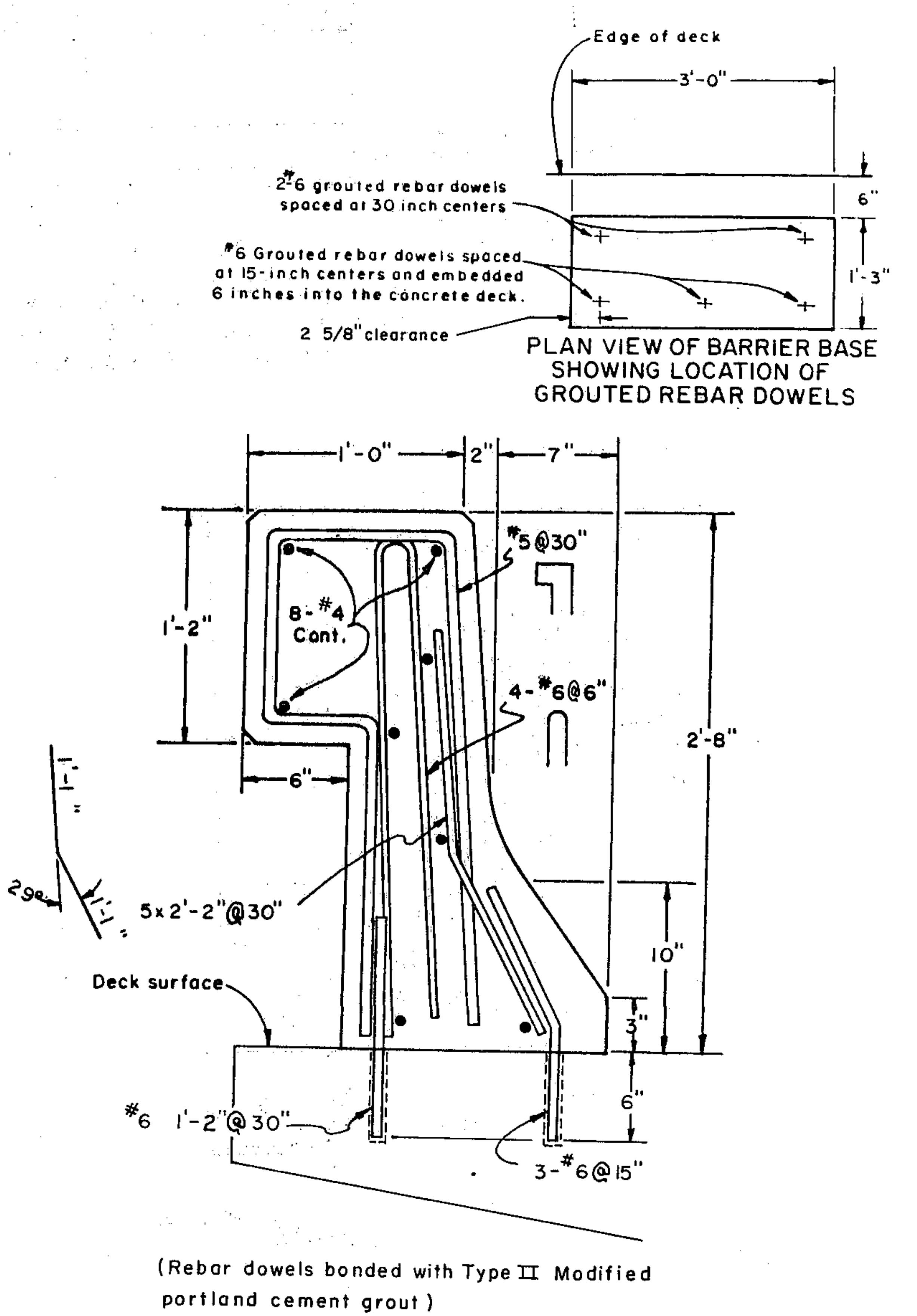


Figure 7. Steel reinforcement in the Type 25 Replacement Barrier prototype, anchored with #6 rebars, embedded 6 inches - Series I, Test Number 1.

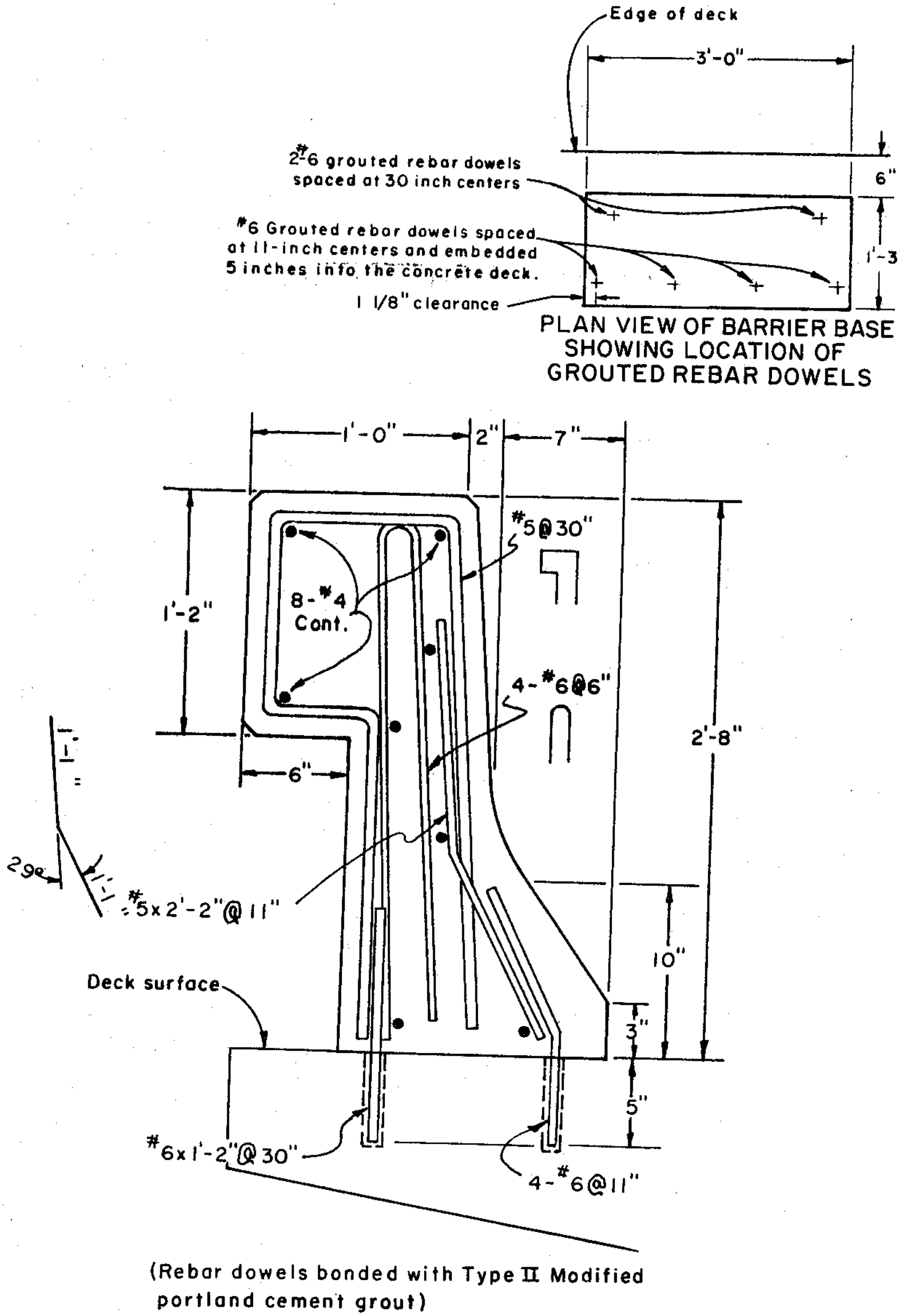


Figure 8. Steel reinforcement in the Type 25 Replacement Barrier prototype, anchored with #6 rebars, embedded 5 inches - Series I, Test Number 3.

One of the three 3-foot-long barrier sections was constructed according to the standard plans for a Type 25 Concrete Bridge Barrier, and the rebars which anchored this section to the deck were originally cast into the concrete when the simulated bridge deck was constructed. The reinforcement details and rebar dowel locations used for this section are shown in Figure 6.

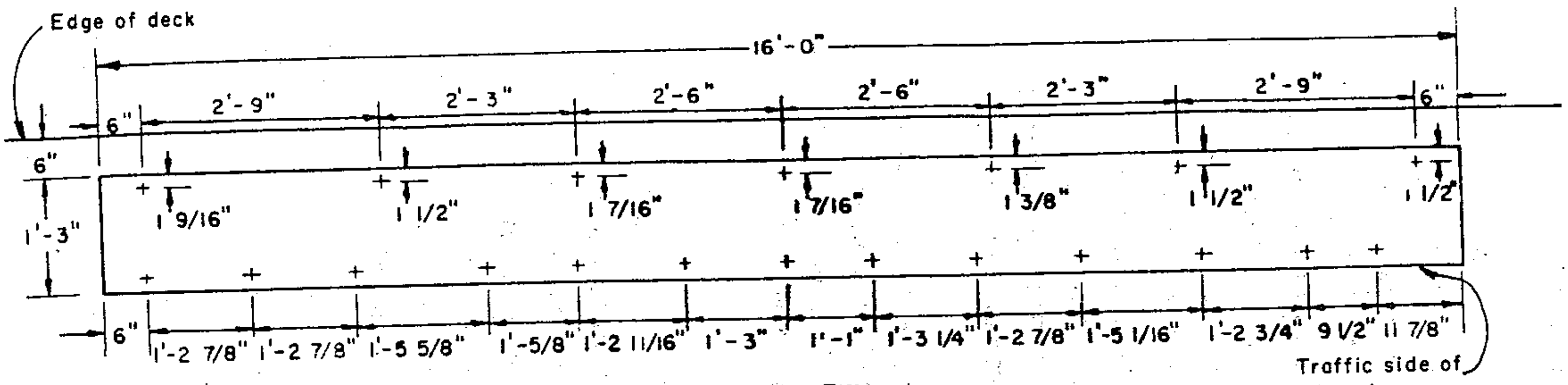
The other two 3-foot-long sections in Test Series I represented replacement barriers for bridge railing. These two barriers were anchored to the concrete deck, using different grouted rebar doweling arrangements found to be promising in the preliminary pullout tests. The traffic side of one of the replacement barrier sections was anchored by three #6 rebar dowels spaced 15 inches apart and embedded 6 inches into the deck. At both rear outside corners of this barrier near the edge of the bridge deck, two #6 rebars spaced 30 inches apart provided mainly shear resistance for the barrier. (See Figure 7.)

The traffic side of the other replacement barrier section was anchored by four #6 rebar dowels spaced 11 inches apart and embedded in 5-inch-deep holes as shown in Figure 8. The two #6 rebar dowels along the bottom back side of the barrier were also installed in 5-inch-deep holes and spaced 30 inches apart. This 3-foot-long barrier section was tested to determine if barrier strength comparable to a standard Type 25 Concrete Bridge Barrier could be achieved with rebar dowel embedment depths restricted to 5 inches. Positions and dimensions of other rebars included in each barrier are also shown in Figures 6, 7, and 8.

4.1.3.2 Test Series II: One 16-foot-long barrier section

As both of the drill-and-grout anchorage systems used in the two short replacement bridge barrier section tests in Series I performed better than the cast-in-place rebar anchoring system for the standard Type 25 Concrete Bridge Barrier, it was decided to test a longer replacement barrier section using the drill-and-grout rebar anchoring scheme with a minimum dowel embedment depth of 5 inches likely to be needed where thin bridge decks exist. An anchoring rebar dowel configuration of #6 rebars at a 15-inch spacing and grouted in the bridge deck at a 5-inch embedment depth was chosen. The three short barrier sections tested in Series I were removed from the deck prior to constructing this test barrier. Holes for new rebar dowels were drilled and the rebars were grouted using the same procedure as was followed in the Series I tests. The positions of the rebar dowels are shown in Figure 9. Altering the exact desired rebar dowel spacing was occasionally necessary to avoid hitting the rebar in the concrete deck.

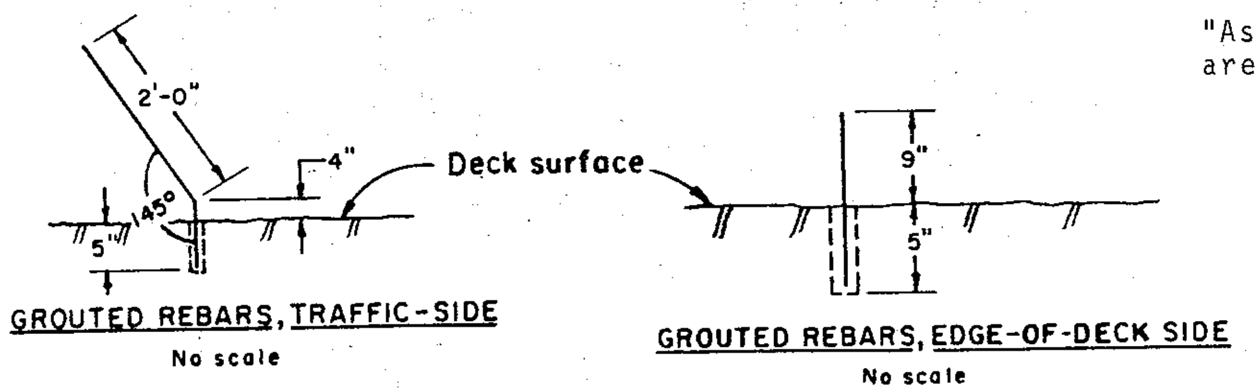
The remaining rebar was tied in place (see Figure 10) and the necessary formwork was positioned after the grouted rebar dowels had cured for 3 days. The barrier concrete was poured and the barrier was load tested after the concrete had cured for 9 days and had attained a compressive strength of 3550 psi. At that time, the grout bonding the anchoring rebar dowels into the bridge deck had cured for a total of 14 days.



PLAN VIEW

BASE OF BARRIER SHOWING LOCATIONS OF GROUTED REBARS

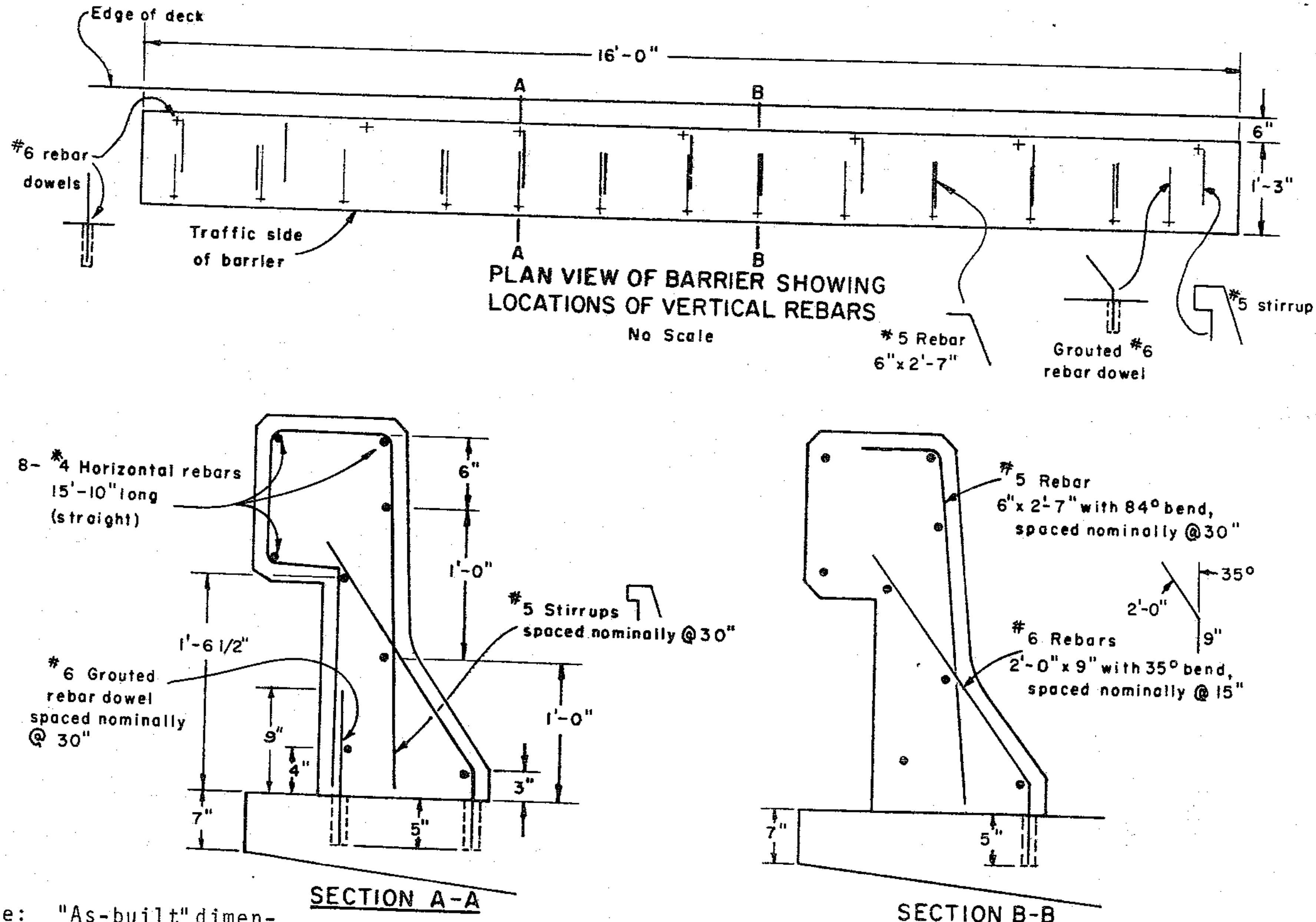
Note:
"As-built" dimensions are shown.



NOTE:

1. – All rebar dowels are #6, Grade 60 bar.
2. – Holes for grouted rebars are 1" dia. percussion drilled holes.
3. – Grout used to bond all rebar dowels was Type II Modified portland cement grout.
4. – Grouted rebars installed along the edge-of-deck side of barrier were installed as illustrated above.
5. – Grouted rebars installed along the traffic side of the barrier were installed as illustrated above.

Figure 9. Locations of grouted rebar dowels in the 16-foot-long replacement barrier section - Series II test.



Note: "As-built" dimensions and positions of rebar are shown.

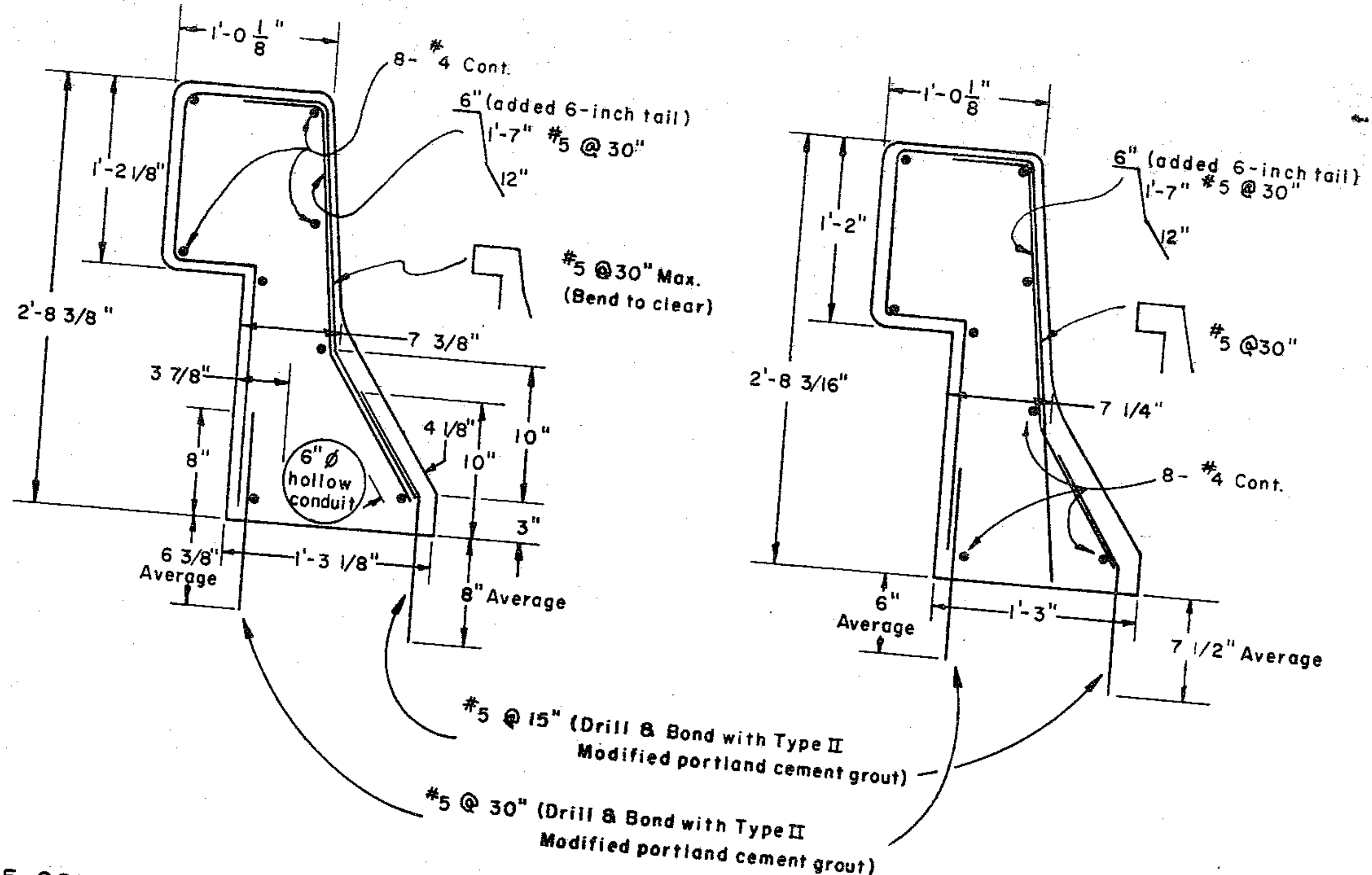
Cross sections Of Barrier Showing Rebar Locations
No Scale

Figure 10. Dimensions and locations of reinforcing steel in the 16-foot-long replacement barrier section - Series II test.

4.1.3.3 Test Series III: Two 6 1/2-foot-long barrier tests

The purpose of conducting the remaining third series of barrier tests was to determine if a standard Type 25 Concrete Bridge Barrier modified to contain a 6-inch-diameter steel duct for housing highway landscape irrigation pipe, or other utilities, would be feasible. The 16-foot-long barrier previously tested in Series II was removed from the bridge deck to provide ample room and to accommodate the testing of these two 6 1/2-foot-long barrier sections. In order to determine the relative strength of the barrier containing the 6-inch duct, a length of standard Type 25 Barrier without the duct was constructed and tested under the same loading conditions. A cross section of the barrier with duct as constructed showing reinforcement contained in the barrier, is depicted in Figure 11, along with a cross section of the standard barrier. The two barrier sections shown represent those which would be constructed on a new bridge. The top portion of every other vertical rebar reinforcing the barrier face was lengthened to provide additional bond and thus slightly more tensile load carrying capacity in order to prevent failure in the upper neck region of the barrier.

Since attaching the two barrier sections to the existing simulated bridge deck overhang with cast-in-place rebars was not practical, the drill-and-grout procedure, previously proven effective, was utilized. To prevent any slippage of grouted rebar dowels in drilled holes in the bridge deck and overhang and better approximate cast-in-place rebars, the depths of the drilled holes for all anchoring rebar dowels were increased, as shown in Figure 12. In order to avoid installing these new grouted anchor rebars in the same locations on the deck slab where rebar dowels utilized in Test Series II had been placed, the normal positions of the two barriers were

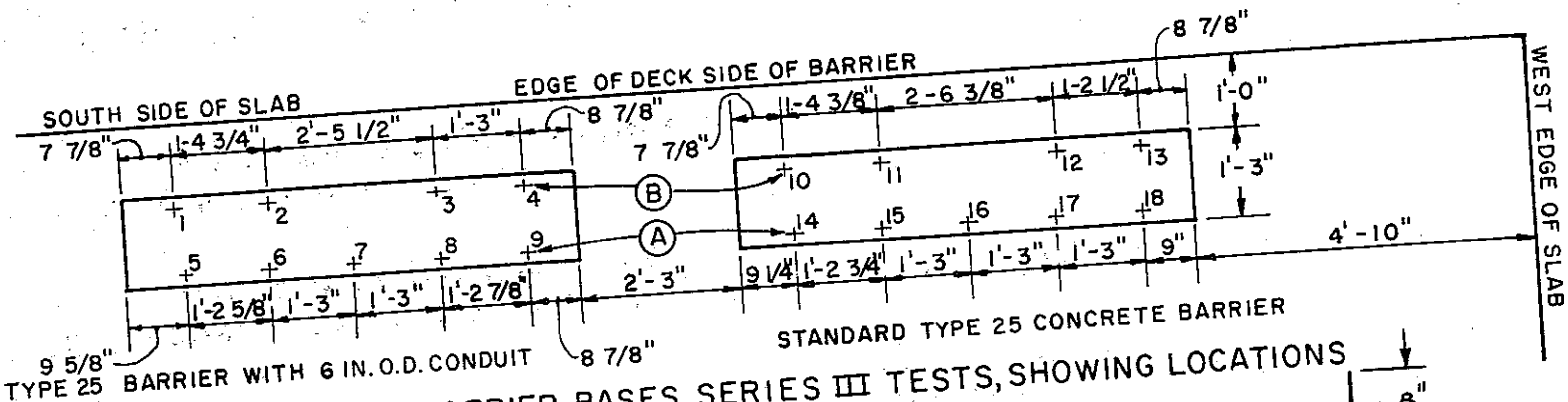


A. TYPE 25 CONCRETE BRIDGE BARRIER SECTION WITH 6-INCH DIAMETER CONDUIT

B. BARRIER SECTION APPROXIMATING STANDARD TYPE 25 CONCRETE BRIDGE BARRIER

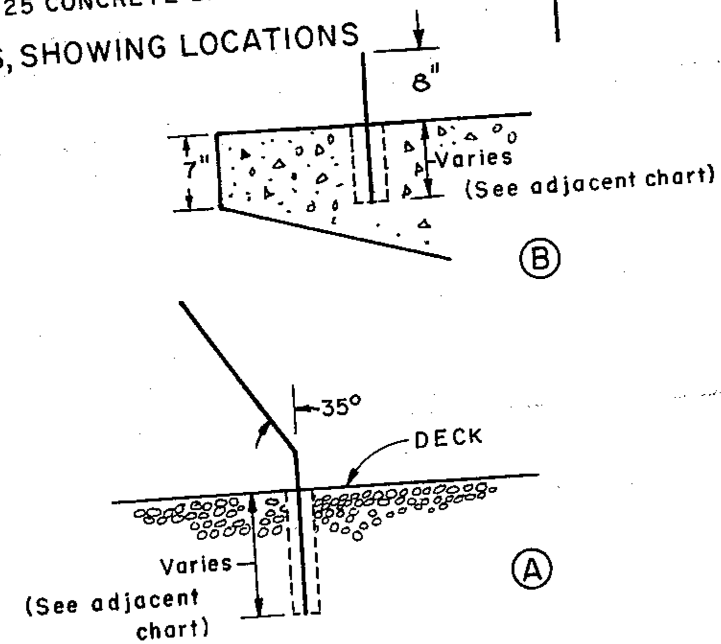
Notes: (1) As-built dimensions are shown.
(2) Dowel embedment depths vary - see Figure 12.

Figure 11. Reinforcing steel in the 6 1/2-foot-long concrete barrier sections - Series III tests.



PLAN VIEW OF BARRIER BASES, SERIES III TESTS, SHOWING LOCATIONS OF ANCHORING REBARS

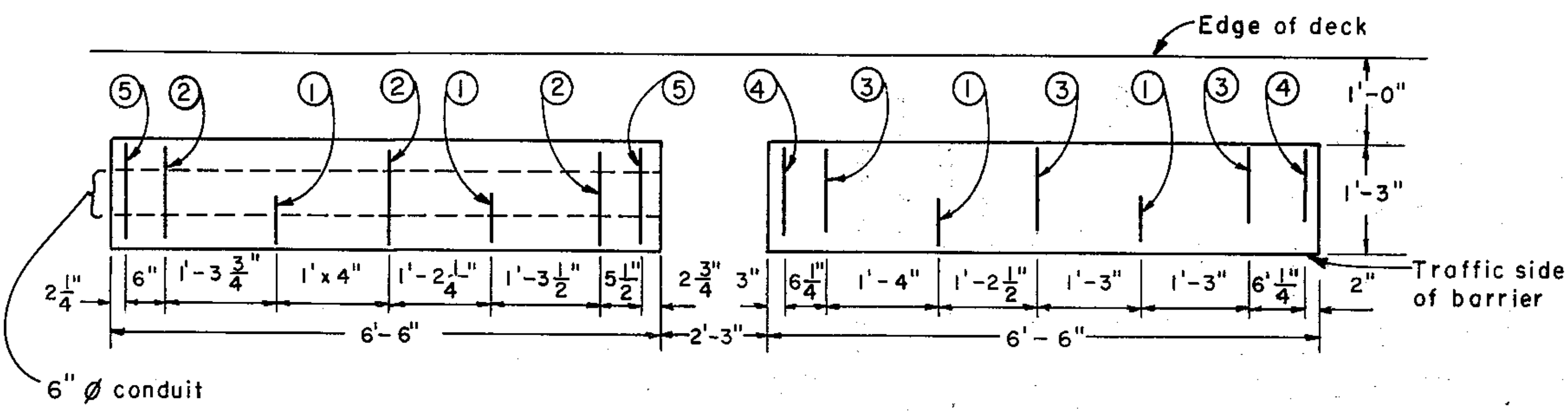
HOLE NO.	HOLE DEPTH	HOLE DIA.	REBAR SIZE	CLEAR DISTANCE
1	6 7/8"	1/2"	3	1 1/2"
2	6 3/4"	7/8"	5	1 1/2"
3	6 3/4"	7/8"	5	1 3/8"
4	5"	1/2"	3	1"
5	7 1/2"	7/8"	5	1 5/8
6	8 3/8"	7/8"	5	1 1/4"
7	8"	7/8"	5	1 3/4"
8	8 1/2"	7/8"	5	1 3/8"
9	7 9/16"	7/8"	5	1 1/2"
10	5"	1/2"	3	1 1/2"
11	6 3/8"	7/8"	5	1 1/2"
12	6 1/8"	7/8"	5	1 1/2"
13	6 13/16"	1/2"	3	1 3/8"
14	7 7/16"	7/8"	5	1 1/2"
15	7 1/2"	7/8"	5	1 1/2"
16	7 1/2"	7/8"	5	1 3/8"
17	7 5/8"	7/8"	5	1 1/4"
18	7 9/16"	7/8"	5	1 3/8"



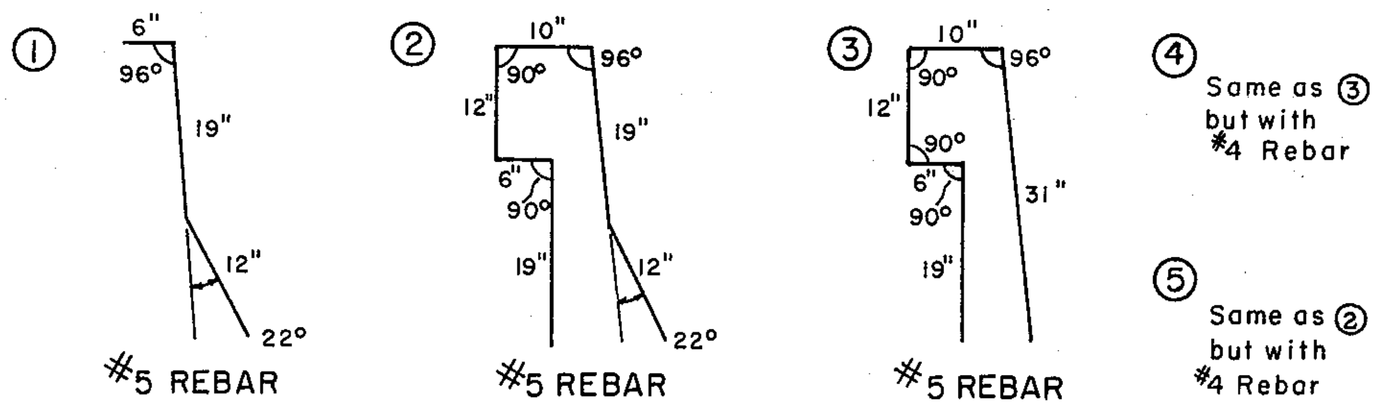
Note: As-built dimensions are shown.
SCALE: 3/8" = 1'

Figure 12. Locations and embedment depths of the grouted rebars for the 6 1/2-foot-long concrete barriers - Series III, Tests 1 and 2.

shifted in from the deck edge 6 inches, as shown in Figure 12. Similar procedures were used for grouted rebar dowels installed in this Test Series III as had been previously followed in Test Series I and II. Grouted rebars were left undisturbed and were damp cured for a 3 day period. They were then air cured for a 4 day period, while other barrier rebar was tied (see Figure 13) and forms were being positioned. Barrier concrete, as described in Section 4.2.1 of this report was then placed and cured for a period of approximately 14 days, until a compressive strength of 3250 psi had been attained. As previously done, cylinders of concrete were made at the time when the barrier concrete was placed and were tested periodically starting 6 days after concrete placement. When the barrier sections had cured for 7 days after placing the concrete, the forms were stripped and the necessary barrier loading apparatus was assembled.



A. PLAN VIEW OF BARRIER BASE SHOWING LOCATION OF VERTICAL REBARS



B. DIMENSIONS OF VERTICAL REBARS

Figure 13. Locations of vertical reinforcing steel in the two 6 1/2-foot-long concrete barriers, Series III tests.

4.2 Test Materials

4.2.1 Concrete

4.2.1.1 Concrete used in bridge barriers

The concrete used for constructing all of the concrete bridge barrier test sections for this research project contained well graded Fair Oaks river-run aggregates having a maximum size of 1 inch and meeting the requirements in Caltrans Standard Specifications, Section 90-3. A cement content of 564 pounds per cubic yard (6 sack mix) was used, and an average slump of 3 inches was attained. A concrete compressive strength of at least 3250 psi at the time of loading each barrier section was required. Further information about this concrete mix design, designated as A-1082A, is shown in Appendix D.

During the placing of barrier concrete for each test series, a number of 6-inch x 12-inch concrete cylinders were fabricated, cured at the barrier site, and tested periodically to determine the proper time to perform each barrier test series. Results of these age/strength tests are plotted in Figure 14.

4.2.1.2 Concrete for the simulated bridge deck

A class "A" concrete mix design conforming to California Department of Transportation 1975 Standard Specifications was used in the simulated concrete slab, beam, and deck overhang. A concrete mix having a maximum coarse aggregate size of 1-1/2 inches and a consistency not exceeding 2 inches of ball penetration was used to simulate typical concrete used in bridge decks.

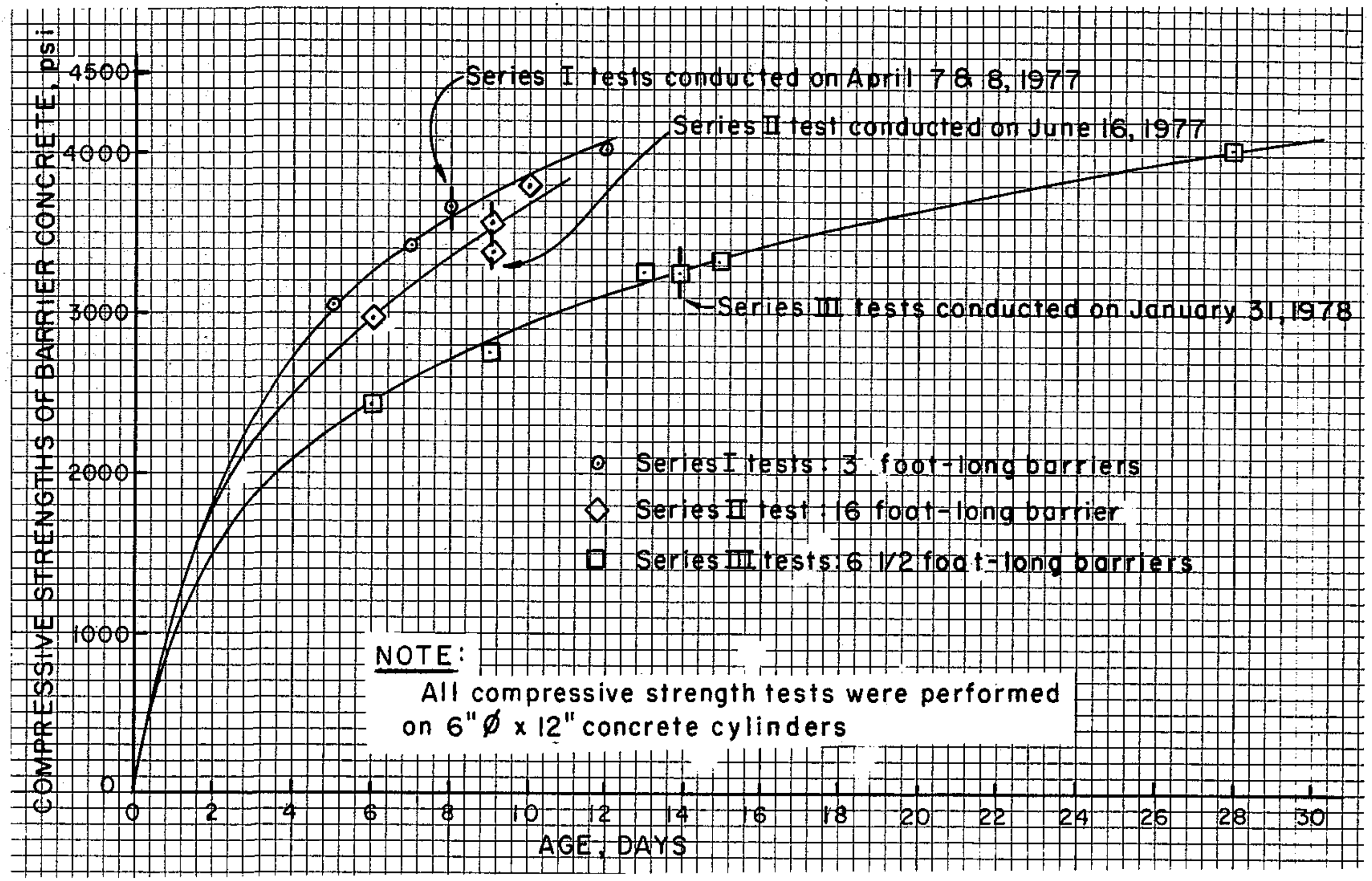


Figure 14. Plots of curing time versus strength for concrete used in Series I, II, and III barriers.

The surface finish of the concrete was performed according to Section 51-1.17, Finishing Bridge Decks, of the 1975 Caltrans Standard Specifications. The surface was struck off, floated longitudinally, and scoured transversely with a stiff bristled broom. Eight 6 inch by 12 inch concrete cylinders were made to determine the compressive strength at the time of rebar pullout tests and barrier load tests. An age versus compressive strength plot of cylinders tested to date is shown in Figure 15.

Curing of bridge deck: The deck surface was water cured for seven days. An automatic sprinkler system available adjacent to the site was used for this purpose.

At the end of the curing period, the forms were removed from the deck overhang to eliminate any additional support they might provide during the barrier load tests.

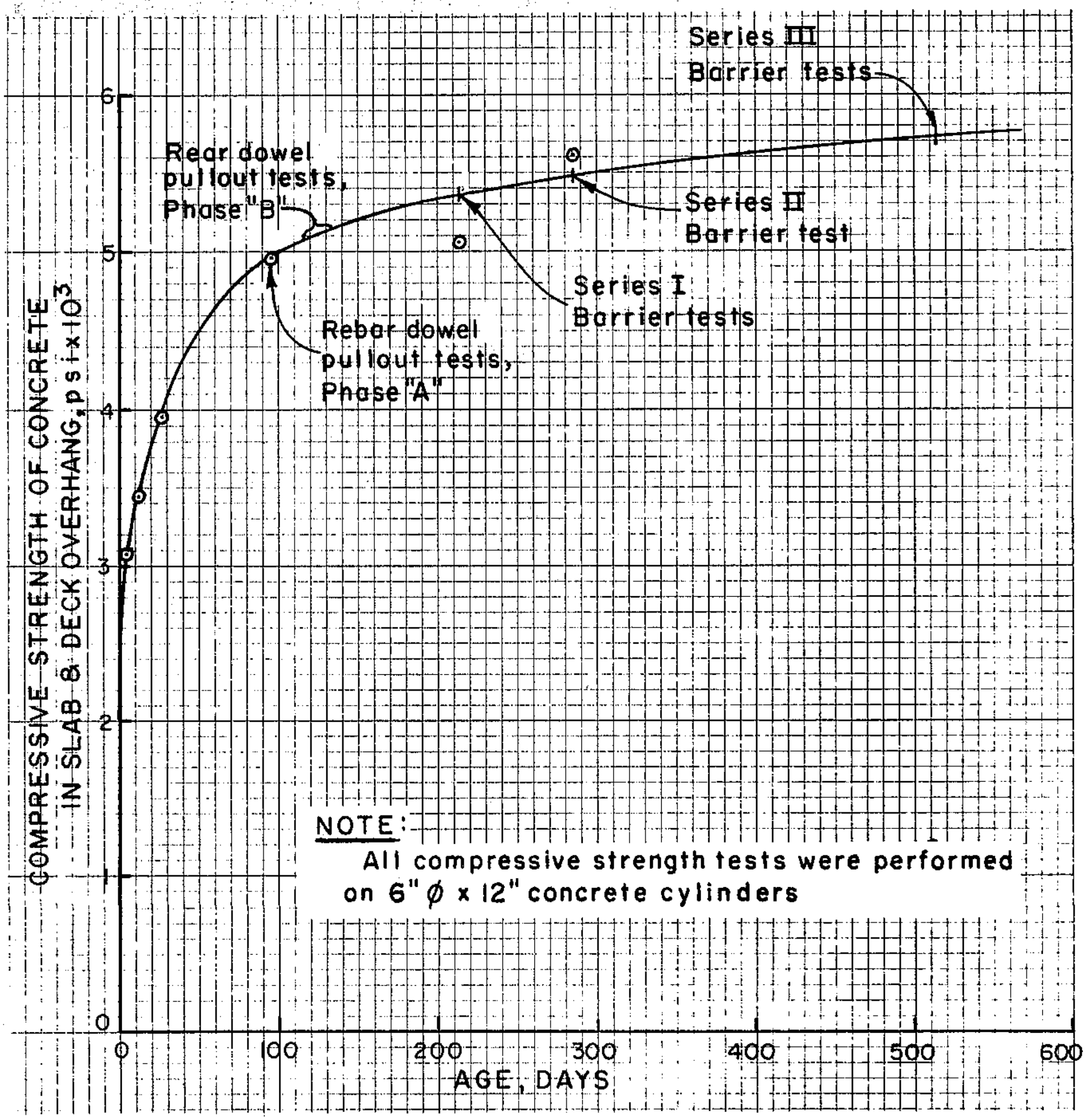


Figure 15. Plot of age versus compressive strength for concrete in test slab and deck overhang.

4.2.2 Bonding Materials Used to Fasten Rebar Dowels

4.2.2.1 Bonding materials used in rebar dowel pullout tests

Four different bonding materials were used in the rebar dowel pullout tests conducted in the 7-inch-thick reinforced concrete slab. These included (1) epoxy mortar (2) Type II Modified portland cement grout, (3) Wil-X shrinkage compensating cement grout, and (4) Bostik-275 quick-set mortar. Their characteristics and application procedures used in this research are described as follows:

° Epoxy Mortar

Characteristics of Epoxy, Caltrans Specification No. 8040-61J-03: The epoxy used in the epoxy mortar for the rebar pullout tests was manufactured to conform to Caltrans Specification 8040-61J-03. This epoxy is a two component, low viscosity liquid polysulfide, with a gel time of between 15 and 30 minutes, and is recommended for bonding steel rebar dowels in vertical holes in concrete.

The rate of strength development of epoxy No. 8040-61J-03 is temperature sensitive. It sets rapidly at 100°F and much slower at 50°F. At temperatures near 70°F, it will fully cure in 3 to 5 days and have a compressive strength of approximately 8000 psi.

Without aggregate fillers, epoxy conforming to State Specification 8040-61J-03 has poor shrinkage and creep characteristics and is not recommended for application under sustained loading(4).

Mineral aggregate fillers (sand) may be mixed with this dpoxy to reduce shrinkage. The use of a filler, however, also increases the amount of time required for hardening.

Some negative aspects of using an epoxy mortar are; (1) high cost, (2) messy to handle and clean up, (3) can cause dermatitis, (4) very critical mixing proportions, (5) recommended for use on dry concrete surfaces only, and (6) limited pot life (must be used within 10 minutes of mixing).

Mixing and Placement of Epoxy Mortar: The epoxy mortar components were measured and mixed according to general instructions contained within Section 95 of the 1978 Caltrans Standard Specifications. An equal volume of epoxy was then mixed with an equal volume of 16 x 30 mesh sand. This ratio aided in reducing shrinkage, yet still provided a mortar which would pour easily.

The holes in which the epoxy mortar was to be placed were kept dry and blown out with compressed air before introducing the epoxy mortar. The holes were approximately half filled with the mortar; then the rebar was inserted and jiggled to remove air voids. After placement, epoxy mortar was allowed to cure in the open air.

- Type II Modified Portland Cement Grout

Characteristics: The portland cement grout used was a mixture of Type II Modified portland cement and water. The Type II Modified portland cement conformed to the requirements of the 1978 Caltrans Standard Specifications. During the initial grout curing period (approximately 3 days at 70°F), the grout is very weak and should not be disturbed as slight movement or shocks may cause fractures and reduce bond strength.

The averages of compressive strength tests on 2-inch x 4-inch grout cylinders made from the same mixture used in installing rebars for pullout tests are shown in Figure 16. The grout mix proportions used were 4 gallons of water to 94 pounds of cement. Two different conditions for curing grout cylinders were employed in an attempt to obtain and compare compressive strengths of grout cured under ideal conditions (kept continuously moist in fog room at 73.4°F) with grout cured at the test site under less desirable conditions (sealed in a plastic bag and buried in the ground adjacent to the test slab).

Mixing and Placement of Type II Modified Portland Cement Grout: Small quantities of portland cement grout were mixed by hand with mixing bowl and spoon until free of lumps.

To avoid absorption of water from the grout by the old concrete, the drilled holes were soaked with water for 15 minutes, then blown out with compressed air prior to placing the grout and rebar dowels.

The holes were filled half full of grout, then the rebar was slowly inserted, and jiggled to remove air and consolidate the grout. In Figure 17, a freshly grouted rebar is shown. After placement, all the portland cement grout was covered with wet rags and plastic sheet to retain moisture (see Figure 18).

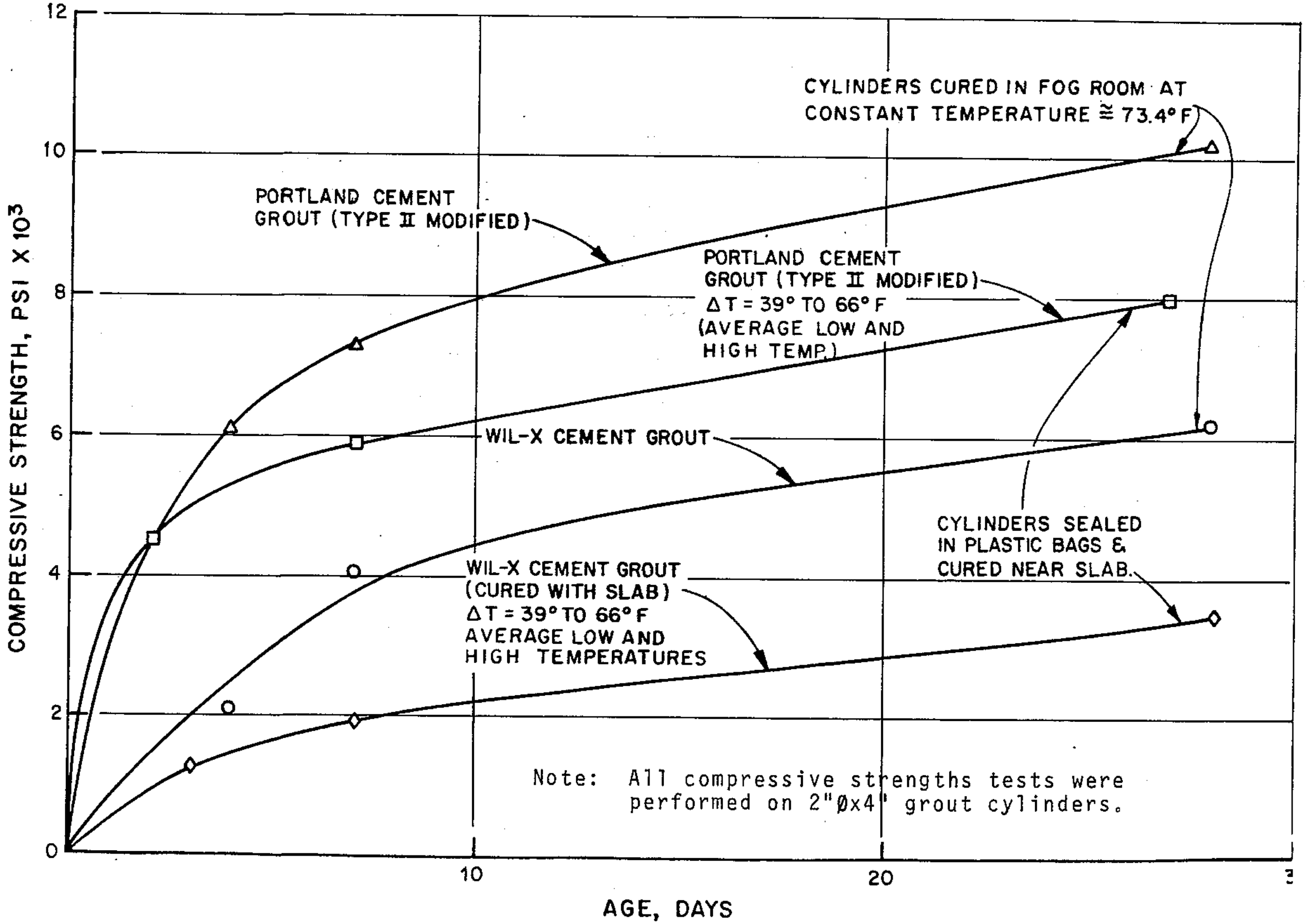


Figure 16. Plots of age versus compressive strength of Type II portland cement grout and Wil-X cement grout, and cured in different environments.

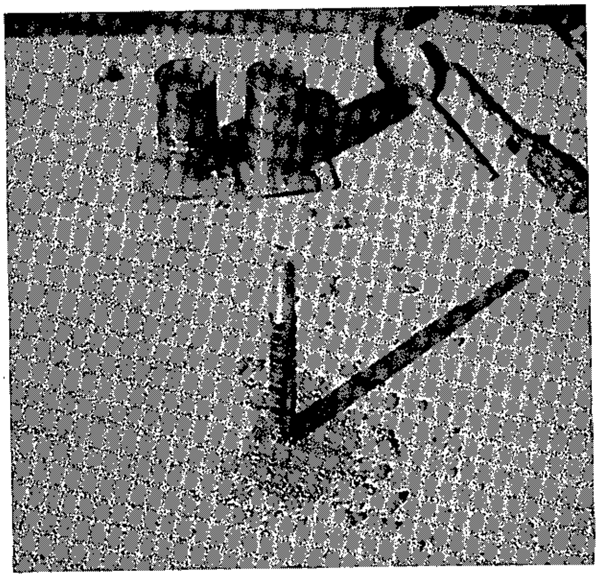


Figure 17. Single #6 rebar dowel bonded with Type II Modified portland cement grout.

Figure 18. Curing of grout surrounding #6 rebar dowels using wet rags and plastic sheet.

o Wil-X Shrinkage Compensating Cement Grout

Characteristics: Wil-X cement is a special base portland cement having a high percentage of calcium sulfo-aluminate blended into the cement during manufacture. According to the manufacturer, Wil-X cement when mixed as a grout requires more water than Type II Modified portland cement grout in order to have similar flow properties. The cement is classified as a shrinkage compensating cement. Wil-X cement contains virtually no chlorides, iron particles, or other material known to promote corrosion of steel. The manufacturer's recommended mixing proportions (4 1/2 gallons of water:94 pounds of Wil-X cement) were used for all grout in this research. Grout cylinders (2 inches x 4 inches) were cast and cured in the same two different environments as were the Type II Modified portland cement grout cylinders. Averages of compressive strengths of cylinders tested at various ages are shown in Figure 16.

Mixing and Placement of Wil-X Cement Grout: The small quantity of Wil-X cement grout used for grouting the pullout test specimens was mixed by hand until free of lumps.

To avoid absorption of moisture from the grout by the old concrete, the drilled holes were filled with water, which was allowed to stand 15 minutes, then blown out with compressed air prior to placing the grout and the rebar dowels.

Next, the holes were filled half full of well mixed grout; the rebar was inserted and jiggled to remove air and consolidate the grout.

After rebar placement, the concrete/grout surface surrounding the rebar was covered with wet rags followed by a small square of plastic sheet to retain the available moisture.

° Bostik-275 Quick Set Mortar

Characteristics: Bostik-275 mortar is a two-part system consisting of a dry component, which includes an aggregate and powdered magnesia, and a liquid ammonium phosphate solution. This material has been found to be acceptable and is used as a patching compound for portland cement concrete highways in California. The manufacturer recommends the use of a mix proportion consisting of 1 gallon of liquid activator to 45 pounds of dry component.

Setting time varies with temperature. When mixed using the recommended proportions, Bostik-275 mortar sets in 5 to 7 minutes at 72°F and in approximately 20 minutes between 40°F to 50°F.

One alleged beneficial characteristic of Bostik-275 mortar is that any cracks which may develop from compressive failure will tend to heal, and strength will be regained as the specimen ages further. Compressive strength tests were performed in the laboratory to verify this fact. One mortar cylinder was cast and loaded three hours later to a maximum load. A maximum compressive strength of 3000 psi was reached. The same specimen, compressed again two hours after the first test, withstood 3260 psi. A third loading was performed 28 days after the initial casting date and produced a compressive strength of 4825 psi.

Water will reduce the strength of Bostik-275 mortar considerably and should not be used to dilute the liquid.

All water should be cleared from the area where Bostik-275 mortar is to be placed.

Limited corrosion tests conducted by the Transportation Laboratory Concrete Section indicate that Bostik-275 mortar should not cause or promote corrosion of steel.

Mixing and Placement of Bostik-275 Mortar: Using an impact rotary hammer and carbide tipped bits, three holes were drilled in the concrete slab in which rebar dowels were installed. The drilled holes were then blown clean with compressed air and dried.

The first batch of Bostik-275 mortar was mixed in a small quantity according to the manufacturer's recommended proportion of 84 ml of a special liquid activator to 1 pound of dry component.

Bostik-275 mortar was poured into the first clean, dry hole until it was filled to approximately one-half of its capacity. The rebar was then inserted and jiggled to remove any trapped air and consolidate the mortar.

This initial mix ratio was judged to be too stiff to provide easy flow into the hole. Only one rebar dowel was embedded using this mix.

A second mixture of Bostik-275, whose workability was improved by increasing the liquid in the mix, was prepared. The new mix ratio used was 126 ml liquid activator to 1 pound of dry component. This second mix was used to bond two additional rebars which were installed in a similar manner as before.

The Bostik-275 mortar surrounding the installed rebar was left to cure in the open air.

4.2.2.2 Bonding material used in all barrier tests

The Type II Modified portland cement grout because of its economy, handling ease, and excellent strength, was used to bond rebar dowels for all of the bridge barrier load test sections. The portland cement grout was prepared in the same manner and mix ratio as was used in the preliminary rebar pullout tests conducted early in the research project. A mix ratio of 4 gallons of water to 94 pounds of Type II Modified portland cement was used.

The strength of the Type II Modified portland cement grout used to bond the rebar dowels for anchoring the concrete bridge barrier test sections was monitored for the Series I tests only. Eight 2-inch-diameter x 4-inch-high cylinders were cast at the same time the rebar dowels were grouted for the Series I barrier tests. The age/strength curve for the grout cylinders is shown in Figure 16. The strength of the grout in Series I barrier tests was 9140 psi at the time when the barriers were loaded. In all barrier tests, grout around the rebar dowels was cured for the initial 3 days with wet rags covered by plastic sheet.

The various curing times and temperature of the grouts around rebar dowels for all three barrier prototype test series are shown in the following Table 3.

Table 3. Curing time for Type II Modified portland cement grout used to bond rebar dowels in barrier tests.

Average ambient temp.	Series No. - Number and length of barrier sections	Total curing period of grout, days, at time of barrier test	Partial curing times of grout, days		
			wet rags & plastic	air	under concrete
56°F	I - Three 3-foot-long barriers	16	3	5	8
70°F	II - One 16-foot-long barrier	14	3	2	9
50°F	III - Two 6 1/2-foot-long barriers	21	3	4	14

4.2.3 Deformed Steel Reinforcing Bar

All deformed steel reinforcing bar used in this research project for use in the concrete bridge deck prototype, bridge barriers, and rebar dowel conformed to requirements in Section 52-1.02 of the 1978 edition of the Caltrans Standard Specifications.

Further, all steel reinforcement conformed to the specifications of ASTM Designation: A615, Grade 60.

4.3 Testing Equipment and Procedures

4.3.1 Dynamic Pullout Load Tests on Bonded Rebar Dowels

In general, equipment and procedures used to conduct all dynamic pullout tests on bonded rebar dowels were the same.

A 1-inch-diameter threaded steel rod conforming to requirements in ASTM Specification A449 and a special coupler made from AISI 4140 heat treated steel were used to extend the short rebar dowels so that they could be loaded in tension. As previously mentioned, the embedded dowels were threaded on one end so that the coupler could be attached. As shown in Figure 19, the threaded steel rod projected through a 120-kip hydraulic jack which was used to apply the tensile load; the load was monitored with a load cell.

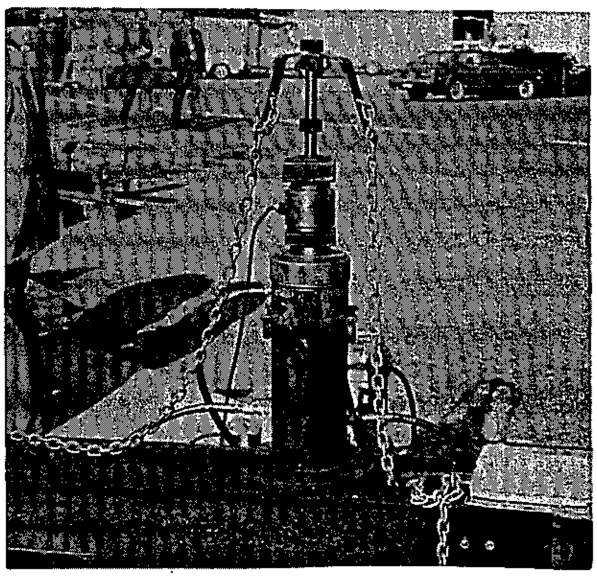


Figure 19. View of loading apparatus sitting on channel beams.

Figure 20. Pumps and test apparatus used in rebar pullout tests.

The jack was supported by two heavy channel sections which rested on two short sections of "I" beam.

Heavy hex nuts and a plate washer were installed at the top end of the threaded rod to transfer the force from the jack ram to the grouted rebars.

To approximate an impact loading condition which would be experienced by rebar anchoring a bridge barrier if hit by an automobile, two techniques were used: (1) a free travel distance of approximately 1 1/2 inches was left between the jack ram face and plate washer so that load transfer to the grouted rebar would be sudden, and (2) two hydraulic pumps were connected in a parallel circuit to provide an increased fluid flow to the jack. An overall view of the assembled test apparatus is shown in Figure 20.

Load and deflection were plotted against time using an XYY recorder.

The lower 50-kip range of a 200-kip load cell was calibrated in the 60-kip Baldwin testing machine in the Structural Materials Laboratory to a readable accuracy of ± 500 pounds. Calibration of the load cell was checked with a resistance shunt calibration box before each pullout test.

Deflection was measured with a pair of potentiometers, positioned on a line and on equal distance from the test rebar with one attached to each end of a rigid bracket. This bracket was slipped over the rebar dowels and attached firmly just above the concrete slab surface with two set screws. The two deflection readings were averaged electronically and the resulting deflection was plotted continuously by a XYY recorder during each test.

So that only bond slippage and/or rebar elongation below the surface of the concrete could be measured, the bracket was attached to the rebar dowels just above the concrete surface. Figure 21 shows the bracket with potentiometers attached.

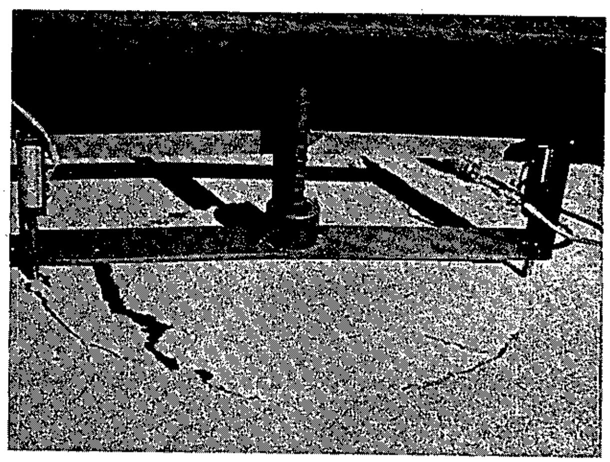


Figure 21. Steel bracket and potentiometers used to measure vertical movement of bonded rebars during pullout.

Calibration of the potentiometers was checked before each test with a resistance shunt calibration box.

The time sweep on the XYY recorder could be set at various speeds. The two rates used in the pullout tests were: 1/2 second and 1 second per inch of travel on the X axis.

4.3.2 Static Load Tests on Barrier Sections

4.3.2.1 Description of the system used to load the barriers

The apparatus necessary to apply a static horizontal force near the top of the barrier face, consisted of (1) a heavy load frame, (2) a hydraulic jack assembly consisting of a ram head, a hydraulic jack having a 150-ton capacity, a load cell, and a rounded bearing head, (3) a bearing plate and pad with socket bolted onto the barrier face, and (4) two hydraulic pumps, hoses, and fittings. The load frame constructed of heavy structural plates and channel sections welded together is shown in Figure 22. It was attached to the simulated bridge deck using the 2-inch-diameter cast-in-place steel anchor bars and provided a solid foundation against which to jack. Prior to loading the barrier, the hydraulic jack assembly was held in place by two cradle supports.

The hydraulic jack was coupled to two hydraulic pumps, plumbed in parallel to maximize the loading rate. A load cell was placed directly behind the hydraulic jack (see Figure 23) so that the horizontal load which was applied to the barrier could be monitored.

A heavy steel wedge-shaped 8-inch x 14-inch bearing plate shown in Figure 24 was centered near the top of the barrier face, approximately 26 inches above the deck surface (see

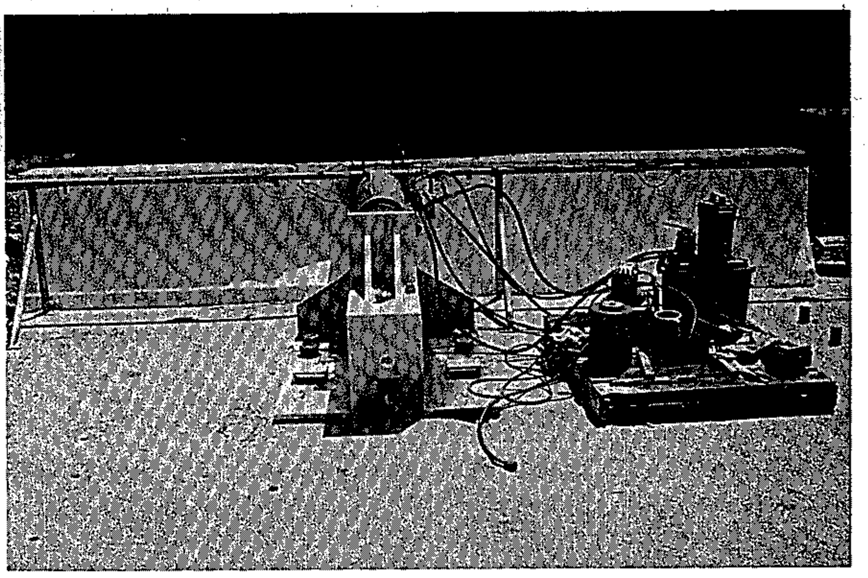


Figure 22. Front view of 16-foot-long barrier, Series II test, shown with load frame and testing apparatus.

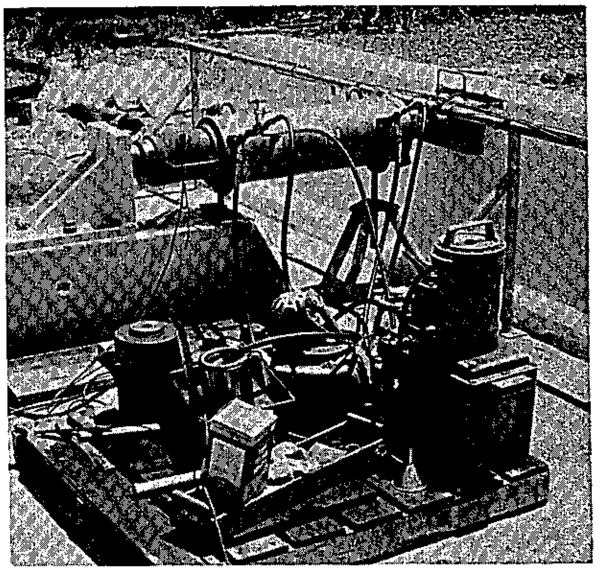


Figure 23. Side view of load frame and testing apparatus - Series II test.

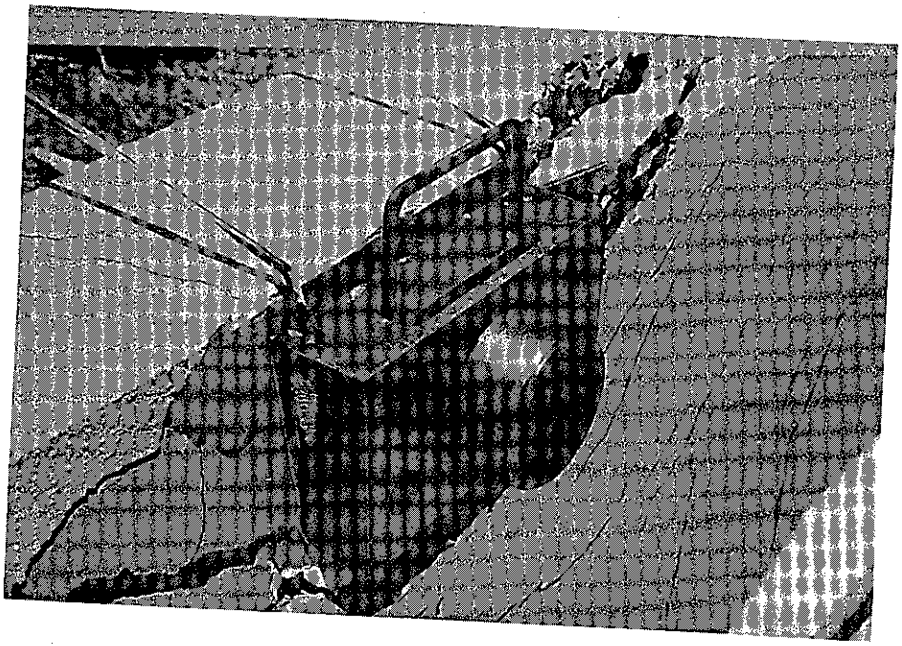


Figure 24. Heavy 8-inch x 14-inch tapered bearing plate bolted to barrier face.

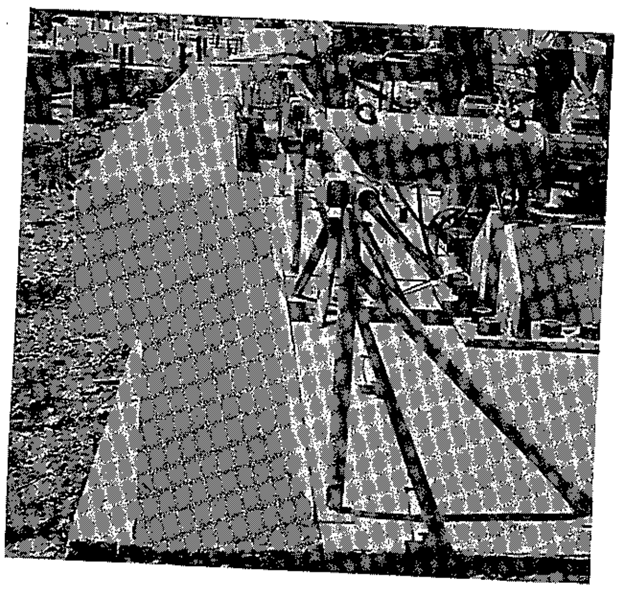


Figure 25. Side view of barrier in Series II test before test showing position of jack, ram, and deflection bracket.

Figure 25). The particular position of this bearing plate on the barrier face was chosen to represent a typical load area and height which would be experienced in a severe impact from a heavy automobile at a speed of 60 mph and at an impact angle of 25° with the barrier face. This bearing plate was attached firmly to the face of the barrier with four high strength steel cap screws. A thin rubber shim was placed underneath the bearing plate in order to distribute the horizontal load evenly to the concrete in the barrier face.

During the application of a horizontal load on each barrier section, the position of the bearing plate, bolted onto the barrier face rose slightly when the front edge of the barrier uplifted and pivoted about the bottom rear edge of the barrier. The hydraulic jack assembly was permitted to rotate upward slightly about the one end which was in bearing against the load frame, due to two ball-and-socket connections, one at each end of the assembly.

4.3.2.2 Instrumentation of barriers to measure deflection

In each of the three series of full-scale concrete bridge barrier static load tests, deflections of the barriers were measured. In the Series I tests where three 3-foot-long barrier sections were loaded, two transducers were positioned along the bottom front and one foot in from the edge of each barrier section in order to measure the amount of uplift (vertical deflection) of each section (see Figure 26).

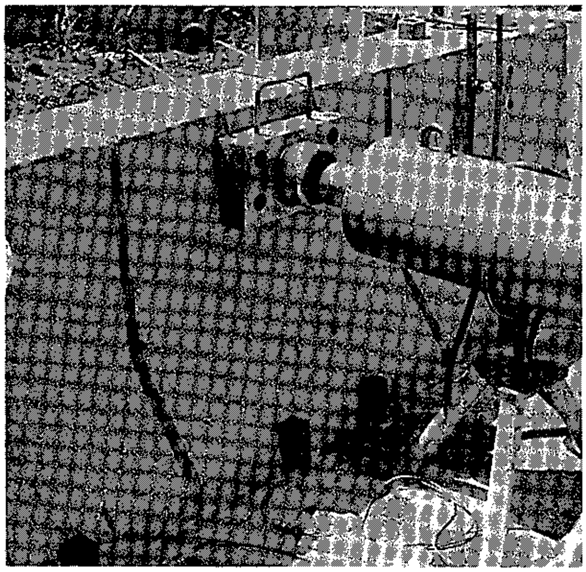


Figure 26. Transducers mounted on angle brackets at base of the 3-foot-long barrier sections in Series I tests.

Unfortunately, because of the severe cracking of concrete along the bottom front edge of the 3-foot-long barrier sections, this deflection measuring system did not work.

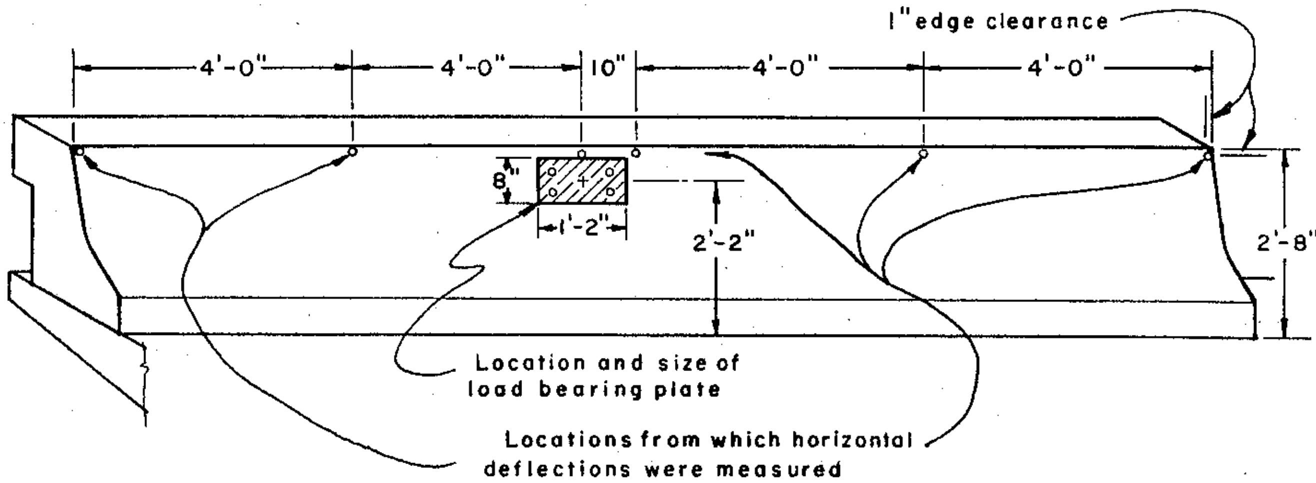
In the succeeding Series II and III tests, horizontal deflection near the top front edge of the barrier faces was measured. A rigid bar frame (see Figure 25) was bolted to the deck surface, and Houston potentiometers, fastened to this frame, were used to monitor the change in horizontal distance between the frame and the top edge of the barrier face. Small hooks were epoxied onto the barrier face at the positions shown in Figures 27 A and B, and wire cables from the potentiometers were attached to these hooks. This system worked well.

4.3.2.3 <u>Data recording methods for barrier tests</u>

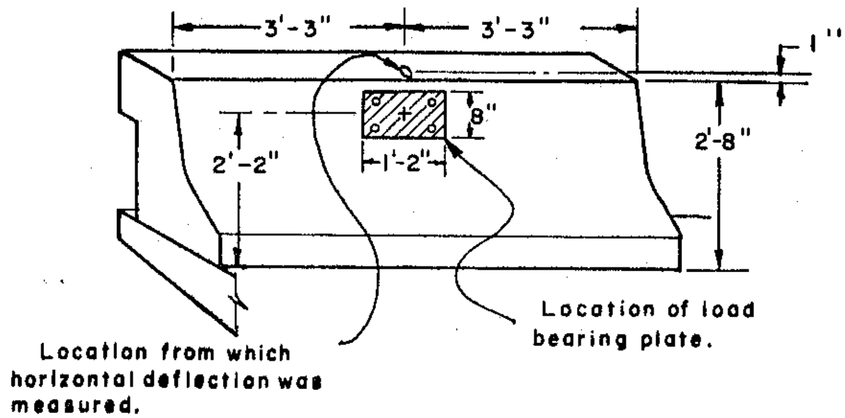
In each of the three barrier loading tests in Series I, results were recorded using the XYY plotter. Load versus time and average vertical deflection versus time were recorded on the same graph.

In the Series II tests horizontal deflection of the top of the barrier was measured at six different points using potentiometers as previously described. A visicorder equipped with a light sensitive paper chart was used to simultaneously record (1) time, (2) horizontal force applied on the bearing plate, and (3) deflections at each of the six selected points near the top edge of the barrier.

An XYY recorder was used in the Series III tests to monitor the horizontal load, time, and the horizontal deflection of a single point at the top edge of each barrier face.



A. Six locations from which horizontal deflections were measured during Series II test.



B. Single location from which horizontal deflection was measured for both barriers loaded in Series III tests.

Figure 27. Locations at which horizontal barrier movement was measured - Series II and Series III tests.

5. TEST RESULTS AND ANALYSIS

5.1 Results of Dynamic Pullout Tests on Bonded Rebar Dowels

General Discussion: On the whole, the results of the preliminary dynamic pullout tests of bonded rebars conducted in this research program were very good. High pullout loads were attained from shallowly embedded bonded rebar dowels by using carefully regulated grouting procedures. Dynamic pullout tests in this research project were conducted in two distinct Phases, A and B. A complete summary of results of the dynamic pullout tests conducted in both testing phases is shown in Table 4. As can be seen from these results, extremely high and consistent maximum pullout loads, ranging between 25 and 35 kips, were obtained in the Phase A tests in which #6 rebars were bonded in 6-inch-deep holes with all of the types of bonding materials used. Lower ultimate pullout loads were obtained with the #5 and #6 rebars embedded only 5 inches into the slab in the Phase B tests. A basic explanation of the tests conducted, as well as a description of the test results for pullout tests conducted in both phases is presented in the following paragraphs.

5.1.1 Discussion of Pullout Tests, Phase A

In the Phase A pullout tests, nine #6 ASTM A615 Grade 60 rebar dowels were embedded to a depth of 6 inches in a 7-inch-thick reinforced concrete slab; the following four bonding materials were used and the number of rebar specimens bonded with each shown in parenthesis: epoxy mortar (2), Type II Modified portland cement grout (2), Wil-X shrinkage compensating cement grout (2), and Bostik-275 quick-set cement mortar (3). All hole diameters were 1 inch except for one 1 1/8-inch-diameter hole which was

MATERIALS INFORMATION									TEST RESULTS								
REBAR (1)			BONDING MATERIAL			HOLE DIMENSIONS (2)		CONCRETE IN REINFORCED SLAB (3)	PHASE - TEST NO.	LOADING RATE (4)	LOADS AND DEFLECTIONS P(KIPS) Δ(INCHES)				AVERAGE BOND STRESS	TYPE OF FAILURE	TYPE OF THREADS ON EXPOSED PULLING END OF GROUTED REBAR
MINIMUM TENSILE STRENGTH REQUIRED (KIPS)	ACTUAL TENSILE STRENGTH (KIPS) (5)		TYPE	AGE AT TEST (DAYS)	INITIAL 7 DAY CURING TEMPERATURE AVG.HIGH/AVG.LOW	DIAMETER (INCHES)	DEPTH (INCH)	STRENGTH TEST DATE (PSI)		(KIPS PER SECOND)	P @ Δ= 0.01 IN. (KIPS)	P @ Δ= 0.02 IN. (KIPS)	P ULT (KIPS)	Δ @ P ULT	@ Δ= .01 IN. (PSI)		
39.6	45.4	#6	TYPE II MODIFIED PORTLAND CEMENT GROUT MIX RATIO: (4 GAL WATER/94 LB SK CEMENT)	29	68°F/54°F	1	6	5000	A-1	10.8	23.8	27.9	34.1	.055	1680	REBAR RUPTURE IN THREAD	END OF #6 REBAR TURNED AND THREADED WITH 5/8" - UNF
				29	68°F/54°F	1	6	5000	A-2	8.4	20.7	24.0	25.5	.053	1460	REBAR RUPTURE IN THREAD	
				27	62°F/33°F	1	5	5200	B-1	14.7	16.4	20.0	22.5	.062	1390	CONCRETE AND BOND INTERFACE	#8 REBAR STUB THREADED WITH 7/8" UNF & BUTT WELDED TO #5 GROUTED REBAR
				27	62°F/33°F	1	5	5200	B-2	17.9	16.5	19.3	20.0	.025	1400	CONCRETE AND BOND INTERFACE	
39.6	45.4	#6	EPOXY MORTAR EPOXY: STATE SPECIFICATION 8040-61J-03 FILLER: 16-30 MESH SAND MIX RATIO: 1PART EPOXY TO 1PART SAND(BY VOLUME)	30	68°F/54°F	1	6	5000	A-3	12.4	22.5	24.7	25.0	.026	1590	CONCRETE AND BOND INTERFACE	END OF #6 REBAR TURNED AND THREADED WITH 5/8" - UNF
				30	68°F/54°F	1	6	5000	A-4	10.4	19.9	28.0	35.0	.080	1410	REBAR RUPTURE IN THREAD	
				14	62°F/33°F	1	5	5100	B-3	19.4	20.0	21.5	21.5	.020	1700	CONCRETE AND BOND INTERFACE	#8 REBAR STUB THREADED WITH 7/8" UNF & BUTT WELDED TO #5 GROUTED REBAR
				15	62°F/33°F	1	5	5100	B-4	17.8	16.6	18.6	18.7	.025	1410	CONCRETE AND BOND INTERFACE	
39.6	45.4	#6	WIL-X GROUT (SHRINKAGE COMPENSATING CEMENT) MIX RATIO: (4.5 GAL WATER/94 LB SK CEMENT)	28	68°F/54°F	1	6	5000	A-5	11.9	26.5	27.5	30.7	.069	1870	CONCRETE AND BOND INTERFACE	END OF #6 REBAR TURNED AND THREADED WITH 5/8" UNF
					68°F/54°F	1	6	5000	A-6	13.0	25.2	--	25.7	--	1780	REBAR RUPTURE IN THREAD	
					62°F/33°F	1	5	5200	B-5	17.3	12.4	12.3	13.0	.065	1050	CONCRETE AND BOND INTERFACE	#8 REBAR STUB THREADED WITH 7/8" UNF & BUTT WELDED TO #5 GROUTED REBAR
					62°F/33°F	1	5	5200	B-6	17.5	16.7	19.9	20.0	.023	1420	CONCRETE AND BOND INTERFACE	
39.6	45.4	#6	BOSTIK-275 QUICKSET MORTAR MIX RATIOS: 1. 45 LBS DRY AGGREGATE/GAL LIQUID ACTIVATOR 2. 45 LBS DRY AGGREGATE/1.5 GAL LIQUID ACTIVATOR	2. 28	68°F/54°F	1 1/8	6	5000	A-7	12.0	29.0	30.2	30.5	.045	2050	REBAR RUPTURE IN THREAD	END OF #6 REBAR TURNED AND THREADED WITH 5/8" - UNF
				2. 28	68°F/54°F	1	6	5000	A-8	13.3	23.5	25.3	25.5	.034	1660	REBAR RUPTURE IN THREAD	
				1. 30	68°F/54°F	1	6	5000	A-9	16.6	29.2	33.4	34.8	.033	2070	CONCRETE AND BOND INTERFACE	
27.9	32.4	#5	TYPE II MODIFIED PORTLAND CEMENT GROUT (SEE MIX RATIO ABOVE)	27	62°F/33°F	7/8	6	5200	B-7	8.8	19.4	21.2	26.5	.137	1650	CONCRETE & GROUT	#8 REBAR STUB THREADED WITH 7/8" UNF AND BUTT WELDED TO #5 GROUTED REBAR
						7/8	6	5200	B-8	5.4	20.7	21.6	31.7	.308	1760	CONCRETE & GROUT	
						7/8	5	5200	B-9	14.1	16.0	18.6	19.7	.052	1630	CONCRETE & BOND INTERFACE	
						7/8	5	5200	B-10	14.9	19.7	23.6	25.5	.050	2010	CONCRETE & BOND INTERFACE	
27.9	32.4	#5	EPOXY MORTAR - STATE SPECIFICATION 8040-61J-03 (SEE MIX RATIO ABOVE)	14	62°F/33°F	7/8	6	5100	B-11	4.3	16.0	21.7	30.7	.411	1360	CONCRETE & MORTAR	
						7/8	6	5100	B-12	16.7	17.1	21.1	21.6	.028	1450	CONCRETE & MORTAR	
						7/8	5	5100	B-13	22.5	3.1	6.0	14.2	.172	320	CONCRETE & BOND INTERFACE	
						7/8	5	5100	B-14	14.9	--	--	23.5	--	--	CONCRETE & BOND INTERFACE	

NOTES:
(1) REBAR - ALL ASTM A-615 GR 60
(2) ALL HOLES DRILLED WITH IMPACT HAMMER AND CARBIDE TIPPED BIT, THEN CLEANED WITH COMPRESSED AIR.
(3) CONCRETE MIX DESIGN USED FOR TEST SLAB: CALTRANS STANDARD SPECIFICATIONS - CLASS A, 1-1/2" MAX. AGGREGATE, 2"-3" SLUMP.
(4) LOADING RATE - DEFINED AS AVERAGE AT WHICH MAX LOAD WAS ACHIEVED.
(5) ACTUAL TENSILE STRENGTHS LISTED ARE AVERAGES FROM TEST RESULTS OF #5 AND #6 REBARS WELDED TO THREADED #8 REBAR STUBS AND PULLED IN TESTING MACHINE.

Table 4. Summary of dynamic pullout tests conducted on rebar dowels in Phases A and B.

necessary to facilitate the placement of the viscous Bostik-275 mortar. Each piece of #6 rebar was threaded for a distance of two inches at one end with 5/8-18 UNF threads so that the coupler and pull bar could be attached.

The ultimate pullout load for each of the tests was 25 kips or greater. Tensile failure in the rebar occurred at the base of the threaded stub in seven of the nine rebar dowels tested. In the remaining two rebar pullout tests, loss of tensile load was caused by combined concrete tensile strength failure and the loss of bond between the grout and the concrete in the drilled hole. The maximum tensile loads at failure for these two specimens, however, were similar to those of other specimens in which the rebar broke in the threaded regions. The two specimens that failed by combination of concrete tensile cracking and bond loss had been bonded, one with Bostik-275 mortar and the other with Wil-X cement grout. The length of curing time for the bonding material of each specimen in Phase A, prior to testing, was approximately 28 days.

5.1.2 Discussion of Pullout Tests, Phase B

A total of fourteen grade 60 rebar dowels (eight #5 rebars and six #6 rebars) were bonded, two with Wil-X cement grout, six with Type II Modified portland cement grout, and six with epoxy mortar. For the two latter types of bonding materials the following rebar sizes and embedment depths were employed:

- two #5 rebars at a 5-inch depth,
- two #5 rebars at a 6-inch depth,
- two #6 rebars at a 5-inch depth.

Both #6 rebars bonded with Wil-X cement grout were embedded 5 inches.

All holes were 1/4 inch larger in diameter than the nominal rebar size. The length of curing time of the bonding materials prior to conducting the pullout tests was 14 days for the six rebars bonded with epoxy mortar and 28 days for the remaining specimens grouted with Type II Modified portland cement grout or Wil-X grout.

When loaded, all specimens embedded 5 inches failed as a result of a combination of concrete tensile failure and bond failure at the grouting material/concrete interface in the drilled hole. A typical rebar dowel which was bonded with epoxy mortar is shown in Figure 28 following a pullout test.

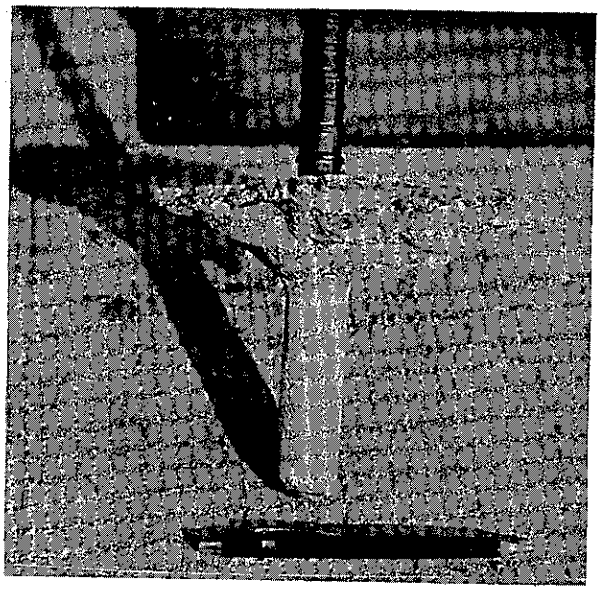


Figure 28. Rebar dowel bonded with epoxy mortar following pullout test, showing typical mode of failure.

The #5 rebar dowels embedded 6 inches with epoxy mortar and Type II Modified portland cement grout failed as a result of shear loss within the bonding material.

Graphs of load versus deflection for all preliminary pullout tests performed in Phases A and B were drawn from plots of load/deflection versus time curves made by a XYY recorder during actual pullout tests and are included in Appendix B. Values of ultimate pullout loads and loads at deflections or pullout movements of 0.01 inch and 0.02 inch are tabulated for reference and are shown in Table 4.

5.1.3 Discussion of pullout tests conducted in previous research

A previous State-financed research study(5) was performed to determine what effects variations in the roughness of the sides of shallow drilled holes have on pullout strength of bonded rebar dowels. In this research project, a total of 21 pullout tests were performed, eighteen on #6 and three on #8 Grade 60 rebar.

Two types of equipment commonly used to drill holes in concrete, namely; (1) a rotary impact hammer with a carbide-tipped bit, and (2) a drill motor with a water cooled, diamond impregnated core bit, were used to provide rough and smooth sided holes, respectively. Secondary variables considered important to this project were:

(1) Degree of cleanliness of bond surfaces in holes prior to installing rebars.

(2) Type of bonding material.

(3) The effects of equivalent bond areas of different rebar sizes installed at different embedment depths.

A summary and evaluation of the twenty-one pullout tests performed in this previous research project(5) are contained in Appendix E of this report.

Grout types and mixing proportions and installation procedures were the same as those used in this research project.

5.1.3.1 General observations

From the results of the series of pullout tests completed in this previous study(5), the following observations were made:

- #6 Rebar embedded 6 inches in a reinforced concrete slab

(1) In all tests conducted on #6 rebar bonded in 6-inch-deep holes, including variations due to all parameters investigated, averages of dynamic pullout strengths were high and ranged from 29.2 kips to 41.0 kips.

(2) In general, when the holes were cleaned with compressed air, the variations in the roughness of the bonding surfaces of holes had little effect on pullout strength of doweled rebars bonded with Type II Modified portland cement grout. Although not tested in this previous research project, rebars bonded with epoxy mortar are expected to have similar pullout strengths as indicated by results of pullout tests shown in Table 4 of this report.

(3) A considerable improvement in average pullout strength, from 34.4 to 41.0 kips, was observed when rough as opposed to smooth sided holes were used and rebars, bonded with Type II Modified portland cement grout, were installed in holes which were thoroughly brushed and washed with water.

(4) With epoxy mortar, however, no improvement in pullout strength resulted with rebars installed in rough as opposed to smooth sided holes, thoroughly brushed and washed with water, then air dried prior to applying bonding material.

- #8 Rebar embedded 4.5 inches in a reinforced concrete slab

A 29 percent decrease in average pullout strength of rebar (from 29.2 to 20.7 kips) was observed when embedment depth of rebar was decreased from 6.0 to 4.5 inches and rebar size was increased from #6 to #8 to produce equal rebar bond area. Therefore, the relationship between maximum pullout strength and bond area of rebar is not linear. A minimum embedment depth is evidently necessary before the actual strength of a rebar becomes effective and pullout strength begins to increase significantly. It was determined that the pullout strength of large diameter rebar installed at extremely shallow embedment depths will not equal that of a smaller diameter rebar installed at a greater depth and having a bond area equal to that of the larger diameter rebar.

5.1.3.2 Recommendations

As a result of this previous study completed in March 1978(5), it was recommended that:

(1) Either the core or impact rotary hammer drilling method be allowed where a hole depth of 6 inches or greater is desired.

(2) For holes shallower than 6 inches where optimum strength is required, the impact rotary hammer drilling method should be used and the holes washed and scrubbed prior to bonding the rebar.

(3) Either epoxy mortar or Type II Modified portland cement grout as were prepared and used in this research project be allowed for grouting rebar dowels where environmental conditions permit.

(4) Epoxy mortar not be allowed for grouting rebar dowels in wet weather or where bonding surfaces or holes are damp or wet upon installing rebar.

(5) Where Type II Modified portland cement grout is used, exposed grout surfaces around rebars should be cured using wet rags where optimum strength is desired. In this previous research project, no tests were conducted to determine if any loss in the pullout strength of grouted rebars occurred as a result of not wet curing portland cement grout for a period of 3 days. However, it is known that a hot, dry environment will cause grout to crack or shrink without proper curing and a loss in rebar pullout strength may result.

5.1.4 Discussion of Important Variables in Pullout Tests

5.1.4.1 The effect of hole variables on rebar pullout strength

Hole Diameter: Although no verification testing was done in this research study, changes in hole diameter can significantly affect the pullout strengths of bonded rebar dowels. The hole diameter should be only slightly greater than the nominal rebar diameter, but large enough to permit complete coverage and consolidation of the bonding material around the rebar. In this research project, holes were drilled with a diameter 1/4 inch larger than the nominal rebar size being bonded. The main reason for limiting the hole diameter is to minimize potential shrinkage of some of the materials commonly used for bonding rebar dowels; portland cement grout and epoxy for instance. Too small of a clearance between the rebar and the hole sides, on the other hand, would prevent full wetting of both the concrete surface on the sides of the holes and the embedded rebar surface, possibly resulting in poor consolidation of the bonding material and hence low pullout strengths.

Hole Depth: From results of pullout tests conducted at both 5-inch and 6-inch embedment depths, it is apparent that pullout strengths of rebar bonded in holes 5 inches deep are generally somewhat lower and more erratic than those bonded in holes 6 inches deep (see Table 4).

Averaged results from pullout tests conducted on #5 and #6 rebars installed 5 inches into a concrete slab ranged from 16.5 kips for Wil-X cement grout to 22.6 kips for Type II Modified portland cement grout.

At a hole depth of 6 inches, average pullout strengths ranged from 28.2 kips to 30.2 kips for the four bonding materials tested (see Table 1). Even though relatively high and consistent pullout strengths were obtained with both #5 and #6 rebars bonded in holes 6 inches deep, that depth is inadequate to fully develop the tensile strength of either the #5 or #6 rebars as tested.

5.1.4.2 Selection of effective bonding material

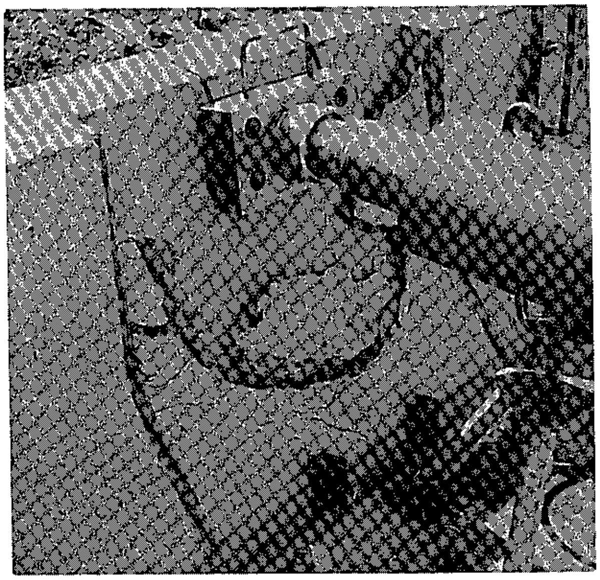
Of the four bonding materials tested in this research, Type II Modified portland cement grout and the epoxy mortar were the two most widely available which produced high ultimate pullout strengths. The most economic material which produced consistently high pullout strength, provided that proper mixing and installation procedures are followed, is the Type II Modified portland cement grout. A cost comparison of equal volumes of the four mixed bonding materials as tested is shown in Appendix F.

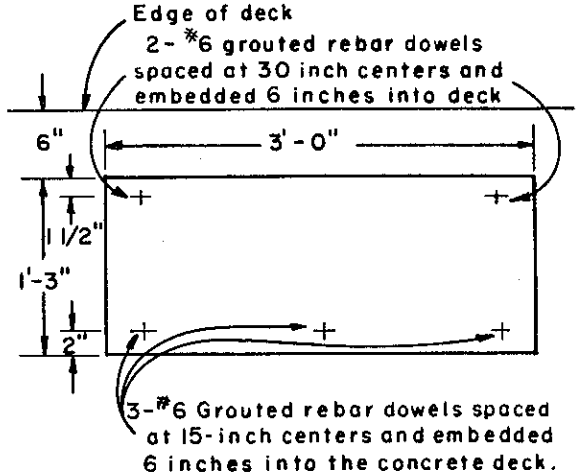
5.2 Results of Static Loading Tests on Barrier Sections

5.2.1 Series I Barrier Tests

General Discussion: Three full-scale barrier load tests were performed in this initial test series. Figures 29, 30, and 31, show pictures of the three failed 3-foot-long concrete barrier sections and summarize vital information obtained from the tests. As previously mentioned, each of these short lengths of barriers were heavily reinforced in the neck or narrow portion of the barrier. This was purposely done to prevent probable cracking or failure there, and to force failure at the base of each section of barrier so that relative strengths of the various rebar anchoring methods could be determined.

In general, fairly high overturning resistance to the externally applied horizontal forces resulted in all three tests. Load-deflection curves for each of the three short barrier tests conducted in Series I are shown in Figure 32. Maximum horizontal loads externally applied to the two replacement concrete bridge barrier sections were 41.2 kips and 34.3 kips for Test Nos. 1 and 3 respectively. Both of these replacement barrier sections, attached to the bridge deck with #6 grouted rebar dowels, proved to be stronger than the standard Type 25 Concrete Bridge Barrier with cast-in-place #5 rebar dowels which failed at an external load of 28.7 kips. Because of severe cracking of concrete along the bottom of the front edge of each of the three barrier sections tested, any deflections measured during these tests and reported here are at best approximate.





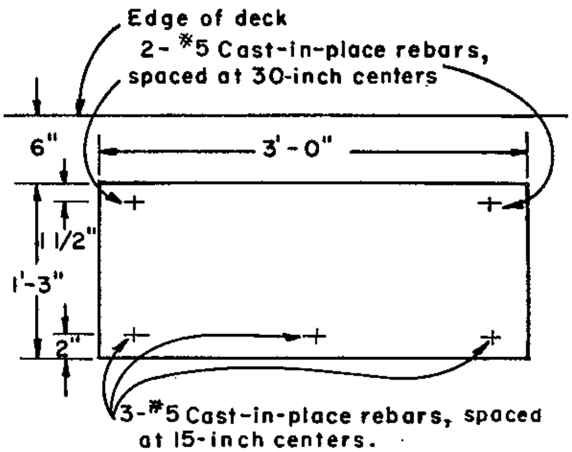
A. Failed section of Type 25 Replacement Barrier shown after horizontal load test.

B. Cross section at base of Replacement Barrier showing locations of grouted #6 rebar dowels anchoring barrier to concrete bridge deck.

Important Test Information:

- Maximum horizontal load attained = 41.2 kips
- Elapsed loading time at maximum load = 10 seconds
- Barrier failure mode: Splitting tensile failure in concrete along face of the barrier base combined with loss of bond strength of upper leg of rebar dowels along the front edge of the barrier.

Figure 29. Results of the static load test on the 3-foot-long section of Type 25 Replacement Barrier - Series I, Test Number 1.



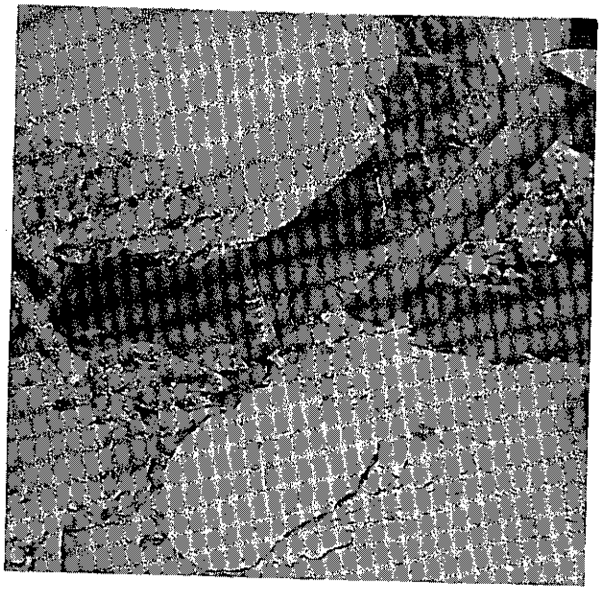
A. Failed section of standard Type 25 Concrete Barrier shown after horizontal load test.

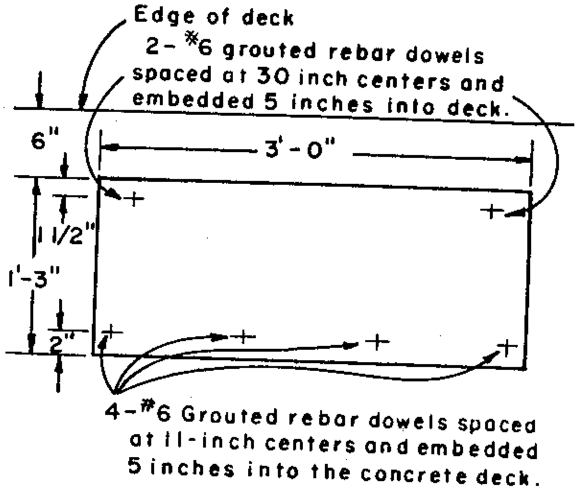
B. Cross section at base of Replacement Barrier showing locations of cast-in-place #5 rebars anchoring barrier to concrete bridge deck.

<u>Important Test Information:</u>

- Maximum horizontal load attained = 28.7 kips
- Elapsed loading time at maximum load = 5.6 seconds
- Barrier failure mode: Loss of bond of tops of front rebars and fracture of the concrete along the front edge of the barrier caused by splitting tension.

Figure 30. Results of the static load test on the 3-foot-long section of standard Type 25 Concrete Bridge Barrier - Series I, Test Number 2.





A. Failed section of Type 25 Replacement Barrier shown after horizontal load test.

B. Cross section at base of Replacement Barrier showing locations of grouted #6 rebar dowels anchoring barrier to concrete bridge deck.

Important Test Information:

- Maximum horizontal load attained = 34.3 kips
- Elapsed loading time at maximum load = 5.5 secs.
- Barrier failure mode: Loss of bond between the two center rebar dowels grouted in the deck, and tensile failure in concrete at outside corners of barrier face combined with loss of bond of upper legs of outside rebar dowels.

Figure 31. Results of the static load test on the 3-foot-long section of Type 25 Replacement Barrier - Series I, Test Number 3.

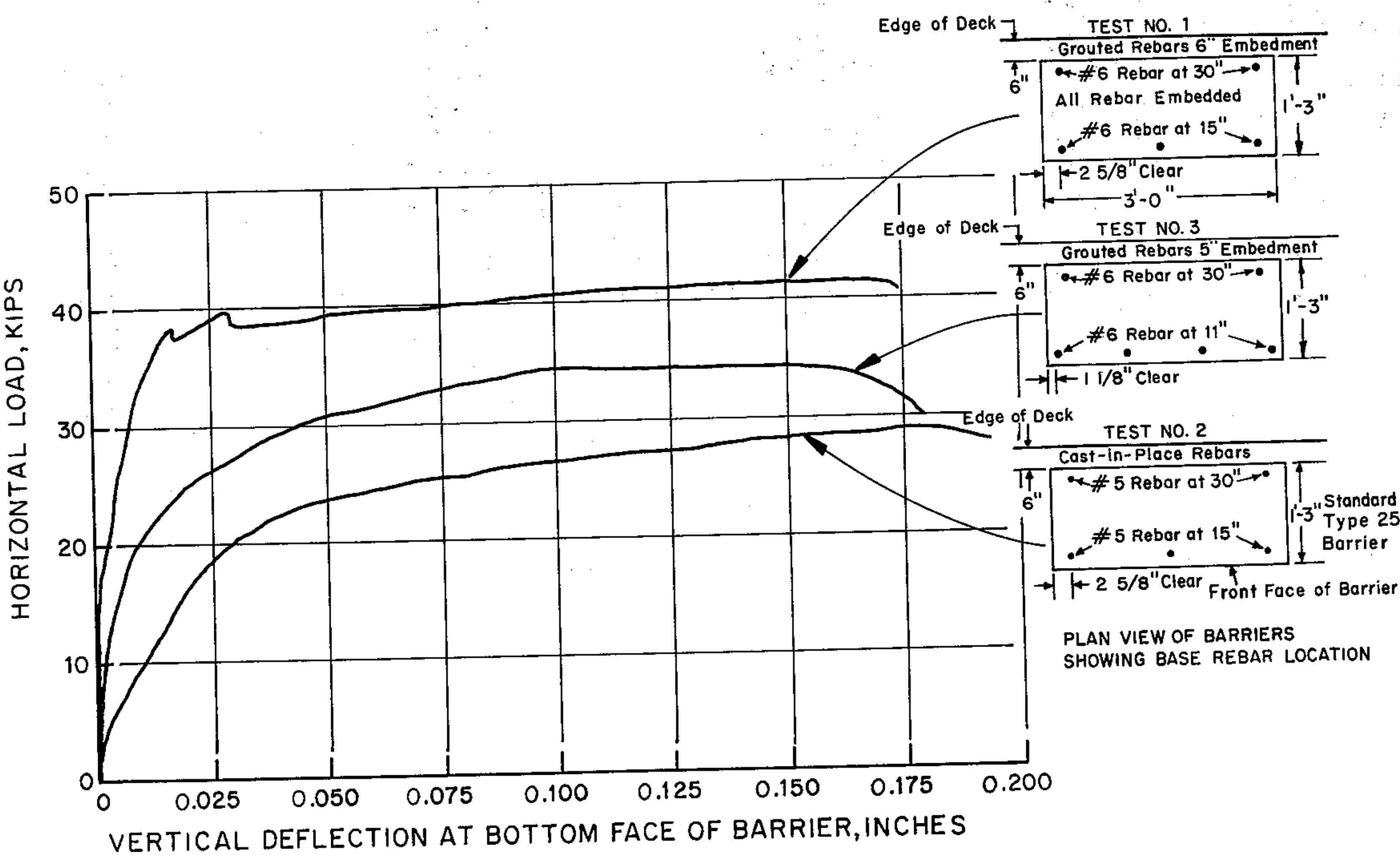


Figure 32. Plots of load versus deflection for the three, 3-foot-long barrier sections tested in Series I.

Significance of barrier failure modes and relationship between reinforcing schemes used, maximum horizontal loads attained, and resulting crack patterns: Failure of the first two barriers tested in Series I (see Figures 29 and 30) resulted because of splitting tension cracks, associated with rebar bond failure, occurring through the bottom front portion of the barrier followed by a complete loss of bond in the upper leg of the three front anchoring rebars. In Test No. 1, the surface area of the upper legs of the front #6 rebar dowels, which is responsible for their bond strength, was approximately 20 percent greater than the upper portion of the three #5 anchoring rebars along the front base of the standard Type 25 Concrete Bridge Barrier loaded in Test No. 2 (Figure 30). This is the main reason why the Type 25 Replacement Barrier in Test No. 1 resisted a 41.2 kip horizontal load, 12.5 kips greater than the load resisted by the standard Type 25 Concrete Bridge Barrier in Test No. 2.

In the third test performed in Series I, Test No. 3, it was desired to test a Type 25 Replacement Barrier with four grouted rebar dowels spaced closer at 11-inch centers and embedded only 5 inches into the bridge deck. In this test, the two grouted rebars installed near the center of the front edge of the barrier failed in bond in the bridge deck, whereas bond failure occurred at the upper legs of the two outer doweled rebars along the front edge of the barrier.

Conclusions from Test Series I: Some very important points were learned from the three tests in Series I.

(1) In both the standard Type 25 Concrete Bridge Barrier, and the other two replacement barriers tested, the short bond length of the upper tails of the anchoring rebars along the front base of the barrier and the minimal cover of the anchoring rebars on the ends of the barrier sections reduced their effectiveness in maximizing overturning resistance of the barrier.

(2) Although two of the grouted rebars in Test No. 3 pulled out of the slab, an embedment length of 5 inches for the front row of #6 rebar dowels at an 11-inch spacing was found to provide greater overturning resistance than did the cast-in-place #5 rebars spaced at 15 inches in the standard Type 25 Concrete Bridge Barrier section.

(3) In Test Nos. 1 and 2, the apparent common weakness in the two barrier systems which finally caused barrier failure was a lack of continuous vertical rebar in the face of the barrier. Transfer of tensile forces in the concrete, in the lower portion of the barrier face, to the short upper tails of the anchoring rebars along the bottom front edge of the barriers was limited. Thus, tensile fracturing of the concrete along the barrier face of the barrier 10 inches or so above the deck surface resulted.

(4) Longer lengths of test barrier providing more cover to anchoring rebars near the ends of the barrier sections would have been preferable.

(5) With the Type 25 Replacement Barrier constructed in Test No. 1, the 6-inch embedment length of the #6 rebar dowel anchors was adequate to prevent pullout of the grouted rebars from the bridge deck.

5.2.2 Series II Barrier Test

General Discussion: A full-scale test on a barrier section 16 feet long was conducted to determine maximum static horizontal load resistance of a barrier having grouted dowels along the front face embedded at the least acceptable depth of 5 inches and spaced 15 inches apart. To prevent vertical cracking along the front face of the barrier which was experienced in Test Nos. 1 and 2 of Series I, the #6 grouted rebar dowels along the front of the barrier were lengthened so that they projected approximately 24 inches above the deck surface. As the actual barrier length, 16 feet, was one foot longer than the length originally planned in order to provide more end cover for the bonded rebar dowels, it was necessary to apply the horizontal load 10 inches to the left of the geometric center of the barrier. This slight offset of the loading point was necessary because of the fixed position of the high strength bolts securing the loading frame to the deck.

Discussion of results: The peak load, 93.0 kips, was reached approximately 20 seconds after initial loading had begun. A load-deflection curve for the 16-foot-long replacement barrier section is shown in Figure 33. As the horizontal load was applied, the first visible effect of load on the barrier was the appearance of a horizontal crack along the base of the front edge of the barrier (see Figure 34).

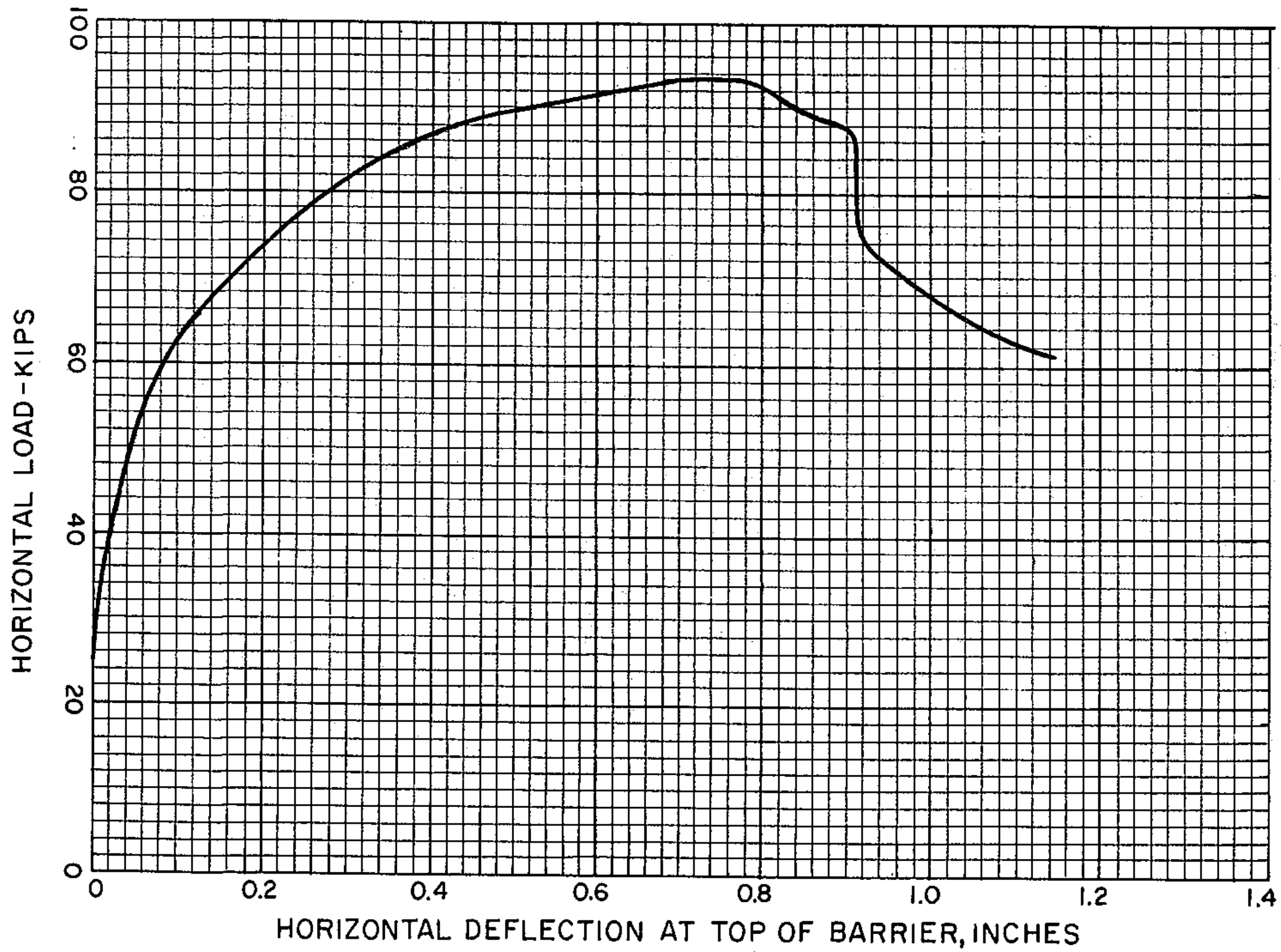


Figure 33. Plot of load versus deflection for the 16-foot-long replacement barrier tested in Series II test.

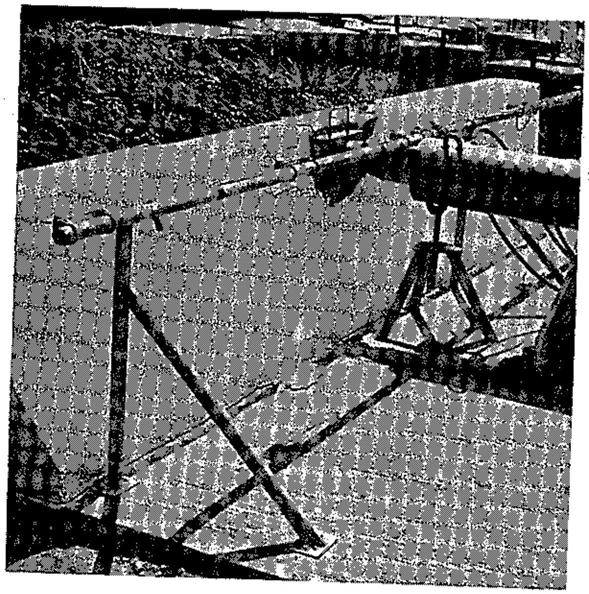


Figure 34. Front face of barrier during Series II test showing crack along bottom edge of barrier face and cracks around loading plate.

As the width of the crack along the front base of the barrier began to increase, radial cracks formed around the loading plate. These cracks passed diagonally through the beam section of the barrier and were indicative of a punching shear failure. As the horizontal load was increased, the size of the shear cracks continued to grow around the loading plate, and many more small cracks running diagonally across the face of the barrier appeared as seen in Figure 35. Once the deep diagonal cracks directly adjacent to and on both sides of the loading plate had propagated and appeared on the back or edge-of-deck side of the barrier (see Figure 36), the horizontal load applied to the loading plate began to decrease. The width of the crack along the bottom of the barrier face reached a maximum size of about 1/4 inch near the left end of the barrier

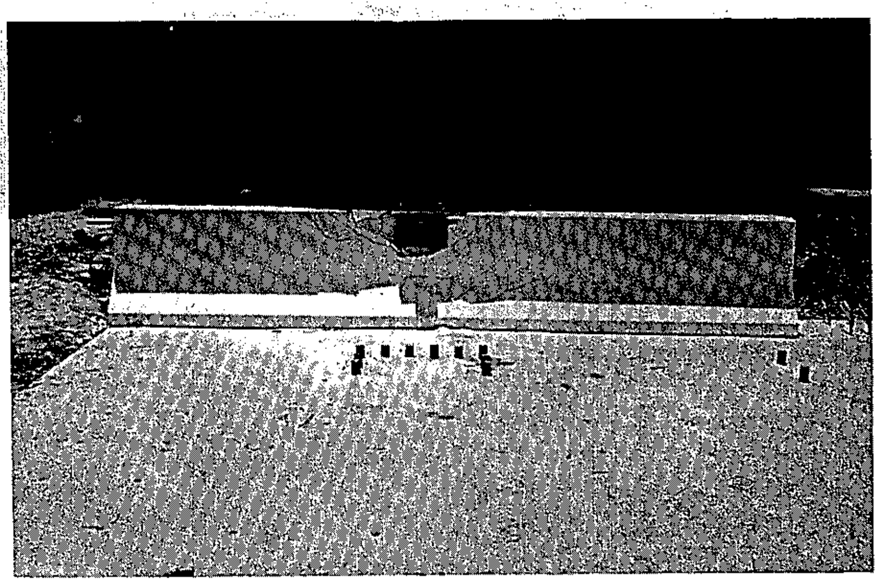


Figure 35. Front view of barrier face following Series II test.

Figure 36. Oblique view of edge-of-deck side of barrier showing diagonal cracking through top beam section in Series II test.

when the maximum horizontal load of 93.0 kips was reached, and narrowed after the load resistance of the barrier had decreased. Some spalling of the deck concrete near one of the grouted front rebar dowels to the left of the loading plate occurred (see Figure 37).

Conclusions: The sequence and location of crack formations of this 16-foot-long barrier is significant. It is evident that:

(1) The 5-inch embedment depth of the front row of grouted #6 rebar dowels spaced at 15 inches was adequate to resist the overturning force applied to the barrier and develop the ultimate punching shear resistance of the concrete.

(2) The size and location of the rebar placed in the 16-foot-long barrier resulted in a good balanced design, with a horizontal crack appearing along the base of the barrier (signifying the front row of rebar dowels beginning to pull out of the deck) just as punching shear cracks occurred around the loading plate.

(3) The final or extreme failure mode of the barrier section was punching shear through the top beam of the barrier, not pullout of the grouted rebar dowels and overturning of the barrier.

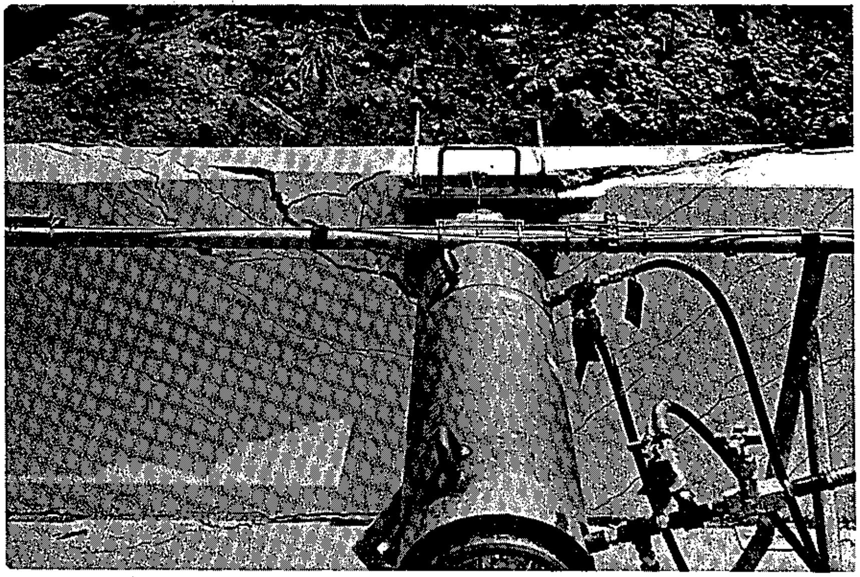


Figure 37. Close-up view of barrier face in Series II test showing crack pattern around bearing plate.

5.2.3 Series III Barrier Tests

General Discussion: As previously mentioned, two additional sections of concrete bridge barrier were built and tested in this third test series. Each section was 6 1/2 feet in length. One section of barrier was constructed similar to a standard Type 25 Concrete Bridge Barrier; the other barrier was constructed with similar reinforcing, but having a 6-inch-diameter prestressing conduit running continuously through the center of the bottom section (see Figures 11 and 12 for reinforcing details). Both barriers were loaded following the same procedures as were used in Series I and II barrier tests. The failure mode of the standard barrier section was nearly the same as that observed in Series I, Test No. 2, with a horizontal splitting tensile crack occurring through the concrete just at the top of the front row of anchoring rebars and extending to the center of the barrier base (see Figure 38). A maximum horizontal load of 44.5 kips, reached in about 9 seconds, was required to fail the standard Type 25 Barrier. The load deflection curves for the two barriers tested in this third test series are shown in Figure 39. Again as in the Series I tests, minimal overlap of the tails of anchoring rebar along the front base of the barrier with stirrups and vertical reinforcing bars allowed the concrete to fail in tension.

Discussion of Results: The barrier section containing a 6-inch-diameter conduit failed in a similar manner as did the standard section, but at a lower load of 34.9 kips. A picture of the failed barrier with conduit is shown in Figure 40. The apparent reason for the lower load failure level of the barrier containing the conduit is because of a loss of bond around stirrup legs along the front of the barrier face. It was necessary to bend legs of the front

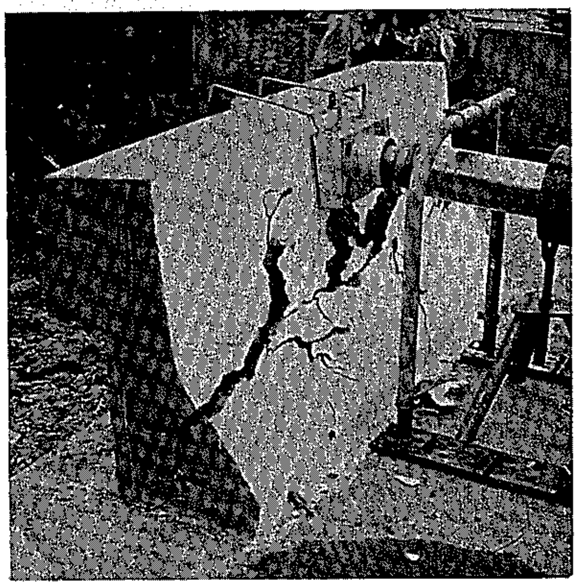


Figure 38. Oblique view of the 6 1/2-foot long standard Type 25 Concrete Bridge Barrier section after horizontal load test in Series III, Test Number 2.

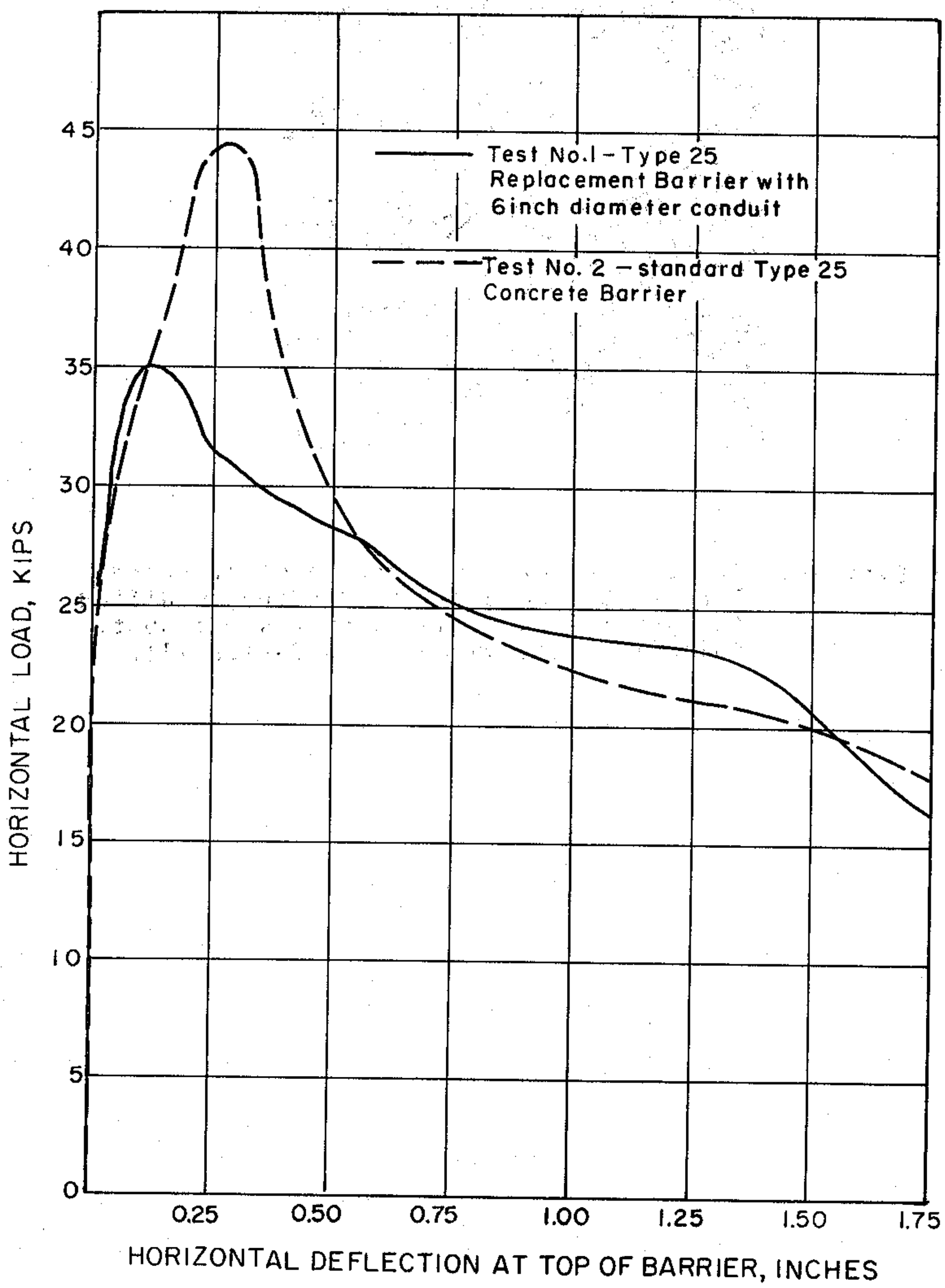


Figure 39. Plots of load versus deflection for the 6 1/2-foot-long barrier sections in Series III tests.

Figure 40. The 6 1/2-foot-long section of standard Type 25 Concrete Bridge Barrier, modified to contain a 6-inch-diameter steel duct, following Test Number 1 in Series III.

row of stirrups outward to provide ample room for the 6-inch-diameter conduit. When the barrier was loaded, the bent legs of these stirrups straightened somewhat. This caused severe spalling of concrete around each stirrup leg, resulting in bond failure. The maximum applied horizontal load was attained after 7 seconds of loading.

<u>Conclusion</u>: In the static load test series conducted, Series III, the horizontal load resistance of the barrier with conduit was 34.9 kips, 22 percent less than that of a standard barrier. Thus, the strength of the modified barrier containing the conduit is not considered equivalent to that of a standard Type 25 Concrete Barrier.

6. REFERENCES

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3. Transportation Research Circular Number 191, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances, February 1978.

4. Dusel, John P. Jr., a memorandum report titled "Dynamic Pullout Tests of Rebar Dowels Bonded in Shallow Holes in a Reinforced Concrete Slab", State of California, Department of Transportation, Transportation Laboratory, Research Project Number 636871, May 1977.

5. Dusel, John P. Jr., "The Effect of Surface Roughness of the Sides of Shallow Holes Drilled in Concrete on the Pullout Strength of Bonded Rebar Dowels", State of California, Department of Transportation, Division of Construction, Office of Transportation Laboratory, Research Report 19601-762504-646930, March 1978.

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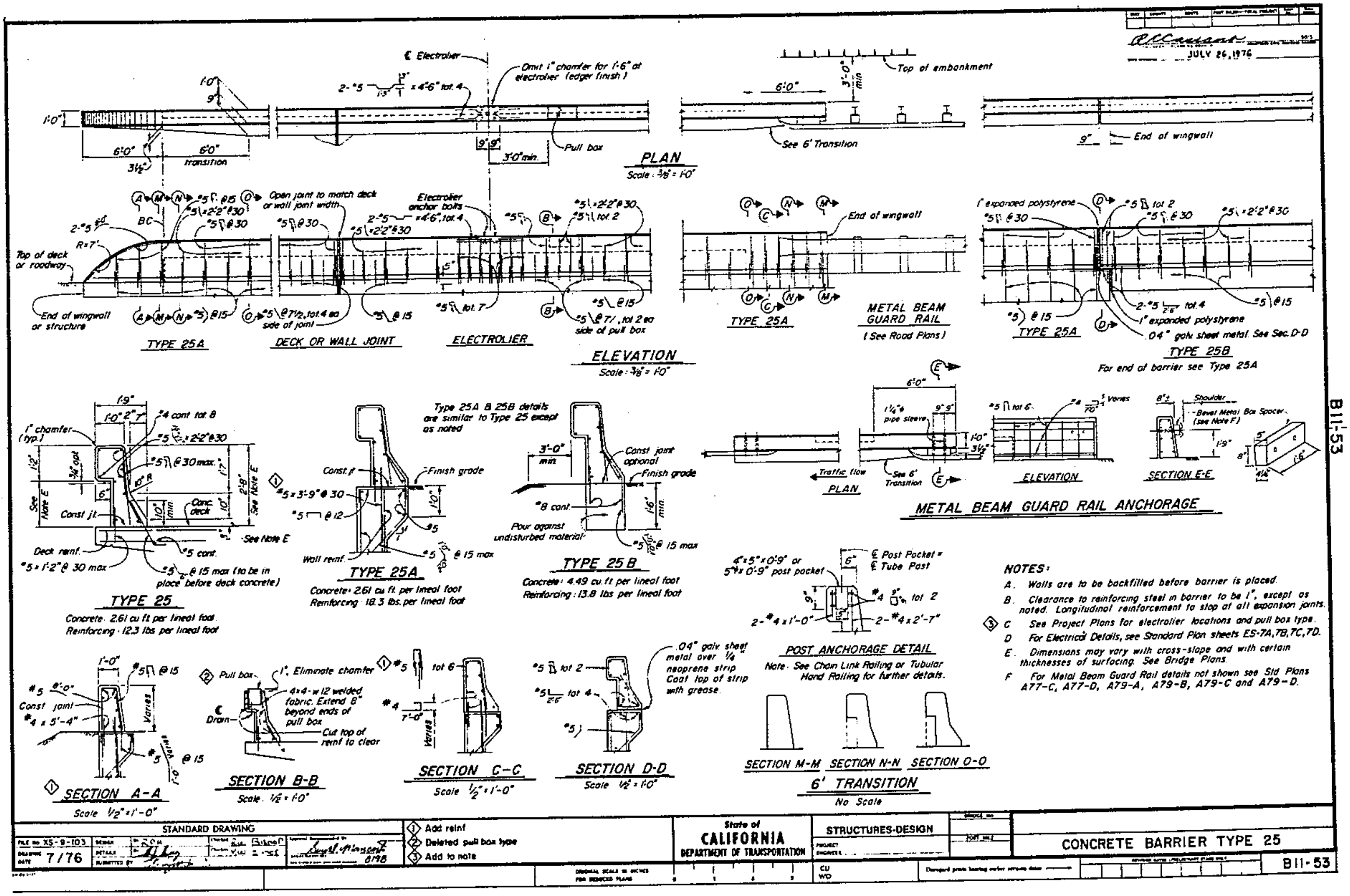
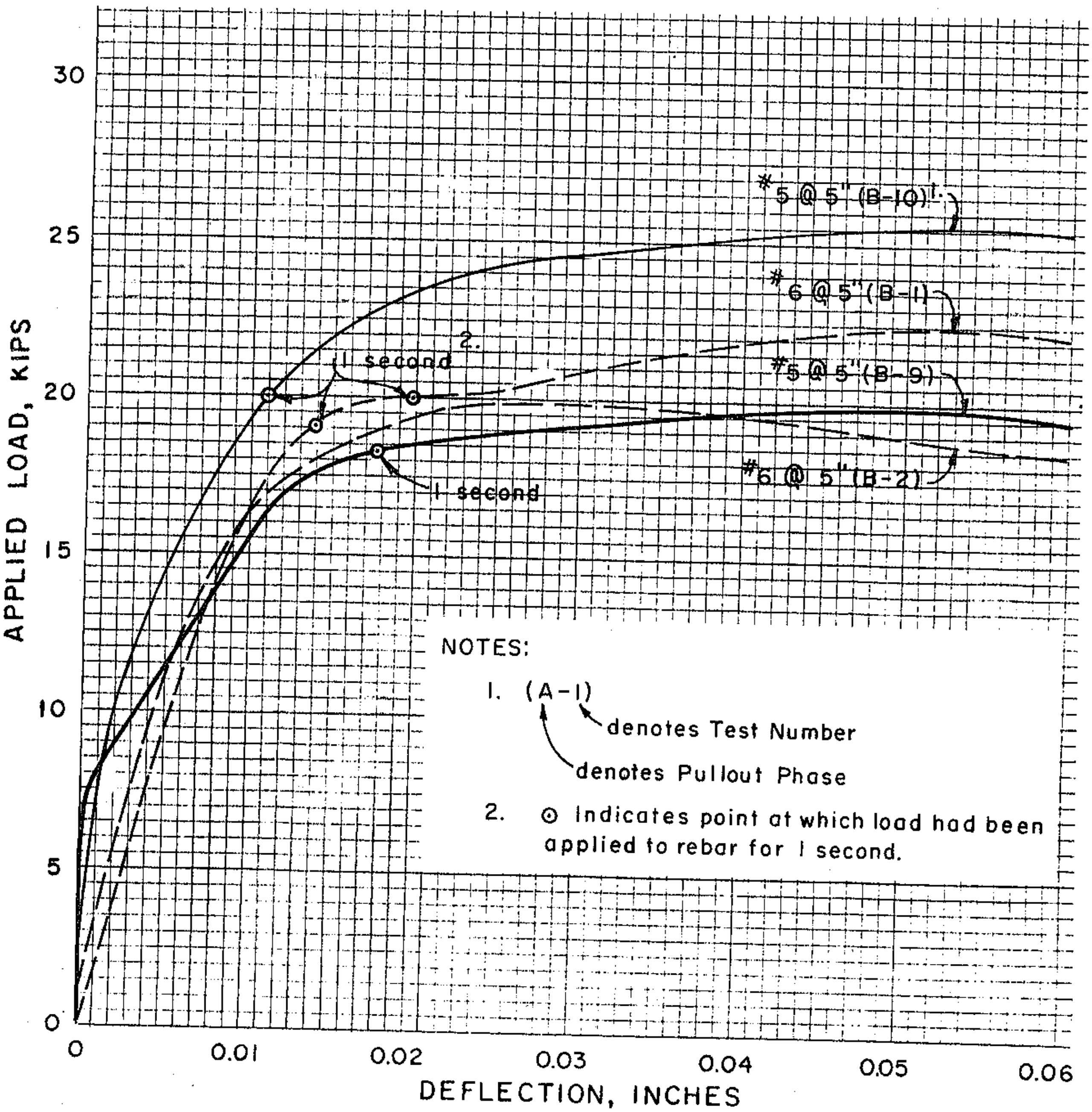
7. State of California, Department of Transportation, "Standard Plans", Section 90-7.07, January 1975.

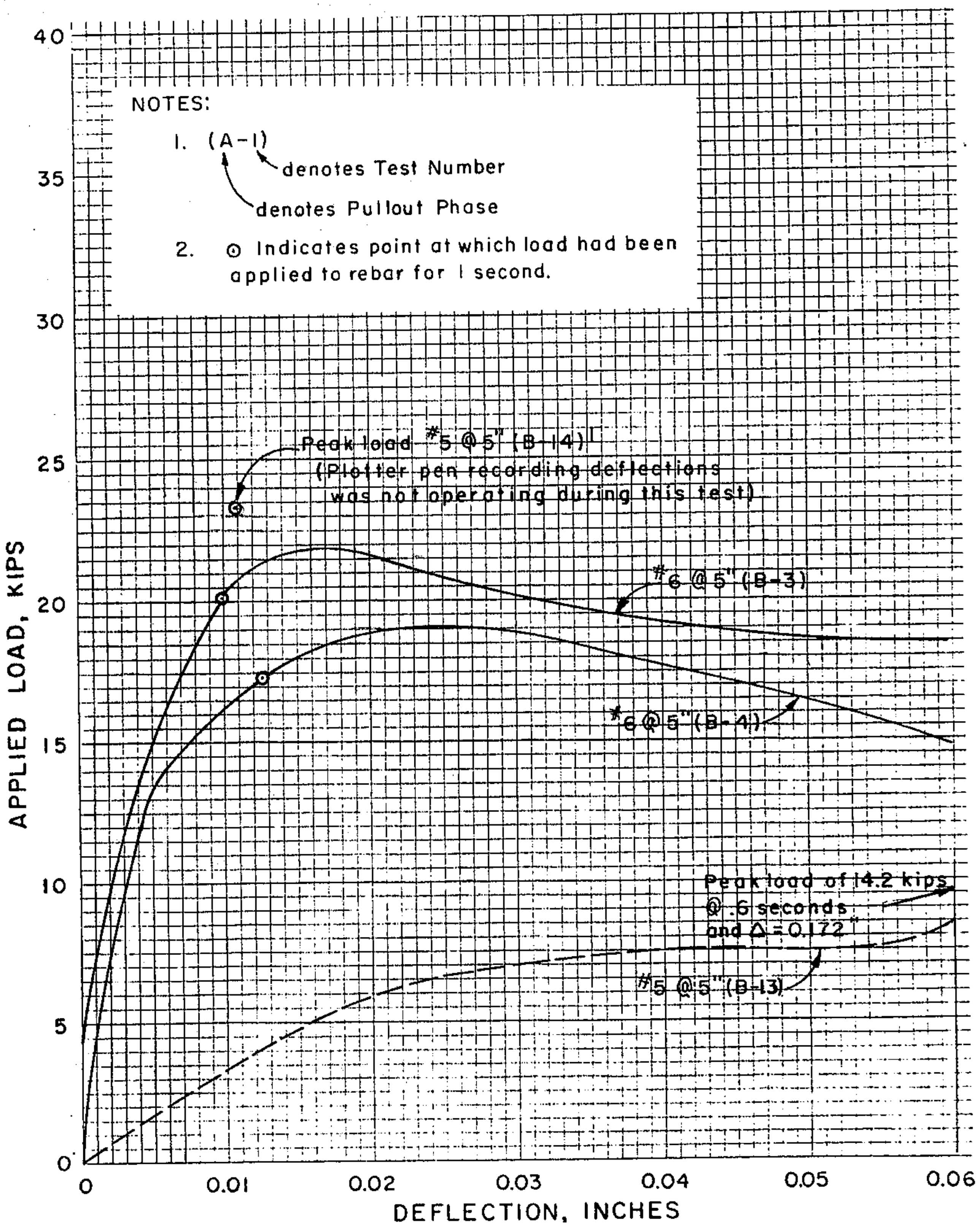
8. State of California, Department of Transportation, "Standard Specifications, January 1978.



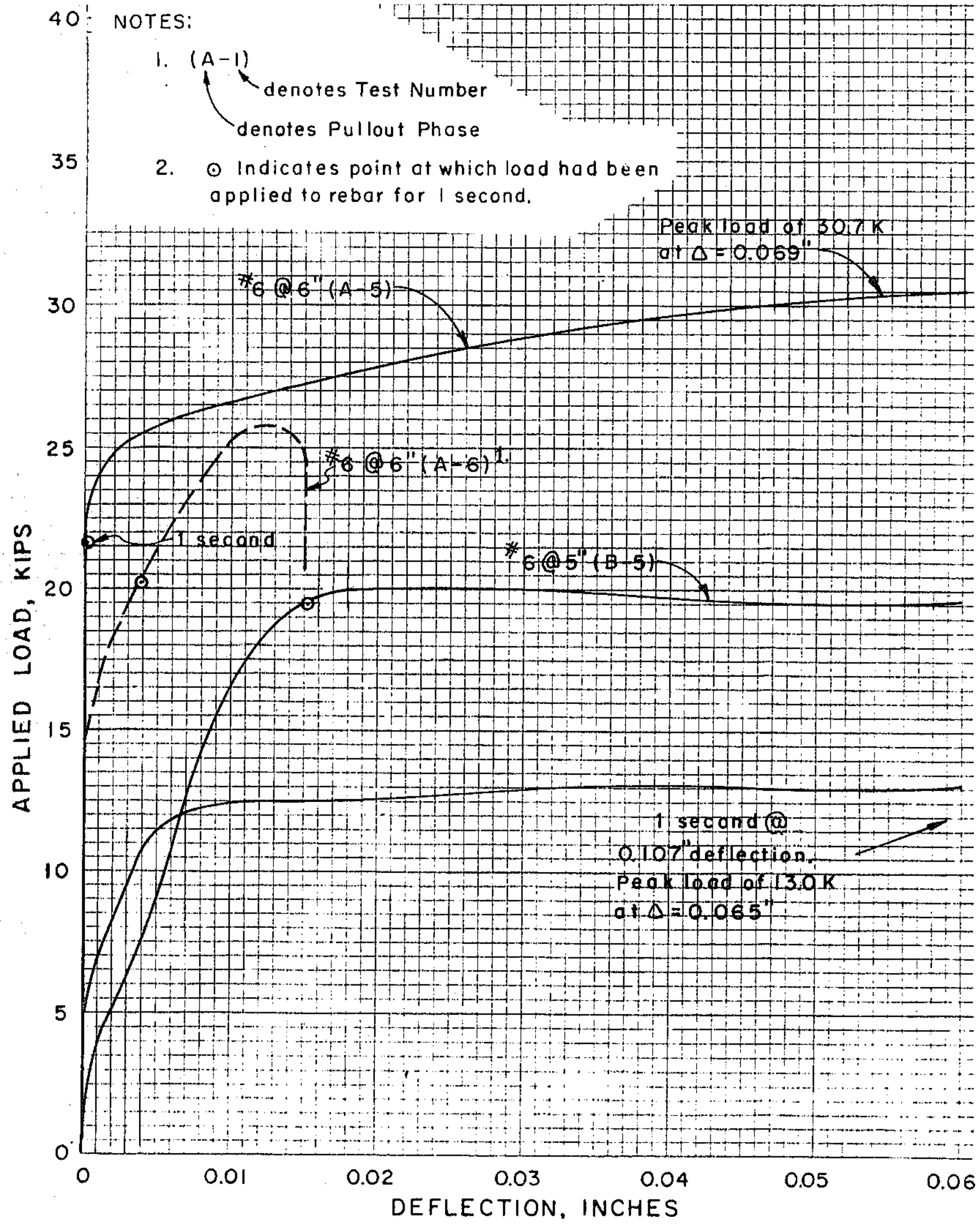
Appendix A. Sheet B11-53 of the Caltrans 1978 Standard Plans titled "Concrete Barrier Type 25".



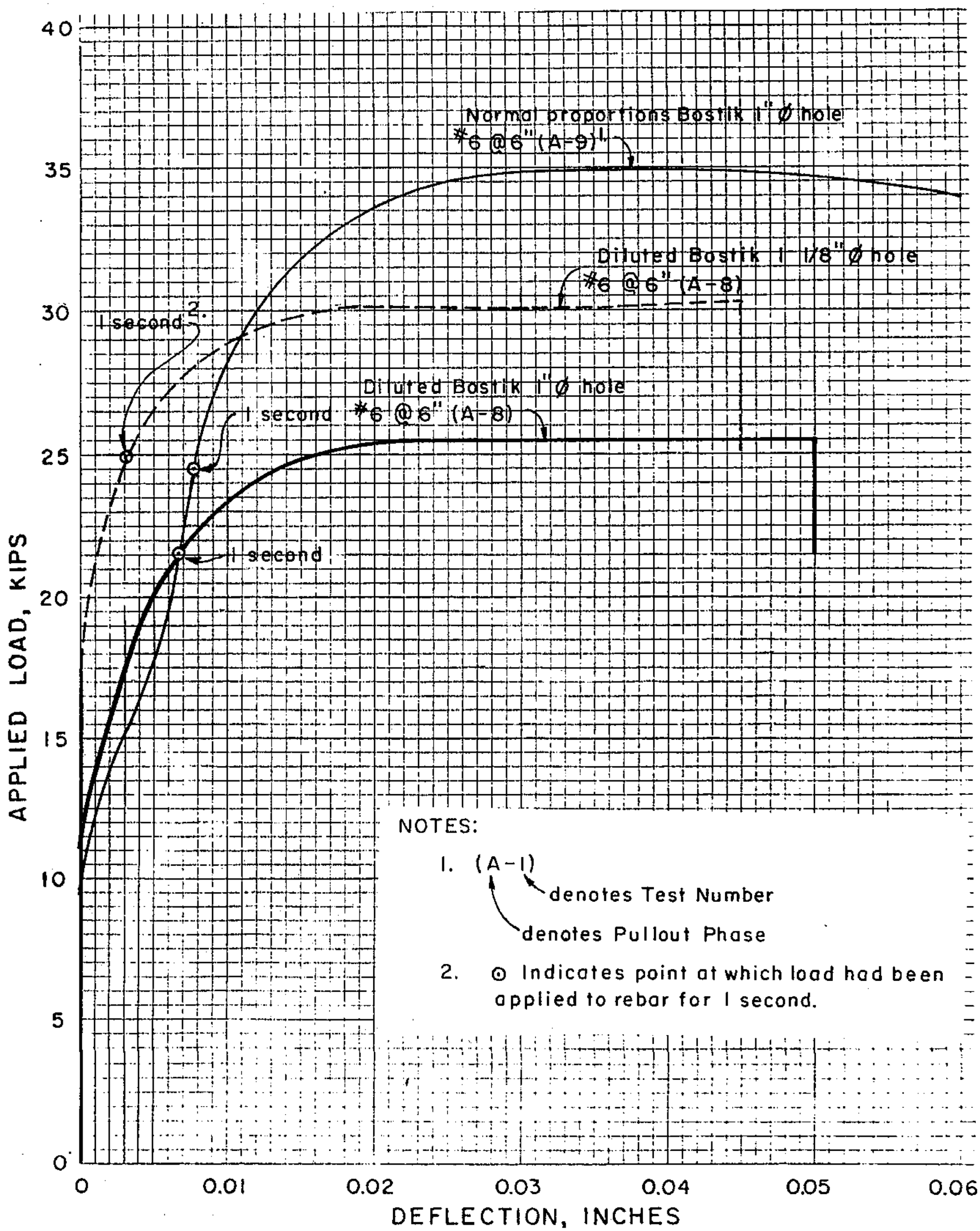
Appendix B-1. Graphs of load versus deflection from individual pullout tests on rebar dowels bonded with Type II Modified portland cement grout and embedded five inches into a reinforced concrete slab.



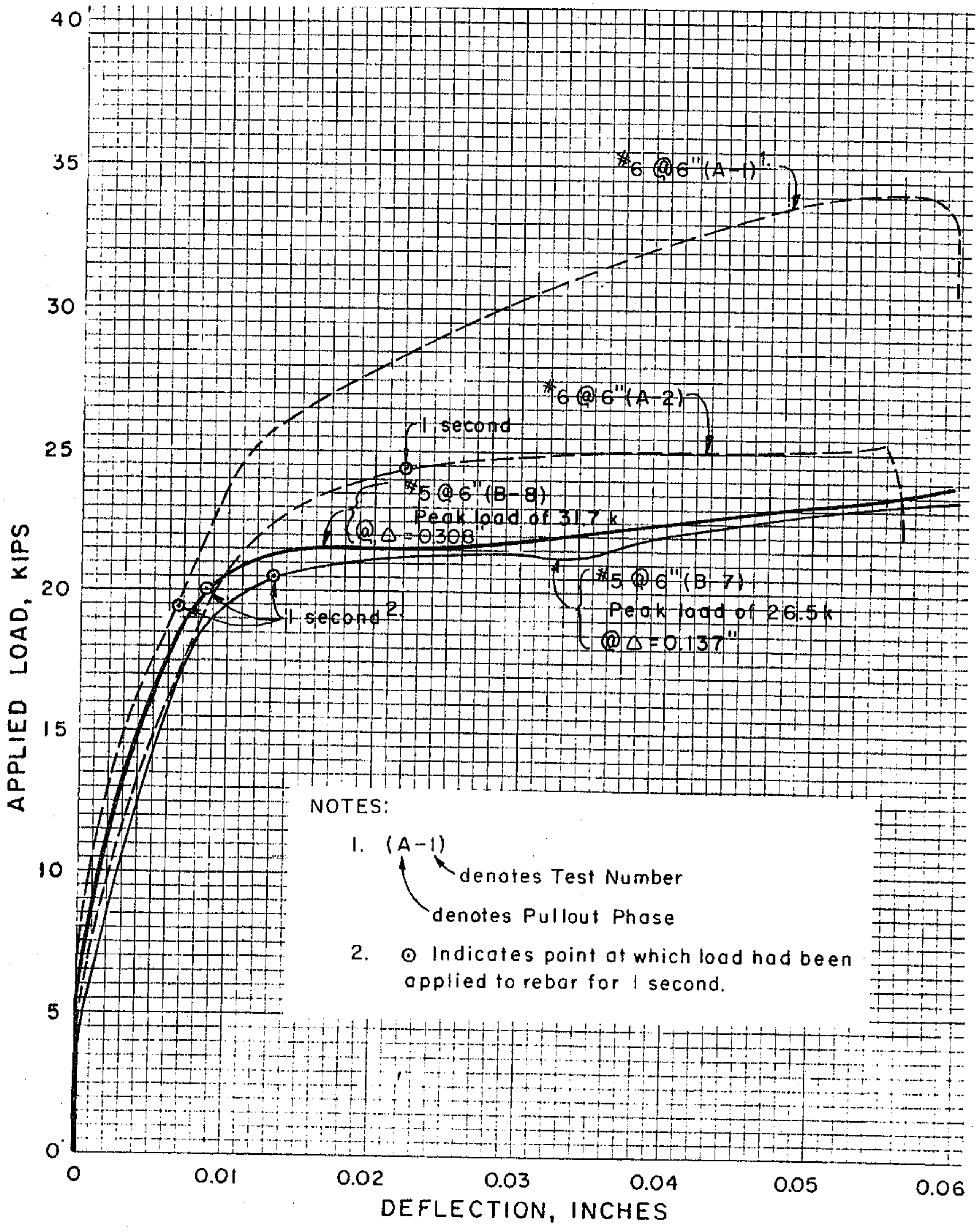
Appendix B-2. Graphs of load versus deflection from individual pullout tests on rebar dowels bonded with epoxy mortar and embedded five inches into a reinforced concrete slab.



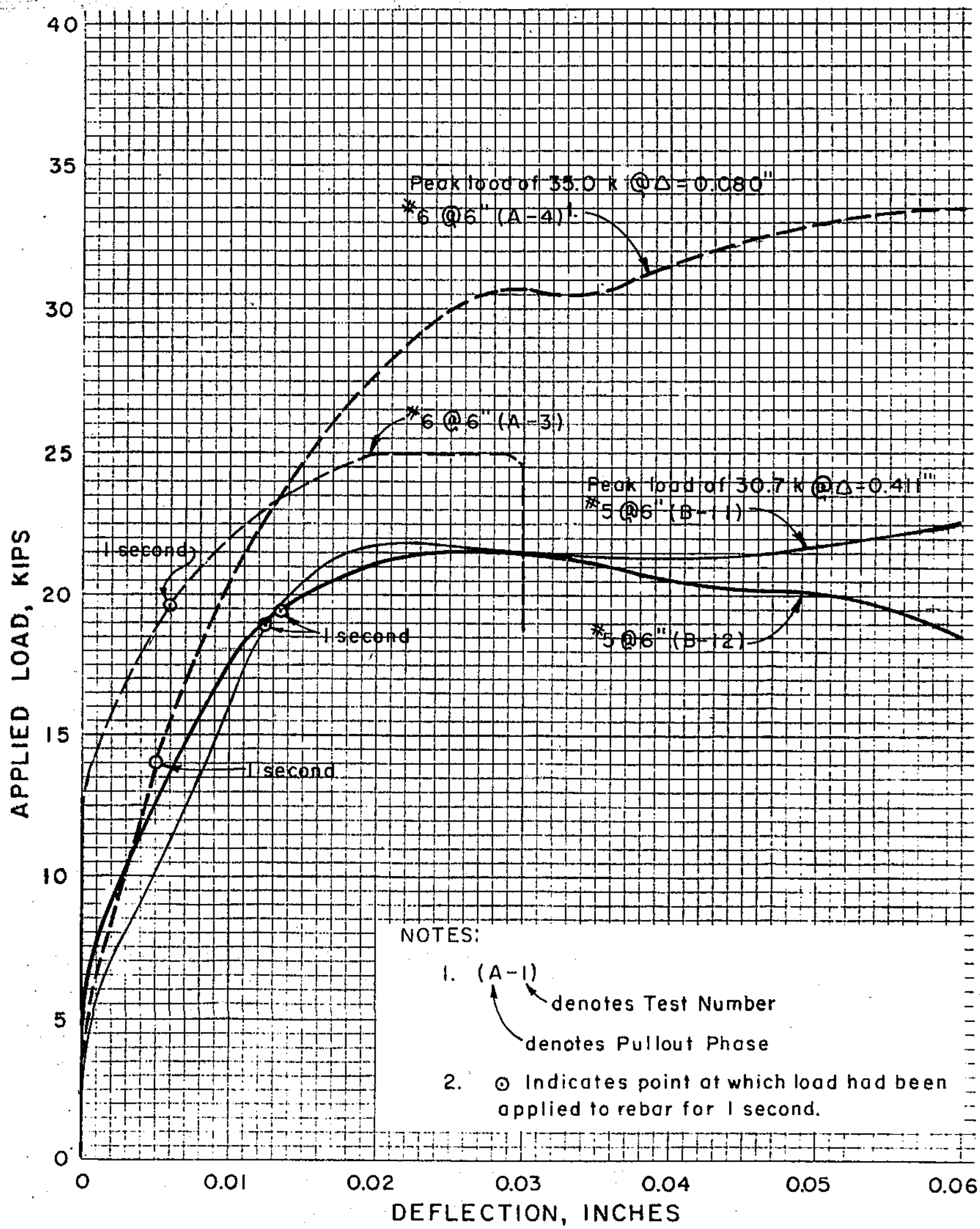
Appendix B-3. Graphs of load versus deflection from individual pullout tests on rebar dowels bonded with Wil-X cement grout and embedded five and six inches into a reinforced concrete slab.



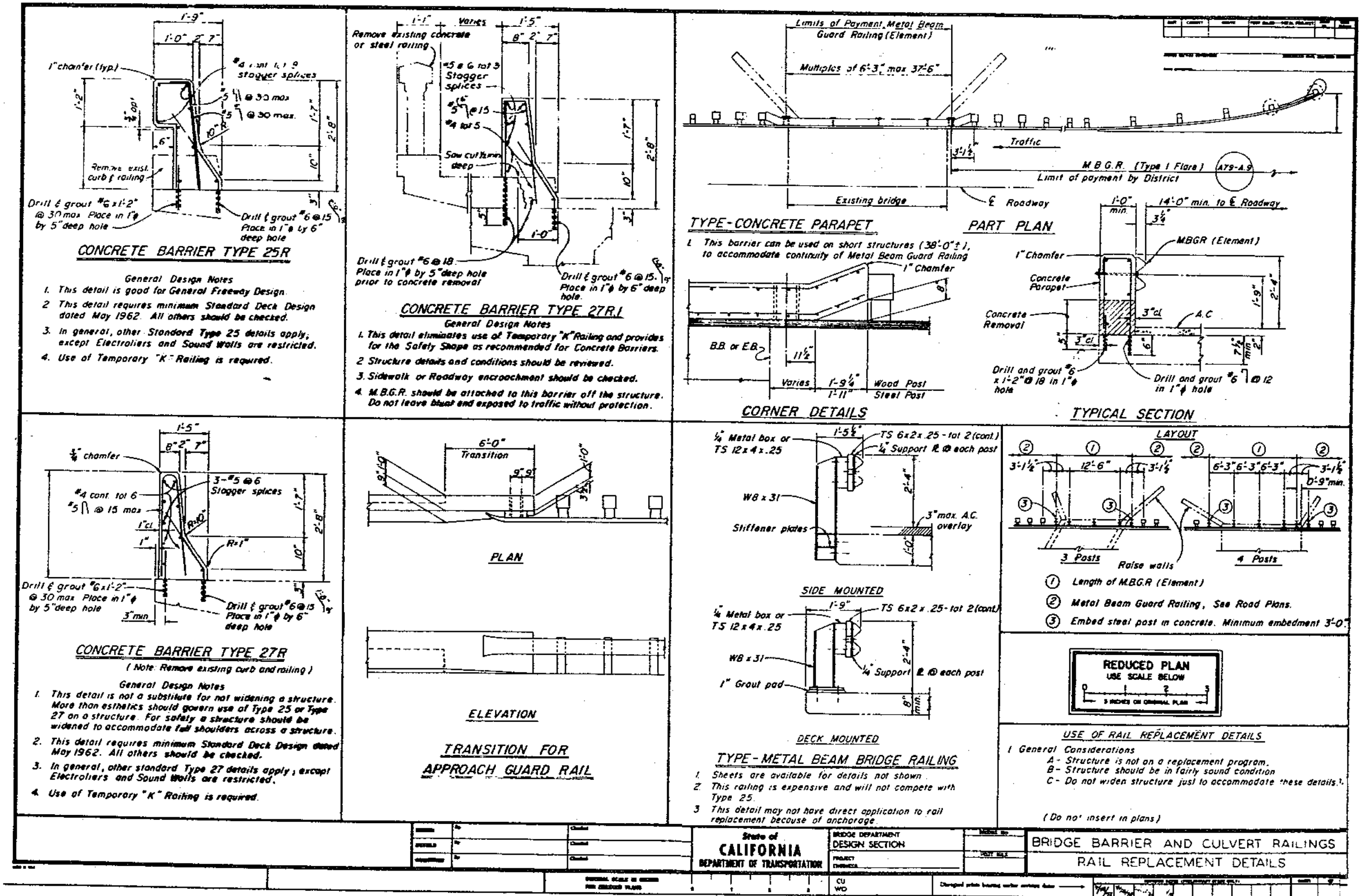
Appendix B-4. Graphs of load versus deflection from individual pullout tests on #6 rebar dowels bonded with Bostik-275 cement grout and embedded six inches into a reinforced concrete slab.



Appendix B-5. Graphs of load versus deflection from individual pullout tests on rebar dowels bonded with Type II Modified portland cement grout and embedded six inches into a reinforced concrete slab.



Appendix B-6. Graphs of load versus deflection from individual pullout tests on rebar dowels bonded with epoxy mortar and embedded six inches into a reinforced concrete slab.



Appendix C. Proposed Detail Sheet for the bridge rail replacement barrier designated as "CONCRETE BARRIER TYPE 25R".

CONCRETE MIX DESIGN DESIGNATION - No. A-1082-A

• Maximum Aggregate Size	1 inch
• Minimum 28 Day Compressive Strength Required	4000 psi
• Maximum Slump (ASTM Slump Cone)	4 inches
• Water/Cement Ratio, by weight	0.50
• Cement Content	564 lb/yd^3
• Fine Aggregate (No. 4 x No. 200)	1280 lb/yd^3
• Coarse Aggregate (1" x No. 4)	1990 lb/yd^3
• Admixtures	None Added

Appendix D - Mix design information for concrete used in bridge barrier test sections.

GENERAL INFORMATION AND TEST RESULTS

SPECIMEN I.D. NUMBER	DRILLING METHOD	HOLE CLEANING METHOD	TYPE OF BONDING MATERIAL	PULLOUT STRENGTH AT 1ST PEAK, KIPS	LOADING TIME, SECONDS/ REBAR DEFLECTION AT 1ST PEAK LOAD, INCHES	ULTIMATE PULLOUT STRENGTH, KIPS	LOADING TIME, SECONDS/ REBAR DEFLECTION AT MAXIMUM LOAD, INCHES	AVERAGE OF ULTIMATE PULLOUT STRENGTHS, KIPS	AVERAGE BOND STRESS AT MAXIMUM PULLOUT STRENGTHS, PSI	AGE OF BONDING MATERIAL AT TEST, DAYS	HOLE DIAMETER, INCHES	REBAR EMBEDMENT DEPTH, INCHES	REBAR SIZE AND GRADE
1	DIAMOND IMPREGNATED CORE BIT - WATER COOLED	Blown clean with air only	Type II modified portland cement grout	26.6	2.1/0.019	26.6	2.1/0.019	30.6	2160	33	1 →	6 →	#6, Grade 60 →
2				29.4	2.4/0.020	29.4	2.4/0.020			33			
3				30.8	2.6/0.028	35.8	4.5/0.131			34			
4		Brushed and washed using water		32.5	2.3/0.022	33.8	2.9/0.050	34.4	2430	34			
5				31.3	2.3/0.027	33.8	3.6/0.112			34			
6				30.7	3.1/0.020	35.9	5.5/0.112			35			
7			Epoxy mortar	20.2	2.2/0.027	32.2	3.8/0.143	35.0	2480	35			
8				31.7	2.4/0.035	40.0	5.1/0.202			35			
9				31.0	2.2/0.025	32.9	3.1/0.080			35			
10	IMPACT ROTARY HAMMER WITH CARBIDE TIPPED BIT	Blown clean with air only	Type II modified portland cement grout	19.8	1.5/0.015	28.5	3.9/0.198	29.2 (29.8)*	2070	34			
11				31.4	2.4/0.030	35.5	4.0/0.132			34			
12				17.7	1.1/0.012	23.5	2.7/0.135			33			
13		Brushed and washed using water		33.3	2.6/0.037	42.5	5.6/0.180	41.0	2900	34			
14				32.6	2.3/0.028	40.3	4.9/0.170			34			
15				31.7	2.3/0.026	40.2	5.3/0.180			35			
16			Epoxy mortar	28.0	2.3/0.025	30.8	3.3/0.105	33.3 (30.0)*	2360	35			
17				30.5	2.3/0.029	30.5	2.3/0.029			35			
18				31.2	2.3/0.018	38.5	5.8/0.220			34			
19		Blown clean with air only	Type II modified portland cement grout	19.5	1.7/0.071	19.5	1.7/0.071	20.7	1460	34	1 1/4	4.5	#8, Grade 60
20				22.7	2.2/0.090	22.7	2.2/0.090			34			
21				19.8	1.5/0.053	19.8	1.5/0.053			34			

Appendix E. Summary of results of dynamic pullout tests of rebar dowels conducted in a previous research project, PWO 19601-762504-646930

Material	Mix Proportions	Price/Ft^3 of Mixed Material
Epoxy Mortar (Epoxy - State Specification 8040-61J-03)	Equal volumes of epoxy and 16 x 30 mesh sand	$118.10
Type II Modified Portland Cement Grout	4 gallons water/ 94 pound sack cement	$ 5.08
Wil-X Shrinkage Compensating Cement Grout	4.5 gallons water/ 94 pound sack Wil-X cement	$ 11.79
Bostik-275 Quick Set Mortar	1 gallon Liquid Activator/ 45 pound sack dry aggregate	$ 38.50

Appendix F. Cost comparison of typical mix proportions of bonding materials tested.