Guide for Widening Highway Bridges

Reported by ACI Committee 345

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Many highway bridges become functionally obsolete due to inadequate width before they become structurally deficient. Because widening is almost always more economical than complete replacement, there is a need to make available the results of research and field experience pertaining to the widening of bridges. This guide discusses many problems unique to the widening of concrete bridges and bridges with concrete decks. The primary focus of this document is on bridge decks. Substructure issues, however, also are raised and discussed. The effects of differential movements between the existing and new portions, including movements due to traffic on the existing structure during construction, are discussed. General recommendations are made pertaining to the choice of structure type, design details, and construction methods and materials.

Keywords: bridge decks; bridge widening; bridges (structures); concrete construction; deflection; formwork (construction); reinforced concrete; reinforcing steels; substructures; superstructures; traffic vibrations.

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CHAPTER 1—INTRODUCTION

1.1—Purpose

The widening of highway bridges has become common. Several factors contribute to this demand for wider bridges:

a. Increased traffic volumes requiring additional lanes;

b. Safety hazards of narrow bridges requiring wider shoulders; and

c. Provision for bikeways and pedestrian ways.

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Fig. 1.1—Shoring to protect roadway during abutment widening.

The availability of funds under special programs, such as the Intermodal Surface Transportation Efficiency Act (ISTEA), is enabling public agencies to widen many functionally obsolete bridges as needed to eliminate safety problems. If a bridge was designed for current live loads and has not deteriorated appreciably, widening is likely more cost-effective than complete replacement.

Many problems unique to bridge widening are not encountered in work on new bridges. Failures or serious maintenance problems can be created by misunderstanding these problems. Each bridge widening is unique. This report provides the designer and constructor with general guidelines for bridge widening.

Emphasis is placed on construction practices, but because construction sequence, structure type, framing details, and other decisions critical to the success of the work are determined during the design phase, some discussion of design concepts must be included. Structural analysis and design for bridge widenings is not addressed. Much of the discussion that follows also applies to new bridges constructed in stages, part width at a time.

1.2—Common widening considerations

When a bridge is to be widened, several potential problems should be considered by design and construction engineers. These include retention of bridge elements, traffic control, structural constraints, and construction limitations. Moreover, certain elementary procedures should be followed for all structures:

- Review the record drawings and specifications of the original structure.
- Review any change orders that might have been approved during the original construction.
- Thoroughly inspect the structure and note changes in site conditions, such as bank scour.
- Obtain additional subsurface information, including borings, when footings are to be widened.

The first consideration for bridge widening is whether to retain structurally sound parts of the deck. Entire deck replacement should be considered if the remaining old deck will become less than half of the new deck width, or the deck is severely deteriorated, or both (Operation, 1992; Seible, 1991).

If the deck is to be retained, the design should provide for moment and shear transfer through the longitudinal joint between the new and old portions of the deck.

1.2.1 *Maintenance of traffic*—Prime concerns are the safety and convenience of the traveling public, the safety of construction personnel, and potential damage to the work. Another consideration is the effect of the widening on the safety of the public using the roadway or railway beneath the bridge and any traffic-related impact that the widening can have on that roadway.

Ideally, a convenient alternate route should be used as a detour during bridge widening operations, so that all traffic can be kept off the bridge. However, this is seldom the case. Due to the high cost of a temporary detour bridge, economy usually dictates that traffic be carried on the bridge during widening. This creates congestion at the work site, and resulting vibrations and deflections from live loads on the bridge can affect concrete in the new work (Transportation Research Board, 1981; Furr, 1981; Deaver, 1982; Arnold, 1980; Whiffen, 1971; Harsh, 1983; Silfwerbrand, 1992). Vibrations can cause settlement and other movement of fresh concrete and fractures in hardened concrete although examples of the latter are rare.

1.2.2 *Prevention of damage to existing structure*—Bridge widenings generally involve shored excavation immediately adjacent to the existing bridge and removal of portions of the existing bridge (Fig. 1.1).

Shoring of excavations is usually the responsibility of the contractor. Construction engineers should monitor this phase of the work carefully because public safety and safety of the existing bridge or adjacent highway facilities can be jeopardized by failure of shoring. Specifications should require that shoring be designed and monitored by licensed engineers. Designers should minimize lengths and widths of excavations.

1.2.3 *Differential foundation settlement*—The amount of tolerable differential foundation settlement between old and new construction depends on the configuration of the widening. If the joint between the existing structure and the new structure is outside of the traveled way (that is, in the median) or if rigid attachment of the widening to the existing structure is not required for overall stability, the existing and new structures can be left unconnected and differential settlements tolerated. It is usually necessary, however, for the new foundation to be compatible with the existing one. This means that the new foundation must be designed to settle very little, dictating piles or drilled shafts, unless rock is present near the surface.

1.2.4 *Differential superstructure deflections*—Differential deflections between new and existing superstructures are not a problem if the joint between the two occurs in a median or untraveled area. Generally in such cases, the superstructures are not connected. Joints should be located out of the traveled lanes whenever possible, but most frequently the joint between new and existing decks does occur within the traveled way. If decks are not connected, differential deflections will create offsets in the riding surface that could result in potentially

Fig. 1.2—Transverse view showing vertical lip.

Fig. 1.3—Longitudinal view showing proximity of wheel path.

hazardous vehicle control problems. Fig. 1.2 and 1.3 show two different views of a joint with differential deflection. Fig. 1.4 and 1.5 show attempts to minimize such differences; however, such situations should be avoided. Maintenance of joint seals in such working joints can be difficult, hazardous to workers, and expensive.

A new deck should be connected structurally to the existing deck, if deicing salts are to be used, because leakage through the joint allows corrosion-inducing materials to reach the girders and substructure (Fig. 1.6).

Whenever the new deck joins the existing deck within the roadway, the two should be structurally connected (Transportation Research Board, 1981; Furr, 1981; Deaver, 1982; Arnold, 1980; Whiffen, 1971; Harsh, 1983; Concrete Repair Digest, 1997; McMahon, 1965; Shaw, 1974). If proper attention is not given to construction sequence and details (for example, use of closure placements between the new deck and the existing deck), large differential deflections

Fig. 1.4—One view of an unsatisfactory attempt to minimize differential deflections by means of a continuous bituminous wedge.

Fig. 1.5—Another view of an unsatisfactory attempt to minimize differential deflections by means of a continuous bituminous wedge.

can cause overloading of the existing structure or distress in the new work along the joint line (Fig. 1.7). The deflections can be elastic deflections resulting from the release of the falsework, or time-dependent deflections due to creep.

1.2.5 *Differential longitudinal shortening*—For cast-in-place, post-tensioned concrete widenings, it is essential that the new work be allowed to shorten longitudinally without restraint from the existing bridge. Restraints will cause some of the stressing force to be transferred into the existing bridge, creating undesirable stresses in it, and possibly reducing the prestressing force in the new work. When the two are to be rigidly connected in their completed state, a specific con-

Fig. 1.6—Chloride damage under leaking longitudinal deck joint.

struction sequence and the use of delayed closure placements are mandatory.

1.2.6 *Vibrations from traffic*—Traffic-induced vibration has been blamed for distress occasionally observed in new construction that connects to structures carrying live loads. Research (Effects, 1981; Furr, 1981; Deaver, 1982; Arnold, 1980; Whiffen, 1971; Harsh, 1983) indicates that such damage is relatively rare and can be eliminated by the use of a proper construction sequence and correct design details. See Section 3.4 for an extended discussion.

1.2.7 *Removal of deck surfaces*—Generally, bridge widenings involve removal of curbs, sidewalks, or railings. This often exposes a rough surface not suitable for traffic. The deck in these areas may have been intentionally left rough or may have been damaged during removal work, and should be restored to a smooth profile in conjunction with the widening work. This is best resolved by removing concrete to a minimum depth of $1^1/_2$ in. (38 mm) below grade and casting a new surface to match the adjacent grade. Saw cuts at least 1 in. (25 mm) below final grade should be used to provide any necessary hardened concrete vertical faces to cast the new concrete against.

Fig. 1.8, 1.9, and 1.10 show unsatisfactory patches adjacent to a newly widened deck. In such cases, it would have

Fig. 1.7—Deck soffit spalls under reinforcing steel dowels.

been more desirable to have scarified the old deck surface and repaired it as part of a combined bridge-widening and rehabilitation plan.

CHAPTER 2—GENERAL DESIGN CONSIDERATIONS

2.1—General

Certain aspects of structural type selection, framing considerations, and design details are unique to bridge widenings. For specific design guidance, refer to the American Association of State Highway and Transportation Officials (AASHTO) Load Resistance Factor Design (LRFD) Bridge Design Specifications and other standards and guides (Silano, 1992) as noted in the references. Among the questions that a designer should investigate prior to commencing design are:

a. Can the widening be accomplished solely on the superstructure, or does the substructure also require widening?

b. If widening the substructure is necessary, was this foreseen in the original design?

c. Should one or both sides be widened?

d. Is a parallel structure justified as an alternative to widening?

e. Does widening the structure provide adequate vertical clearance?

In general, current design codes and loadings applicable to the route on which the structure is located should be used for bridge widenings. If the original bridge was designed using outdated codes or smaller than current live loadings, designing the widening to the old codes and loadings perpetuates a deficiency. Constructing widenings to current standards creates the opportunity of later replacing or strengthening all or portions of the original bridge so that the entire structure can be upgraded. Bridges on private lands or outside the limits of the United States can require designing for higher loadings

Fig. 1.8—Excessive spalled area degrades the benefits of a widened span.

than AASHTO standards due to industrial loads, a lack of load limits, or a lack of enforcement of load limits.

2.2—Selection of structure type

Many factors influence the designer's choice of type of structure for a widening. The natural choice is to use the same type as the original, but this is not mandatory. Some of the factors that influence the choice of structure type for a widening are: aesthetic and historical considerations; roadway geometrics; maintenance of traffic; deflection characteristics; and differential expansion characteristics.

2.2.1 *Aesthetic and historic considerations*—Aesthetic and historic factors can favor maintaining the original appearance of a classical design or landmark structure. For example, open-spandrel concrete arches have been widened successfully with thin prestressed members matching the depth of the original superstructure (Fig. 2.1).

This does not necessarily mean that the same structure type should be employed. For example, the arch-shaped steel truss bridge over Auckland Harbor in New Zealand was widened with steel box girders outside of the truss on both sides, the soffits of which matched the curve of the original lower chords (Fig. 2.2). To all but the very astute viewer, the architectural integrity of the original design was not altered.

In most cases, however, matching the original architectural style requires the use of the same structure type. The widening should be accomplished in a manner such that the existing structure does not look "added on to." When widening a historic closed spandrel masonry arch constructed in England in 1755 (Reay, 1976), the original rock facing was removed, the bridge widened with a modern concrete arch, and the original facing reinstalled.

2.2.2 *Roadway geometrics*—If the widening consists of doubling the bridge width (for example, two lanes to four lanes divided), the work is generally much less complicated and costly if the widening is done entirely on one side. The widening can be built as an independent bridge without the problems of making closure placements or matching deflection characteristics. Traffic handling during construction is also simplified. When vertical clearances beneath separation structures are insufficient to allow for falsework during construction of a widening, the use of precast concrete or steel girders is generally required. The widened portion must provide adequate vertical clearance.

2.2.3 *Maintenance of traffic*—The problems associated with maintaining traffic include the safety of the public and

Fig. 1.9—Corner spall should have been repaired immediately after widening.

Fig. 1.10—Severe edge spall need immediate permanent repair.

Fig. 2.1—Concrete arch widening with prestressed sections.

Fig. 2.2—Bridge over Auckland Harbor in New Zealand.

the workers. When a detour is not feasible and traffic must be carried through the work area, proper sequencing of construction operations is essential to minimize these problems. It is normally preferable to do as much of the work as possible before the removal of the existing curb and railing. Sometimes it is possible to complete the entire widening, including making the connection between old and new decks, before removing the existing rails. Otherwise, temporary barriers or railings must be provided after the existing bridge railings have been removed.

Part VI of the Manual on Uniform Traffic Control Devices for Streets and Highways (U.S. Department of Transportation, 1988) details the minimum traffic control standards for construction and maintenance operations on streets and highways. This manual sets forth principles and standards that apply to both rural and urban areas and are intended to direct the safe and expeditious movement of traffic through construction and maintenance zones and provide for the safety of the work force. These are minimum standards for normal situations, but additional protection is always desirable, and should be employed when special complexities or hazards prevail.

The sequence of construction operations, permissible lane closure periods, minimum temporary roadway widths, temporary traffic striping and signing layouts, as well as locations and details for temporary barrier railings, should all be indicated in the design documents. Contractors should be encouraged to propose alternative schemes.

When high volumes of traffic need to be carried on a bridge in which both sides are to be widened, it can be necessary to complete one side before the other is started, to minimize disruption of traffic.

When heavy volumes of commuter traffic prevent closing the existing bridge lanes except during brief off-peak periods each day, special measures may be needed (Sprinkel, 1985; Precast/Prestressed Concrete Institute, 1980). In such cases, use has been made of precast deck slabs* and concrete-filled steel grating, placed during nighttime closures and either connected mechanically or with concrete placements between the girders in the existing and new superstructures.

2.2.4 *Deflection characteristics*—Deflection characteristics should be taken into account when the new deck is to be connected rigidly to the existing deck. In such cases, the designer should consider the relative deflection characteristics of the existing and the new portions of the bridge when selecting the type of structure to use in a widening.

Appreciable differences in stiffness between existing and new superstructures can cause the transfer of a larger portion of live load between the structures than would otherwise occur. This can result in a greater amount of live load being carried by the stiffer of the two. Transverse load distribution assumptions must be reviewed and modified as necessary for such changed conditions.

For spans where differential deflection from live load (LL) or dead load (DL) is expected to exceed 1/4 in. (6 mm), the designer should specify the sequence of attaching new work to existing. Generally, a delay in the attachment of diaphragms and the placement of deck closure is needed. This is discussed in more detail in Chapter 3.

2.2.5 *Differential expansion characteristics*—Whenever the widening is to be connected to the existing bridge, it is important that transverse deck joints be located in the superstructure of the widening in the same longitudinal locations where such joints occur in the existing bridge.

CHAPTER 3—DESIGN AND CONSTRUCTION DETAILS

3.1—General

Standards and guides normally used for new bridge construction also should be used for widenings. These include the AASHTO LRFD Standard Specifications for Highway Bridges, ACI 343R, and ACI 345R.

Some construction operations unique to widenings are discussed in this chapter. Because each widening represents a unique situation, however, all of these operations do not necessarily occur in every project.

3.2—Concrete removal

Most bridge widening projects require that a portion of the existing bridge be removed. This is usually the railing or sidewalk and sometimes portions of the deck, substructure, or wingwalls. Methods of removal that could damage the existing structure should not be permitted. Special care should be

*Warner, P. C. (1981). "Rehabilitation of the High Street Overhead," California Department of transportation. (Paper presented at ACI Annual Convention, Feb.)

Fig. 3.1—Area under old rail prepared for thin overlay.

Fig. 3.2—Deck refinishing complete with concrete overlay in place.

taken to avoid damaging any reinforcing steel that is to remain in place. The following are suggested specification provisions:

When portions of a bridge are to be removed, the removal operations should be performed without damage to any portion of the structure that is to remain in place.Existing reinforcement that is to be incorporated in the new work should be protected from damage and should be cleaned thoroughly of all adhering concrete material before being embedded in new concrete.

Before beginning the removal of a portion of a monolithic concrete element, a saw cut should be made, taking care to avoid the reinforcing steel, to a true line along the limits of removal on all faces of the element that will be visible in the completed work.

Removal can be done by waterjetting (hydrodemolition), which removes concrete efficiently without damaging the reinforcement or introducing microcracking or other damage into the remaining concrete (Weyers, 1993; American Concrete Institute, 1980).

Reinforcing dowels exposed during the rail, curb, or sidewalk removal should be cut off below the finished surface and the recess filled with a nonshrink grout (ASTM C1107-97). When dowels are in a patch or overlay area, they should be cut off at the bottom of the overlay or patch.

3.3—Refinishing exposed areas of the deck

Concrete exposed by rail, curb, or sidewalk removal can be too rough to serve as a riding surface (Fig. 3.1). Unless a concrete or bituminous overlay is to be placed, the area must be refinished. The degree of refinishing, which can vary from minor patching to a complete leveling course (Fig. 3.2), should be specified in the contract documents.

Refinishing can consist of simply grinding off a few high spots or filling in local depressed areas with concrete repair patches. If the surface is too rough and requires extensive grinding or patching, it is generally better and more economical to mill off the entire surface to a depth of at least $^3/_4$ in. (19 mm) below the adjacent deck and place a concrete overlay (Loveall, 1992; Flynn, 1992). In either case, the recommendations in ACI 546.1R should be followed in patching or overlaying the deck surface.

3.4—Traffic-induced vibrations and deflections

There has been a widely held view that once concrete is placed, consolidated, and finished, it should not be disturbed until it has gained sufficient initial strength. This view has led to concerns about permitting traffic on bridge decks during concrete-placing operations. Traffic-induced vibrations are quite noticeable to human senses, and therefore understandably raise concerns among those involved in repair or widening of concrete structures. However, several reports (Transportation Research Board, 1981; Furr, 1981; Deaver, 1982; Arnold, 1980; Whiffen, 1971; Harsh, 1983; Silfwerbrand, 1992; Concrete Repair Digest, 1997) found that vibration in bridges due to highway traffic is not as harmful as theorized. In fact, it can actually be beneficial. In situations where the forms and reinforcing steel are supported by the same structural members, experience and research have shown that damage due to traffic-induced vibrations is very rare. In these cases, fresh concrete reinforcement and forms are in synchronous movement. None of these reports was able to identify any occurrences of damage for these conditions. Therefore, special precautions, such as closing the bridge to traffic in such situations, are generally not necessary.

The most effective way to reduce the amplitude of traffic-induced vibrations is to maintain a smooth structure approach and deck riding surface. Vehicle speed and weight restrictions have only a secondary effect on the magnitude of traffic-induced vibrations.

Traffic-induced vibrations can make the slipform method of constructing concrete barriers or curbs very difficult, if not impossible. Therefore, this method should be avoided.

In situations where the vibrations are carried into freshly placed concrete through reinforcing steel extending from the existing bridge, damage to new concrete can occur (Silfwerbrand, 1992; Concrete Repair Digest, 1997). Such damage is avoidable through use of proper construction techniques, such as attaching the forms to the existing bridge, and traffic control.

When a reinforcing bar moves relative to the concrete, the displaced concrete will flow readily back and forth with the bar, as it is still plastic. As initial set begins, only weak, water-diluted grout flows back to surround the bar. Also, cracks can develop in the plastic concrete and fill with weak material, along a horizontal plane with adjacent bars or along sloping planes running from the bar to the surface of the deck. This condition can result in a severe reduction in bond to reinforcement and premature deck spalling. Similar damage can occur in new bridge decks, if live loads from workers or equipment are allowed directly on poorly blocked-up reinforcing steel on the outside of a construction joint bulkhead. For this reason, during placing and finishing operations, workers and equipment near the perimeter of a reinforced concrete deck should be restricted to planks or runways blocked-up from the forms, rather than bearing directly on any reinforcing steel that extends through bulkheads and into the concrete being placed.

Although it would seem that any movement of reinforcing steel extending from a structure carrying traffic into freshly placed concrete on a widening would result in the defects described, certain practices will generally eliminate such damage. These practices should be employed on all deck closure placements or in other situations where concrete is placed against an existing structural element carrying traffic, and include the following:

a. Use of moderate (2 to 3 in.) (50 to 75 mm) slump concrete—Surveys (Transportation Research Board, 1981) found frequent delamination in bridge decks built or widened in the 1950s and 1960s. This damage was noted in decks connecting to existing structures carrying traffic. Such damage has now been found to be related to the use of high-slump (more than 4 in. (100 mm)) concrete that probably contained excess water. Similar damage was not noted in subsequent work when the slump was reduced. Although no research has been done to examine the effects of using high range water reducing admixtures in concrete used to widen bridges, use of such concrete should reduce the chance for delaminations because the water to cement ratio is typically lower than that of concrete without the admixture.

Limited laboratory research at the University of Michigan (Arnold, 1980) also showed that high-slump concrete mixtures are especially sensitive to segregation in the plane of the reinforcing steel. In limited testing, the hydraulic pressure applied through voids cast in the plane of the top mat of reinforcement were measured. The hydraulic pressure needed to rupture concrete that had been subjected to continuous vibration during its early life, was reduced from 1600 to 800 psi (11 to 5.5 MPa) when the slump of the concrete was raised from 3 to 4 in. (75 to 100 mm).

b. Reinforcing details—The Texas Transportation Institute (Furr, 1981) found that reinforcing dowels extending straight from old concrete and lapping with the new deck reinforcing created in fresh concrete created no defects in the fresh concrete. However, they did find that when the dowels were bent at a right angle in a horizontal plane, voids developed between the dowels and fresh concrete, although these voids were not found to cause problems in the performance of the deck. (Fig. 3.3).

Good practice also requires that when deck closure placements are to be employed, the reinforcing bars or dowels extending from the existing concrete to the new should not be connected to the reinforcing bars in the widening during concrete placement of the widening, but should be attached securely to reinforcing bars in the new deck just before the closure placement is made (Fig. 3.4).

Some damage was observed in California (Shaw, 1974) when a single row of dowels was drilled and grouted into the face of the existing deck midway between the steel mats used in the widening. This problem was solved when two rows of dowels were used, one secured to each plane of steel in the new deck (see the left-side elevation in Fig. 3.4).

c. Forming details—When deck closure placements are employed, the forms for the widening should not be connected to the existing bridge during placement of concrete for widening. When the closure is placed, however, its supporting form should be secured to both the old and the new structure.

Differential live load deflections or relative movements between the first girder of a widening and the adjacent girder of the existing bridge cause racking (shear stresses) in the new deck concrete and closure placement between the two. At first consideration, it would seem that this action would also preclude the practice of connecting decks of widenings rigidly to existing bridges carrying traffic. Research done at Texas A & M University (Furr, 1981), however, determined the magnitude of the change in differential deflection due to dynamic loading that would cause cracking in a $7^3/_4$ in. (200

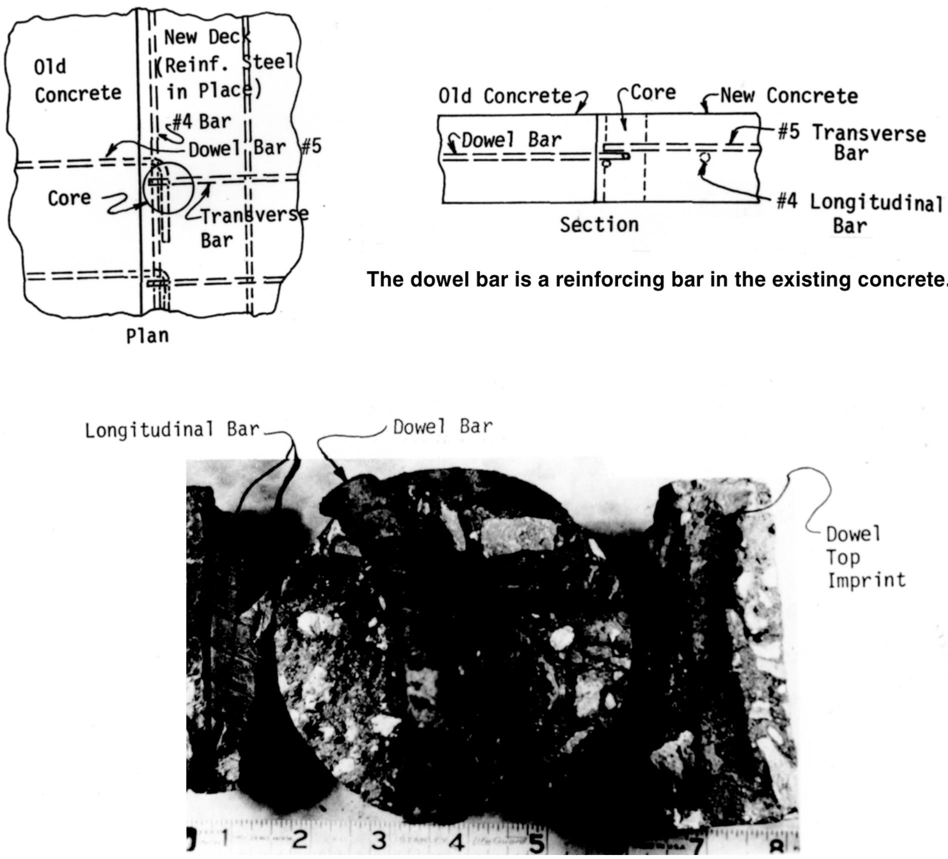

Fig. 3.3—Voids created by right-angle dowel bars.

mm) concrete slab. Field measurements of typical bridges in Georgia (Deaver, 1982) and Texas (Furr, 1981) showed that deflections actually produced in deck slabs by traffic immediately adjacent to the widening during concrete placement and thereafter were only about one-fourth of this magnitude. These results indicate that cracking is unlikely under normal conditions.

Surveys of rigidly connected deck widenings (Transportation Research Board, 1981; Furr, 1981; Deaver, 1982; Shaw, 1974) showed little evidence of distress due to differential deflection caused by traffic. This is probably due to the fact that, in addition to practices recommended previously, one or more of the following measures were taken:

a. Diaphragms between adjacent girders or a rigid temporary blocking system were used to equalize girder deflection until the deck slab gained sufficient strength. Sometimes the forming system itself offers sufficient rigidity.

b. A smooth riding surface was maintained on the deck and the approach roadway, and a good grade match was obtained where they join.

c. Traffic speed, allowable loads, or both were reduced on the existing bridge during and immediately after placing new deck concrete.

d. The traffic lane adjacent to the connecting joint was closed for a few days after placing new deck concrete.

e. Temporary shoring was installed under the existing bridge during this period.

Although all of these measures have been used, items c and d are most economical. They require only a short-term restriction of traffic. These measures need be employed only when very flexible structures are being widened.

3.5—Avoidance of damage due to dead load deflections

Two important facts should be recognized when considering dead load deflection: (1) portions of the superstructure widening should initially be built above the grade of the existing structure to allow for dead load deflection; and (2) the deflected superstructure widening should meet the grade of the existing structure when the final connection is made between decks. If dead load deflection is not properly accommodated, construction, maintenance, and traffic-safety problems can occur.

When discussing dead-load deflections, it is necessary to divide superstructures into two groups: 1) unshored construction, such as precast prestressed concrete girders or steel girders, where the largest percentage of girder deflection occurs when the deck is placed, and 2) cast-in-place concrete superstructure construction where the deflection occurs when the falsework is released.

3.5.1 *Unshored construction*—Sketches in Fig. 3.5 show the different stages of simple-span precast or steel-girder deflection as the deck concrete is placed from one end of the girder to the other. The concept is the same for continuous spans, but the design will change. Analysis of these sketches

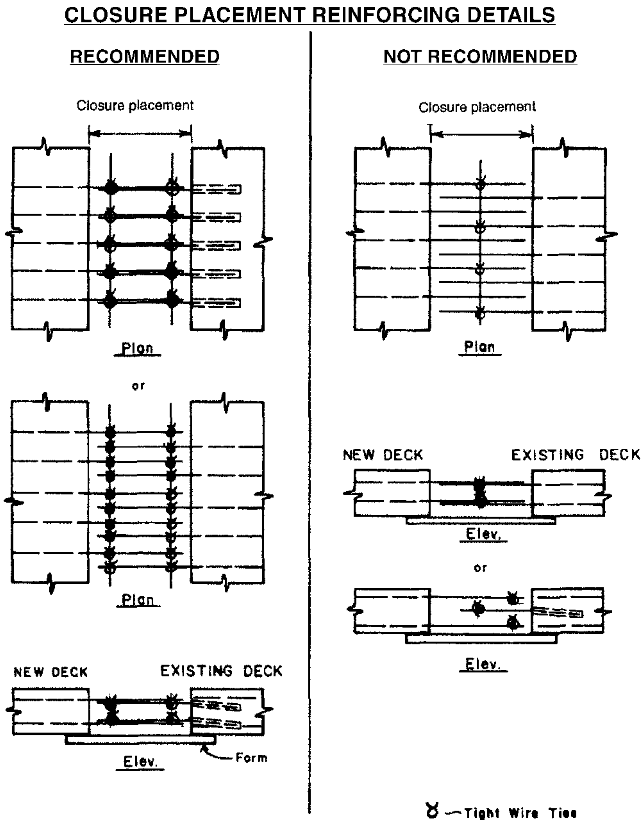

Fig. 3.4—Closure placement reinforcing details.

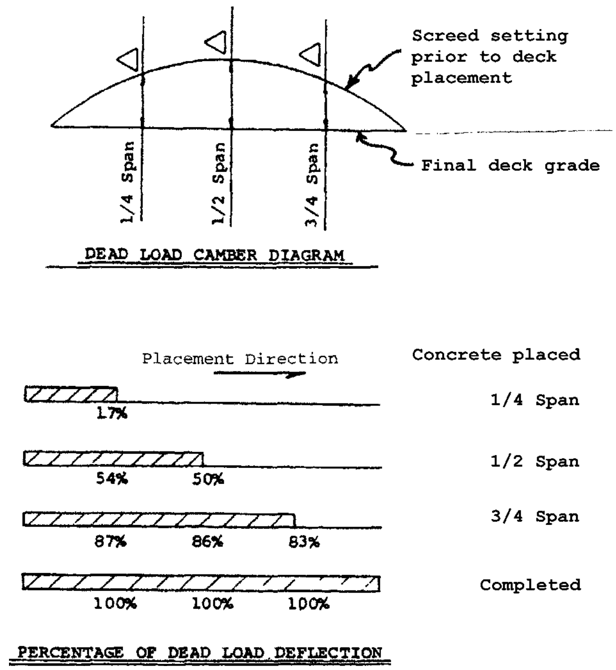

Fig. 3.5—Dead load deflection and camber.

illustrates the importance of using a closure placement between the new deck and the existing deck so that the grade of the widening will match that of the existing bridge. For example, if the calculated deflection due to deck placement is 2 in. (50 mm) at midspan and $1^1/_2$ in. (38 mm) at one-fourth span, and the deck is placed for one-fourth of the span, then the actual quarter point deflection will be only $^1/_4$ in. (6 mm) of the $1^1/_2$ in. (38 mm) calculated deflection. The remaining $1^1/_4$ in. (32 mm) of deflection will occur when the girder has been completely loaded,

A closure placement serves three useful purposes: 1) it accommodates differential deflection along the joint (which is difficult to forecast accurately); 2) it provides width to make a smooth transition between the final grades; and 3) it eliminates differential deflections between the existing bridge and the widening after completion. Section 3.6 discusses closure placement details.

In precast concrete girders, the effect of creep deflection should be considered. Deflection due to creep is the result of many variables, such as the dimensions of the girder, the quality of the concrete, the concrete age, and the rate of loading; no single formula will suffice. ACI 435.1R provides a more complete discussion of this topic.

3.5.2 *Cast-in-place concrete construction*—The elastic deflection of cast-in-place concrete structures, which is only about one-fourth to one-third of the total deflection, occurs immediately after the falsework is released. The remaining deflection (creep) continues at a diminishing rate, which becomes negligible after about 4 years. A theoretical analysis of stresses caused by differential deflection that occurs between the new and existing structures, when connected rigidly and even when a delayed closure placement is used, will usually predict that distress will occur. Observed performance, however, indicates that no distress occurs if the procedures in this guide are followed. It is probable that relaxation in the concrete allows these theoretical overstresses to dissipate before damage is caused to the structures.

When the total dead load deflection of the new cast-in-place structure is expected to exceed $^3/_8$ in. (10 mm), it is common practice to use a closure placement after the falsework is released. This is to minimize the stresses caused by differential deflections and the transfer of dead load from new to old structure. Good engineering practice suggests that the closure width and the length of the delay period "after falsework release and before placing the closure placement" should relate to the amount of dead load deflection that can occur after the closure is placed. This is discussed in more detail in Section 3.6.5. ACI 435.2R provides further information on this topic.

3.5.3 *Prestressed concrete construction*—For the same span lengths, prestressed structures generally deflect less than reinforced concrete structures; therefore, their use decreases the difficulty of getting a good grade match between new and existing decks. However, the use of prestressed concrete design does not eliminate the need for a closure placement. Differential longitudinal elastic shortening during stressing requires that superstructures remain unconnected until all post-tensioning is complete. This longitudinal shortening continues as a result of creep. For some structures, creep can be of sufficient magnitude to warrant a greater delay in placing the closure. Accurate prediction of dead load deflection is more important for widenings than for new bridges, as it is essential that the deck grades match. The total dead load deflection varies with the strength and maturity of the concrete at the time the falsework is released (Scordelis, 1983; Roberts, 1972). Therefore, when determining the camber to be cast into widenings for long spans, it is necessary to consider the length of time the falsework will support the widening. This time period should be included in the contract documents. ACI 435.1R provides further information on the topic.

When the design calls for connecting new and existing substructures on continuous, multiple-span, post-tensioned rigid-frame structures, the piers, caps, and superstructure of the existing bridge must remain unconnected to the new structure until after the new structure is stressed. The only exceptions are piers or caps at the point of zero movement during stressing (for example, the center pier of a symmetrical three-pier frame).

3.6—Closure placement details

The previously discussed problems created by traffic vibrations, deflections after release of falsework, and longitudinal shortening due to post-tensioning can be mitigated by the use of longitudinal expansion joints. When the junction of the widening to the existing deck falls within the traveled way, however, longitudinal expansion joints are generally avoided because such joints create maintenance problems (Fig. 3.6).

Closure placements may not be needed on short spans or on very narrow widenings if deck concrete is placed fast enough to permit dead load deflection and the concrete placement is completed before final strikeoff and initial set of the concrete. Retarding admixtures can be used to ensure that initial elastic deflections have completely taken place before the concrete begins to set.

When closure placements between the new deck and the existing deck are used, the construction sequence and details employed are critical to the successful performance of the structure. Their degree of importance varies from bridge to bridge due to the many variables involved. The recommended width of closure placements is approximately 18 in. (460 mm).

A closure placement accomplishes two purposes: 1) it permits the widening to remain isolated from live load deflections and vibrations from traffic on the existing bridge and 2) it allows dead load deflection and prestressing shortening of the widening to reach a stage where the portion of the new deck that connects to the old will not be overstressed due to differential movements between old and new structures. When deck closure placements are employed, diaphragms connecting new to old girders are left disconnected until all other work is completed, except for the placement of the closure. The diaphragms are then connected just before placement of the closure.

3.6.1 *Attachment to existing bridge*—Structures with large deck overhangs should have a sufficient width of concrete removed from the overhang to permit lap-splicing the original transverse deck reinforcing with that of the widening.

Structures with small or no overhangs should either be connected to the widening with dowels (Fig. 3.7), or have sufficient transverse reinforcement exposed to permit splicing by welding or mechanical connections. A typical weld detail is shown in Fig. 3.8. All existing reinforcement may not be weldable and preheating may be required.

Fig. 3.6—Spalls in bituminous concrete surfacing over longitudinal expansion joint.

Cutting a seat into the existing exterior girder as a means of support has proven to be unsatisfactory because of difficulty in reinforcing the area around the seat.

Double rows of dowels, as shown in Fig. 3.7, perform better than a single row. Dowels can be smooth or deformed and can be anchored into the existing concrete with grout or adhesive. Although presized encapsulated resin cartridges have proven to be a fast, reliable, and economical method to anchor dowels, the preferred method is grouting, with a neat cement paste. This method requires a hole sloped one vertical to three horizontal or steeper so the fluid grout will not escape. Nonshrink grout (ASTM C1107-97) performs better than other portland cement grouts for this use (Dusel, 1979).

The maximum service design load for adhesive-bonded dowels is usually taken as 25 percent of the pullout force,

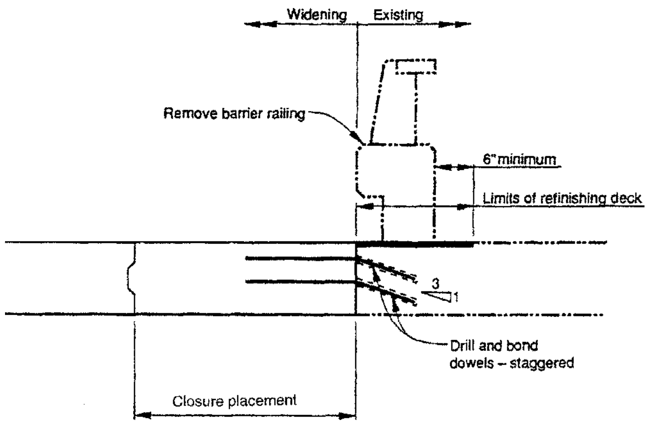

Fig. 3.7—Widening slab bridges.

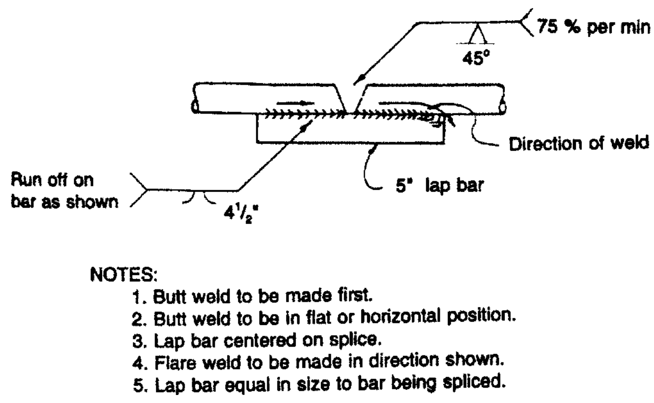

Fig. 3.8—Vee groove splice details—welded option.

determined in accordance with ASTM E 1512. If sustained loads are expected, the total displacement (initial plus creep) should not exceed 0.03 in. (0.8 mm) when tested at 40 percent of the ultimate load, in accordance with the creep testing procedure of ASTM E 1512.

The holes should be drilled by methods that do not shatter or damage the concrete adjacent to the holes. They should be located at least 3 in. (75 mm) from the edge of the concrete and be no more than $^1/_4$ in. (6 mm) larger than the diameter of the dowels or as recommended by the manufacturer. The holes must be free of dust and drilling slurry, and in a surface-dry condition before placing the grout or epoxy. The holes are then filled with grout or epoxy before the dowels are inserted.

As an alternative to inclined holes, horizontal holes about $^3/_4$ in. (20 mm) larger than the dowel can be drilled and the dowels bonded in place with nonshrink grout. The dowel is centered in the hole and the grout is then injected into the hole so that filling is accomplished outward from the base of the hole. A gasket is used around the dowel at the face of the hole to retain the grout while allowing the air to escape.

3.6.2 *Reinforcement*—During placement of deck concrete in the widening, reinforcing bars protruding from the new deck into the closure space should be kept completely free of contact with the existing reinforcing steel, concrete forms, or attachments.

During placement of deck closure concrete, the new and existing transverse reinforcing steel within the closure should be connected securely together or to common longitudinal reinforcement, as in Fig. 3.4.

Reinforcing bars extending from the existing deck should be straight rather than hooked, as in Fig. 3.3. Reinforcing bars extending from the existing deck that are too short to give sufficient development length can be extended by approved mechanical connections or full-strength welds. Welding can be used when the extension being welded is free from restraint during the welding process to permit shortening of the bar as the weld cools.

The American Welding Society's code (1992) contains recommended details for making welded splices in reinforcing steel and suggests making a chemical analysis of the steel to determine its weldability and gives procedures for welding splices if chemical composition is unknown.

In addition, AASHTO LRFD Article 5.11.5.2.2 permits splices made with full mechanical connectors. Several types of mechanical connectors are available that meet the ACI 318 criteria of development of at least 125 percent of the yield strength of the bar. AASHTO LRFD includes requirements for maximum slip not included in ACI 318.

Longitudinal reinforcing bars should be placed in the closure placement to distribute shrinkage cracks and minimize their crack width.

3.6.3 *Forms*—Forms for the deck closure placement should be supported from the superstructure on both sides of the closure. They then act as an articulated ramp to spread the effect of any differential vertical movements over the widths of the closure. These forms should not be placed between old and new structures until all other concrete in the widening has been placed and the shoring released.

3.6.4 *Concrete*—Specific requirements for concrete are necessary for encasing reinforcing steel that is subject to vibration from external forces during the first few days after placement (Furr, 1981; Arnold, 1980; Whiffen, 1971). This applies to concrete for closure placements, and deck widenings when closure placements are not used and traffic is allowed on the old bridge during construction. A minimum cement content of 564 lb/yd^3 (330 kg/m^3), a maximum of 0.45 water-cementitious (*w/c*) ratio, and a maximum slump range of 1 to 3 in. (25 to 75 mm) should be employed. High-early-strength cement (Type III), volume-adjusting types of cement (ASTM C1107-97), chloride-free proprietary high-early-strength cements, or Type I cements with nonchloride accelerators are sometimes used.

3.6.5 *Time of placement*—The timing of the placement of concrete for closure placements depends on the type of structure. For steel girders or precast concrete girder bridges, closure placements can be made as soon as the full dead load is on the widening. For widenings consisting of more than one girder, the exterior railing need not be placed before closure.

For cast-in-place concrete construction, a delay after removal of falsework should be provided to allow the relatively rapid early dead load deflection to occur before the decks are connected. The length of the delay period, along with the width of the closure placement, should be engineered to accommodate the dead load deflection that will occur in the

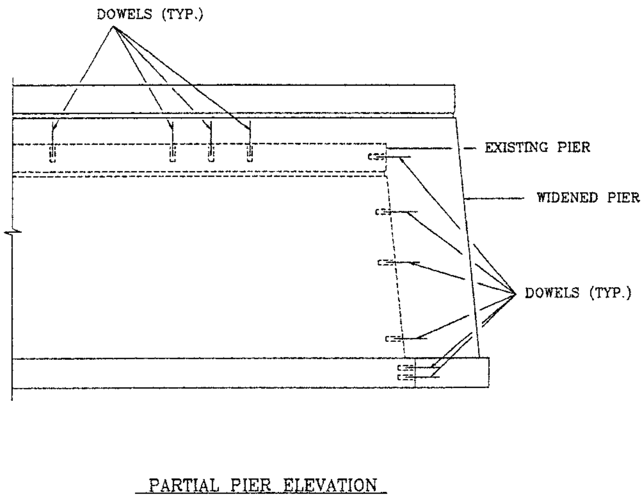

Fig. 3.9—Partial pier elevation.

widening after the closure is placed. This deflection is primarily the result of creep in the concrete superstructure.

In concrete, the amount of creep deflection is a direct function of the level of stress in the concrete. The rate of creep decreases with the age of the concrete and the length of time since the formwork was removed. Any creep deflection of the girders in the widening that occurs after the deck closure has been placed will produce stresses in the closure and adjacent deck. However, these stresses will, in turn, be reduced by creep in the closure concrete. Thus, the rate of deflection of the girders must be permitted to decrease to a level that can be tolerated by the closure concrete before closure concrete is placed.

These combined actions, with younger concrete in the closure than in the widening, make the required delay period very difficult to calculate. It is therefore normally based on experience.

The California Department of Transportation (CALTRANS) has required for several years that whenever the falsework is removed at the earliest permitted date, the closure concrete should not be placed until at least 60 days after the falsework is removed.* As an alternative, if the falsework is left in place for at least 28 days after casting, then the closure concrete should not be placed sooner than 14 days after falsework removal.

3.7—Substructure details

Typically, the new substructure is attached rigidly to the existing substructure as shown in Fig. 3.9. In cases where considerable settlement is anticipated, closure placements in footing and substructures have been used to prevent transfer of load from new to old structures (Interstate, 1991). For example, elastic shortening of the piles at the Hackensack Bridge (Soto, 1978) due to the dead load of the new pier was allowed to occur before the old and new substructures were connected by a closure placement (Fig. 3.10).

CHAPTER 4—SUMMARY OF RECOMMENDATIONS

Many problems are unique to the widening of bridges. Most of the major problems can be avoided by proper decisions regarding the choice of structure type, whether or not

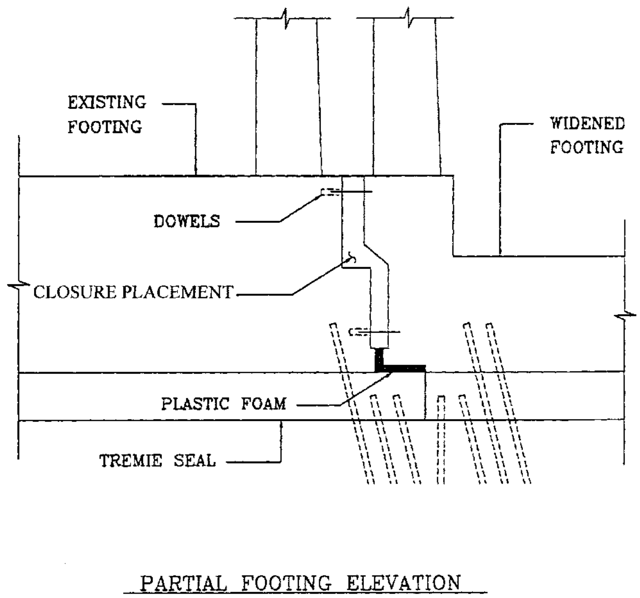

Fig. 3.10—Partial footing elevation.

to connect the deck of the widening to the deck of the existing bridge, and the method and sequence of making such connections.

The joint between the widening and the existing bridge generally occurs within the area of the deck that will be traversed by vehicles. It is recommended that the decks be structurally connected. The type of bridge used for the widening does not have to be the same as the existing. Economy, site geometrics (for example, roadway or waterway clearances), and aesthetics should determine the choice. If the two spans are to be connected structurally, however, the live load deflection characteristics of the type chosen for the widening should be similar to those of the existing bridge.

When the deck of a widening is to be connected structurally to the existing deck, it is generally recommended that the final connection be delayed until the widening is nearly complete. This will avoid the possibility of damage to the new work caused by 1) vibrations of traffic on the existing bridge; 2) dead load deflection of the widening that occurs as deck concrete is placed or as falsework is removed; or 3) shortening of the new work if it is longitudinally post-tensioned. For continuous post-tensioned spans of rigid-frame bridges, the new substructures should also not be connected to the existing bridge in any way that would prevent the longitudinal shortening of the new work. For cast-in-place spans, it may be advisable to delay making this final connection for several days after the falsework is released to allow for some of the more rapid early dead load deflection caused by creep in the concrete to occur (see Section 3.6.5 for suggested delay times).

The recommended method of making structural connections between widenings and existing decks is to leave an approximately 18 in. (460 mm) gap between the two, which is later filled with high-quality (0.45 maximum *w/c*),

*California Department of Transportation (Caltrans) Bridge Memo to Designers Manual, Section 9-3.

low-slump concrete. This closure placement should be reinforced with top and bottom mats of reinforcing bars that extend out of both new and existing deck slabs. Such reinforcement must all be tied together securely to minimize differential movements and the resulting damage to the fresh closure concrete caused by vibrations from traffic. Such reinforcing steel ties should not be made, however, until just before the closure concrete is placed. Likewise, the connection of diaphragms between the existing bridge and the widening, and the installation of the forms for the closure placement, should not be done until just before the closure is placed.

CHAPTER 5—REFERENCES

5.1—Recommended references

The documents of the various standards-producing organizations referred to in this document are listed with their serial designation.

American Association of State Highway and Transportation Officials

LRFD Bridge Design Specifications

American Concrete Institute

117	Standard Specifications for Tolerances for Concrete Construction and Materials
211.1	Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete
212.1R	Guide for Use of Admixtures for Concrete
221R	Guide for Use of Normal Weight Aggregates in Concrete
304R	Guide for Measuring, Mixing, Transporting and Placing Concrete
305R	Hot Weather Concreting
306R	Cold Weather Concreting
308	Standard Practice for Curing Concrete
318	Building Code Requirements for Reinforced Concrete
343R	Analysis and Design of Reinforced Concrete Bridge Structures
345R	Guide for Concrete Highway Bridge Deck Construction
435.1R	Deflections of Prestressed Concrete Members
435.2R	Deflections of Reinforced Concrete Flexural Members

5.2—Cited references

American Concrete Institute (1980). *Guide for Repair of Concrete Bridge Superstructures*, 546.1R, Farmington Hills, Mich.

American Society for Testing and Materials (1993) *Test Methods for Testing Bond Performance for Adhesive-Bonded Anchors*, E1512.

American Welding Society (1992). Structural Welding Code—Reinforcing Steel, D1.4-92.

Arnold, C. J. (1980). “Concrete Bridge Decks: Does Structural Vibration Plus Excess Water Form the Fracture Plane,” *Research Laboratory Section*, Michigan Department of Transportation.

Deaver, R. W. (1982). “March 1982 Bridge Widening Study,” *Final Report*, GDOT Research Project No. 7604, FHWA/GA-82/008, Georgia Department of Transportation.

Dusel, J. P.; Stoker, J. R.; and Nordlin, E. F. (1979). “Development of a Rebar Dowel Anchorage System for Attaching the California Type 25 Barrier to Existing Bridges,” *Report* No. FHWA-CA-TL-69-16, CALTRANS, June.

Flynn, L. (1992). “Contract Drives Raleigh ‘Beltline’ Rubblization,” *Roads and Bridges*, V. 30, No. 1, Jan.

Furr, Howard L., and Fouad, F. H. (1981). “Bridge Slab Concrete Placed Adjacent to Moving Loads,” *Research Report* No. 266-1F, Study 21-5-79-266, Texas Transportation Institute, State Department of Highways and Public Transportation, College Station.

Harsh, S., and Darwin, D. (1983). “Effects of Traffic-Induced Vibrations on Bridge Deck Repairs,” *Project* No. P-0255, Kansas Department of Transportation.

“Interstate Rehab Called Biggest Job in Illinois” (1991). V. 226, ENR.

Loveall, C. L. (1992). “Experience With a Thick Reinforced Overlay for Bridge Deck Rehabilitation,” *Proceedings*, Third International Workshop on Bridge Rehabilitation, Technical University Darmstadt and the University of Michigan.

McMahon, J. E., and Womack, J. C. (1965). “Bridge Widening Problems,” *Report* No. 951120, HPR-1(2), DO422, California Division of Highways.

“Operation Bridgeguard” (1992). *World Highways/Routes Du Monde*, V. 2, No. 1, Nov.-Dec.

Precast/Prestressed Concrete Institute (1980). “Precast Prestressed Concrete Short Span Bridges (Spans to 100 Feet),” Chicago, Ill.

Reay, G. C., (1976). “Widening of Hutton Rudby Bridge,” *Highway Engineer* (London), Mar., pp. 18-21.

Roberts, J. E. (1972). “Effects of Curing and Falsework Support Periods on Dead Load Deflections of Reinforced Concrete Slab Bridges,” California Division of Highways.

Scordelis, A. C., and Seible, F. (1983). “Time-Dependent Behavior of a Skew Reinforced Concrete Box Girder Bridge,” *Concrete International: Design & Construction*, V. 5, No. 1, Jan., pp. 84-92.

Seible, F.; Priestley, M. J. N.; and Krishnan, K. (1991). “Bridge Superstructure Rehabilitation and Strengthening,” *Transportation Research Record* No. 1290, Transportation Research Board.

Shaw, T. V., and Stewart, C. F. (1974). “Effectiveness of Attached Bridge Widenings,” *Report* No. CA-DOT-ST-4165-1-74-2, California Division of Highways.

Silano, L. G.; Swindlehurst, J.; and Parkinson, F. H. (1992). “Steel Structures,” *Bridge Inspection and Rehabilitation: A Practical Guide*, John Wiley and Sons, Inc.

Silfwerbrand, J. L. (1992). “Influence of Traffic Vibrations on Repaired Concrete Bridge Decks,” *Proceedings*, Third International Workshop on Bridge Rehabilitation, Darmstadt, Germany, pp. 416-474.

Soto, M. H., (1978). “Some Considerations in Widening and Rehabilitation of Bridges,” *Transportation Research Record 664*, *Bridge Engineering*, V. 1, Transportation Research Board, Washington, D. C.

Sprinkel, M. M. (1985). “Prefabricated Bridge Elements and Systems,” *NCHRP Synthesis* 119, Transportation Research Board, Washington, D. C.

Transportation Research Board (1981). “Effects of Traffic-Induced Vibrations on Bridge Deck Repairs,” *NCHRP Synthesis of Highway Practice* No. 86, Washington, D. C.

“Thirteen Tips for Better Bridge Widening” (1997). *Concrete Repair Digest*, Addison, Ill., Oct./Nov., pp. 248-251.

U.S. Department of Transportation (1988). *Manual for Uniform Traffic Control Devices for Streets and Highways*, FHWA.

Weyers, R. E.; Prowell, B. D.; Sprinkel, M. M.; and Vorster, M. (1993). “Concrete Bridge Deck Protection, Repair, and Rehabilitation Relative to Reinforcement Corrosion: A Methods Application Manual,” National Research Council, Washington, D. C.

Whiffen, A. C., and Leonard, D. R. (1971). “Survey of Traffic-Induced Vibrations,” *Report* LR418, Transport and Road Research Laboratory, England.