Pre-tensioning and Post-tensioning Utilized in Harmony

Case Study for Route 99/120 Separation Bridge and Hilltop Drive Overcrossing

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ABSTRACT

The California Department of Transportation has several methods of designing and constructing multi-span bridges where the temporary overhead clearance is limited. While there are additional constraints such as complex construction staging requirements, utility relocation, preservation of existing roadway alignment, permanent low overhead clearance, and maintaining existing traffic, few conventional options are available. This paper discusses a unique bridge type alternative that combines both pre-tensioning and post-tensioning technology. Two recent bridge projects using this unique option are illustrated.

The 99/120 Separation bridge replacement project consists of widening Route 120 from 5 lanes to 8 lanes. To maintain the existing traffic, three construction stages are required. Two existing bridges are being replaced while keeping the existing vertical and horizontal alignment of Route 99 and Route 120 intact. In order to speed up construction and meet the economy challenge, the precast prestressed concrete box girder superstructure with subsequently post-tensioning was selected as the preferred superstructure alternative during the type selection process. The new two-span bridge, which is 210 ft long and 110 ft wide, replaces the shorter existing two-span cast-in-place concrete box girder bridge. The bridge utilizes precast girders that speed up construction and post-tensioning that makes the superstructure continuous and reduces the structure depth. Post-tensioning also integrates the superstructure with the cast-in-place bent cap to meet seismic design requirements. The monolithic bent cap is made up of six 3.28 ft diameter columns pinned at the bottom.

The Hilltop Drive Overcrossing widening project consists of widening the existing two-span cast-in-place prestressed concrete box girder from 61’-3” to 87’-6”. Similar to the 99/120 Separation bridge replacement, the Hilltop Drive Overcrossing widening project uses a precast prestressed concrete box girder superstructure with subsequent casting of the bent cap, deck concrete, end diaphragms, and followed by post-tensioning of the superstructure. The precast prestressed concrete box girder with longitudinal post-tensioning system was deemed as the most economical and efficient construction method. With minimum falsework and fast construction, this precast superstructure design combined with post-tensioning systems shows a viable alternative bridge type to compete with traditional CIP post-tensioned box girder bridges.

This paper discusses the structure type selection elaborating on the design, construction, detailing, and seismic considerations, as well as construction sequences of these two projects.

Keywords: Pre-tensioning, Post-tensioning, Spliced Girder, Cast-In-Place (CIP), Seismic, Construction Sequence

INTRODUCTION

Prestressed concrete superstructure can be categorized as “pre-tensioned” or “post-tensioned”. “Pre-tensioned” means the strands are tensioned prior to the placement of concrete, and “post-tensioned” means the strands are tensioned after the concrete has attained a minimum level of compressive strength. Stress transfer to the concrete for both applications occurs once the concrete has reached a design-specified compressive strength; in pre-tensioned concrete, the strands are typically in direct contact with the concrete, while in post-tensioned concrete, the strands are isolated in ducts that are usually grouted upon completion of the stressing operation. The advantages of increased section capacity over conventional concrete results in significant weight and cost reductions. These advantages fueled the renaissance of prestressing technology, which coincided with the rapid escalation of efforts towards the development of the nation’s transportation infrastructure.

On a nationwide level, precast/prestressed sections were popular because they facilitated off-site fabrication leading to rapid construction techniques, and reducing on-site construction time. In addition, precast/prestressed sections limit impacts to the facility users. Precast/prestressed concrete girder bridges rapidly gained favor as the preferred structure type.

However, in California, Caltrans adopted the Cast-In-Place (CIP), Post-tensioned box girder as the preferred structure type for various reasons; predominantly to resist seismic forces by utilizing a continuous superstructure with integrated bent components.. Precast/pre-tensioned girder bridges have always had a place in California, however. In fact, recent statistics reveal an increasing percentage of bridges in California are being designed with precast/prestressed girders. This fact is largely due to demands for accelerated project delivery as a main thrust in the Department and its regional partners. It is expected that this trend will continue well into the future, particularly as new concrete materials such as Self Consolidating Concrete (SCC) and Ultra-High Performance Concrete (UHPC) become mainstream, thereby further enhancing the versatility of precast/prestressed concrete.

With the increasing demand of longer span lengths, tighter vertical clearances, and rapid construction, a new type of precast/pre-tensioned concrete girder, named spliced girders, has been discussed, type selected and used in last several years. A spliced girder is a precast prestressed concrete member that is fabricated in several relatively long pieces (i.e. girder segments). These girders are assembled into a single girder or a continuous girder onsite for the bridge superstructure. Post-tensioning is generally used to reinforce the connection between girder segments longitudinally. The bridge cross section is typically a conventional structure in which multiple precast girders support a cast-in-place concrete composite deck. The spliced girder, with longitudinal post-tensioning, could provide not only superstructure continuity, but also an integral cap-to-column connection if designed properly.

The main advantages of the precast/prestressed concrete spliced girder bridge project can be summarized as follows:

(1) Rapid construction with the use of precast elements to reduce congestion, traffic delays, and the total project cost.

(2) Longer span lengths to reduce the number of piers, avoid obstacles on the ground such as roadways and utilities, improve safety if traffic is underneath, and avoid the placement of piers in waterway to reduce environmental impact.

(3) Eliminating superstructure joints to improve structural performance (including seismic performance), reduce long-term maintenance cost, and increase service life.

(4) Minimizing bridge superstructure depth to obtain required vertical clearance for traffic or railway, through the use of post-tensioning continuous members.

(5) Minimizing falsework to improve the flow of traffic and improve safety for traffic and construction workers.

(6) Increasing the girder spacing to reduce the numbers of girder lines and the total project cost.

Due to special seismic design requirements in California, the spliced girder could not become a reality until physical testing, research, and development of seismic design guidelines and seismic design details were completed. A 50% scale model of a spliced girder bridge was designed and constructed at the University of California San Diego Structural Testing Lab. The model comprised of a spliced girder superstructure with an integrated bent cap connected to a large diameter column. The unit was subjected to incremental displacement cycles, and after 3 displacement cycles, the column demonstrated a ductility of eight. Although there was severe plastic hinging at both top and bottom of the column and moderate joint shear cracking in the bent cap, there was minimal cracking in the girders. The successful performance of the superstructure was due, in part, to the torsion rigidity of the post-tensioned bent cap, which provided a mechanism to distribute forces fairly equally to all 4 spliced girders in the model. The test results validated California's design methodology and details in keeping the superstructure "essentially elastic" during an extreme seismic event.

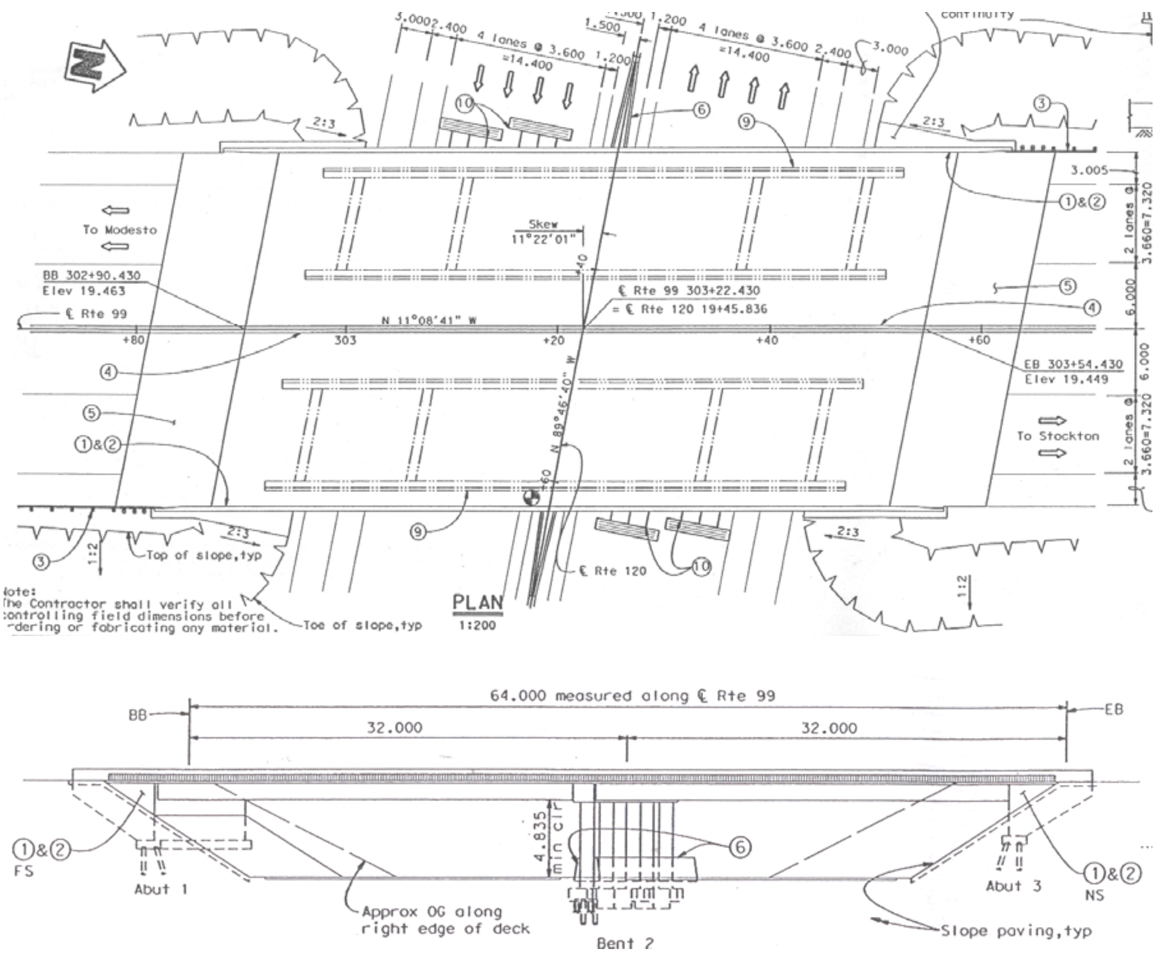
In addition, recent NCHRP Research Project 12-57, which led to NCHRP Report 517, titled "Extending Span Ranges of Precast Prestressed Concrete Girders", brings the much-needed spliced girder design guidelines and examples to a national level. Subsequently, the AASHTO LRFD Bridge Design Code language was developed, and "Spliced Girders" are now been recognized as a unique structure type.

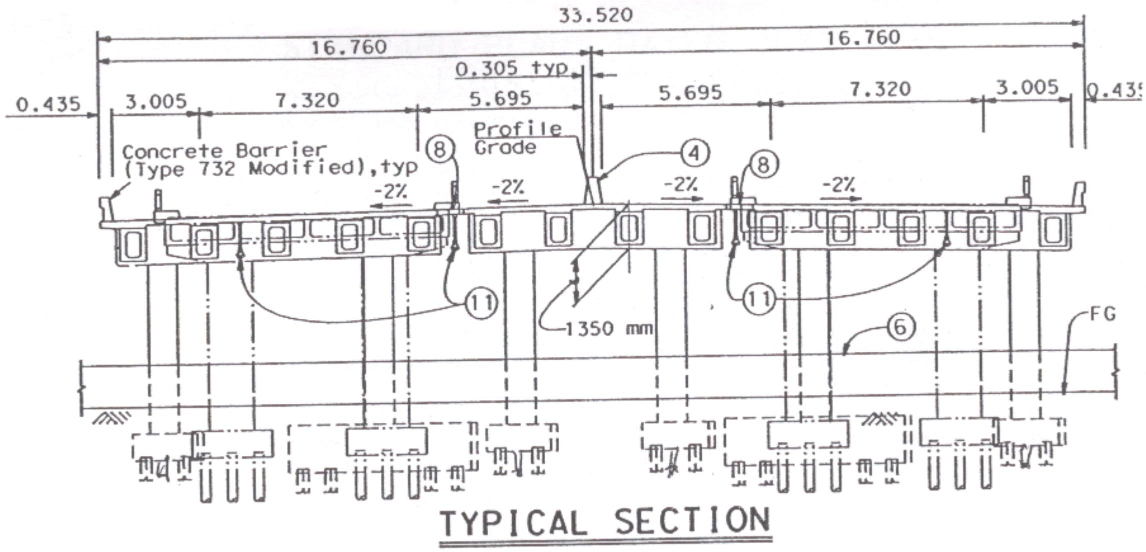
CASE STUDY ONE: Route 99/120 Separation Bridge

This project is located in the City of Manteca, approximately 60 miles south of downtown Sacramento. The primary purpose of the project is to widen Route 120 from 4 to 8 lanes by replacing the right and left structures with a single, wider bridge.

The bridge was designed by Quincy Engineering, Inc. and the contractor is RGW Construction, Inc. The precast girders were provided by Pomoroy Corporation.

The Route 99/120 Separation is 110' wide and consists of two 105' long spans to replace the existing shorter 2-span cast-in-place concrete box bridge structure. The superstructure depth is 4'-5", amounting to a depth-to-span ratio of 0.042. The superstructure type is precast prestressed concrete box girder with cast-in-place bent cap, deck, and end diaphragms, and then longitudinally post-tensioned for continuity and made integral with a cap-to-column connection. At Bent 2, there are six 3.28 ft diameter columns pinned at the bottom to new piled footings. The construction is staged to allow nearly continuous traffic along Hwy 99. The structure was designed under the LFD design criteria.





Type Selection

This unique bridge construction alternative was selected due to several constraints that made conventional bridge alternatives less economical and therefore less desirable.

The primary constraint associated with this project is the severely limited vertical clearance available due to the existing profile grades. This constraint is complicated by the desire to maintain traffic on both Route 120 and Route 99 during bridge construction. This constraint limits the available structure depth and precludes the use of conventional falsework.

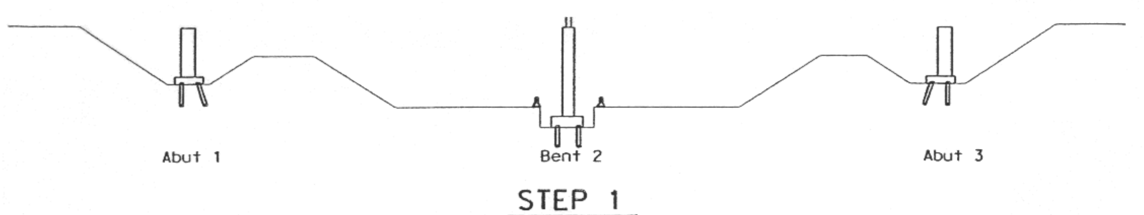
The conventional CIP/PS box girder was initially considered since it was estimated to cost less to build. However, in order for the CIP/PS box girder, with its falsework requirements, to fit the tight vertical constraints, Route 120 would either have to be reconstructed approximately 15” below the existing grade or the bridge would have to be constructed at a higher elevation, then lowered into position. To complicate matters, the existing utilities along Route 120 would require relocation resulting in additional traffic handling challenges. Upon careful review, it was determined that reconstructing the roadway under such circumstances, would have caused staging problems for other aspects of the project including increased impact to traffic flow.

The option of building the CIP/PS box girder high, and then lowering it into place was deemed impractical for three stages of construction. In addition, this option requires the bottom of columns to be fixed as opposed to pinned. Fixing the bottom of columns would require larger footings, which would encroach into the much-needed lane width used to maintain traffic along Route 120.

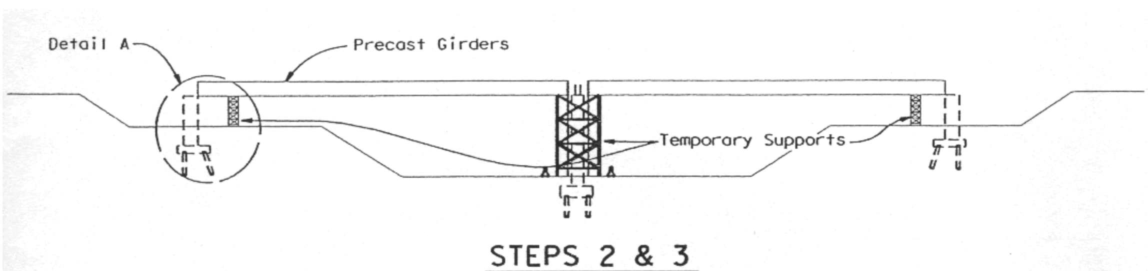
The Bulb Tee girder alternative was considered as well. However, there are limited standard bulb tee dimensions available in California. Of the conventionally bulb-tee girders, the minimum depth available is 4.6 ft, which is 12” too deep to satisfy permanent overhead clearance. Although shallow bulb-tees may be special ordered, they were considered too costly of an alternative.

A custom sized precast box girder was finally selected because of its numerous advantages. There is minimal forming efforts for custom applications, and are easily made from simple forming materials. Also, the girders are stable for transporting and erection. Eight-inch webs can be employed to accommodate post-tensioning ducts. More importantly, casting the deck, bent, and diaphragms in place then post-tensioning the integrated superstructure allows for depth-to-span ratios of less than 0.045. This results in the satisfaction of minimum vertical clearance, which alleviates a lot traffic handling complications associated with lowering the existing grade. Finally, the columns were pinned at the bottom to take advantage of smaller footing designs. The precast prestressed box girder with longitudinal post-tensioning alternative was ultimately chosen since it posed less congestion and cost less overall.

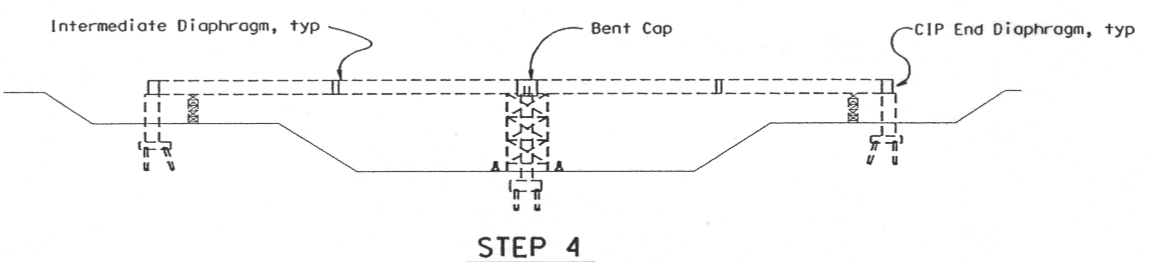
Description of Construction Sequence



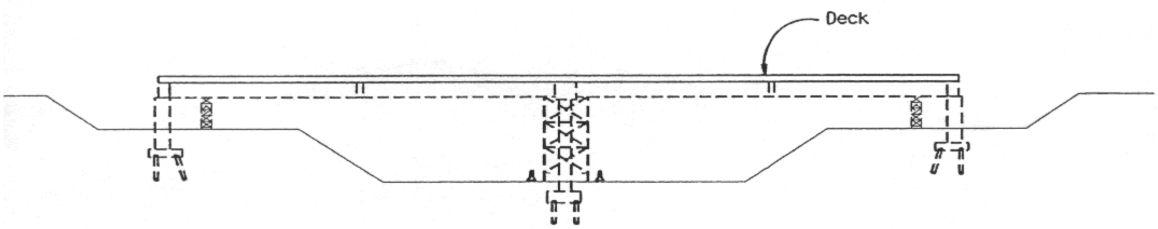
Girder is cast at precasting plant while the substructures are constructed.



Erect temporary supports, and set girder in place.

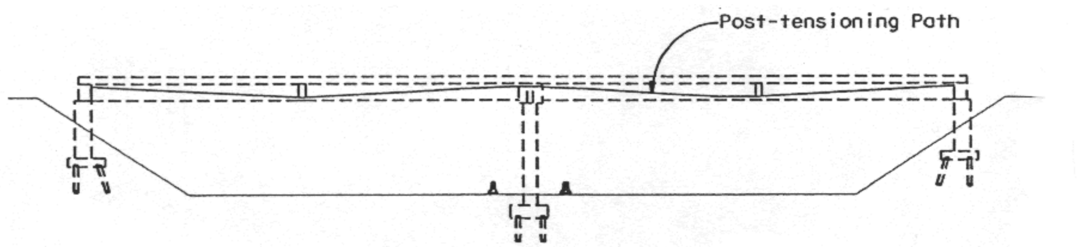


Construct cast-in-place end diaphragms, bent cap, and intermediate diaphragms.



STEPS 5 & 6

Allow CIP portions to reach min concrete strength of 4.0 ksi, then place deck concrete. The temporary supports remain in place as a redundant support system.



STEPS 7 & 8

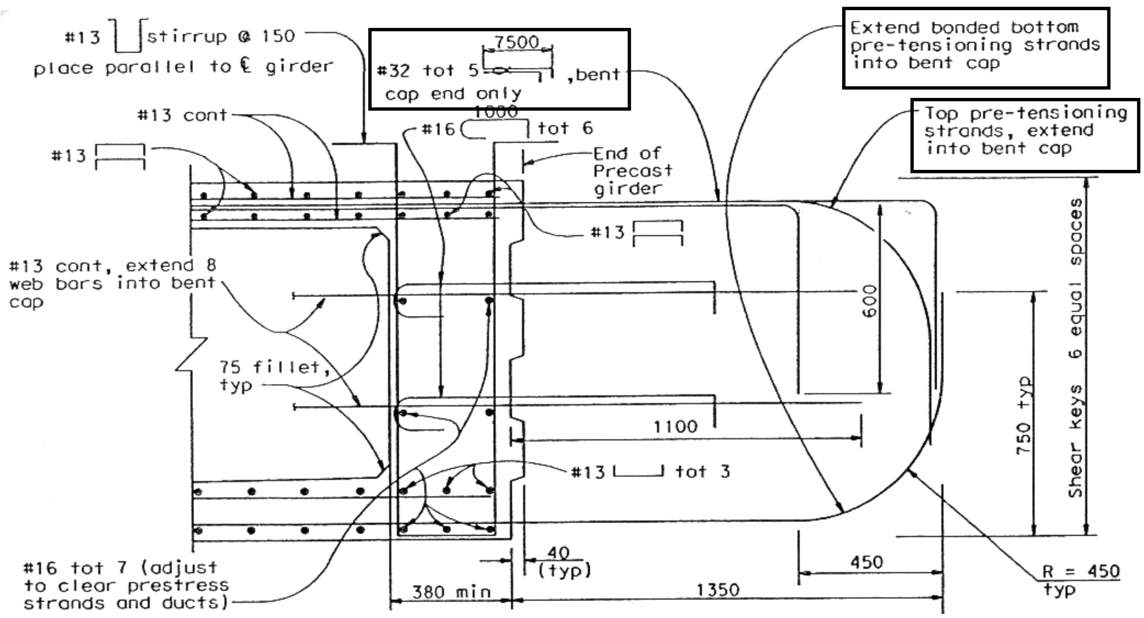
Post-tension superstructure (675 kips/girder), remove temp supports, and complete construction of abutments.

Design Considerations

Designing this unique structure posed some challenges comparable to designing any such structure that undergoes construction stages with changing boundary conditions. It is a matter of bookkeeping loads and stresses. Short of utilizing commercial software that provides structural analysis as well as bookkeeping features, a spreadsheet is perhaps the most effective tool for recording and manipulating data. This project required good spreadsheet skills combined with hand calculations for the simply supported PC/PS box girder analysis and a basic structure analysis tool for evaluating prestressing and live loads forces for indeterminate structures. In this case, Caltrans Bridge Design System (BDS) was used to evaluate superstructure moment and stresses when the structure is continuous during the non-composite stage (before and immediately after deck placement) and when composite (post-tensioned plus live loads). A spreadsheet was used for bookkeeping of loads and stresses between each stage of construction.

Another challenge associated with designing this unique structure is dealing with the negative moment over the bent cap during the cast-in-place deck pour. Bear in mind, this construction stage occurs after the end diaphragms, bent cap, and intermediate diaphragms are cast but before post-tensioning. Because this stage occurs when the superstructure is continuous, negative moment originating from the deck pour must be accounted for over the bent cap.

This challenge was resolved by extending the pre-tensioning strands into the bent cap, and adding bar reinforcing.



GIRDER END DIAPHRAGM (AT BENT CAP)

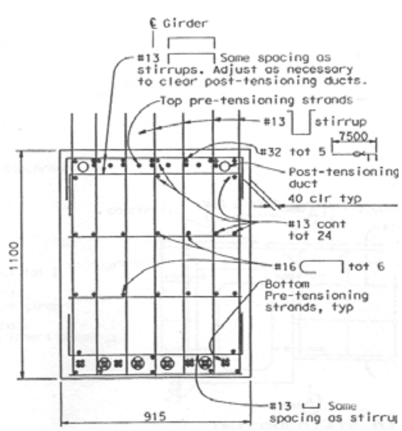
In California, moment reversal at the bent cap due to the cyclic nature of seismic loads has to be considered. It was found that the positive moment associated with seismic loads exceeded the superstructure's dead load moment. This condition was resolved by extending some of the bottom pre-tensioning strands into the bent cap.

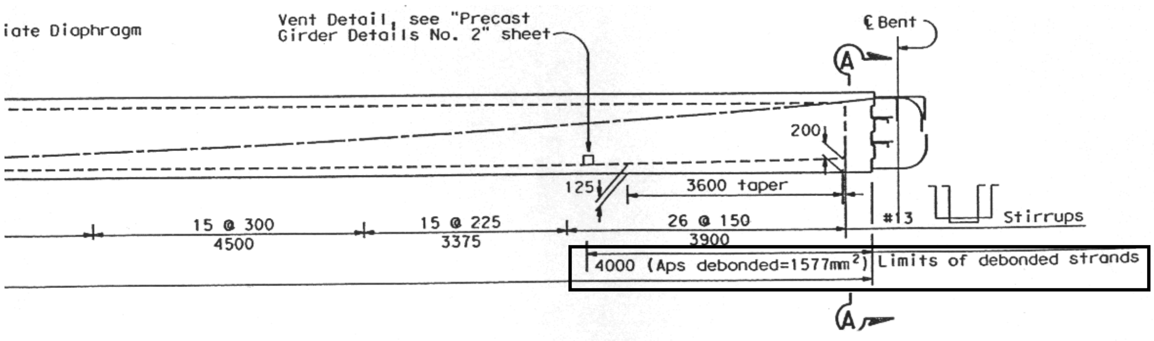
As a final point, the designer has to consider that precast prestressed girders usually do not experience negative moment under service load. However, when the girders are made continuous over the bent, then loaded with additional dead load and live load, the soffit of the superstructure is under tremendous compressive stress near the bent caps. Even before the continuous structure is loaded, the soffit is under some compressive stresses induced by pre-tensioning. De-bonding some of the bottom strands alleviated this problem.

Notes:

1. Top Pre-tensioning:
   Aps bonded = 395 mm^2

   Bottom Pre-tensioning:
   Aps bonded = 3155 mm^2
   Aps debonded = 1577 mm^2
   (4000 mm from bent cap end of precast girder)
   Aps debonded = 788 mm^2
   (4000 mm from abutment end of precast girder)





Detailing/Fabrication Considerations

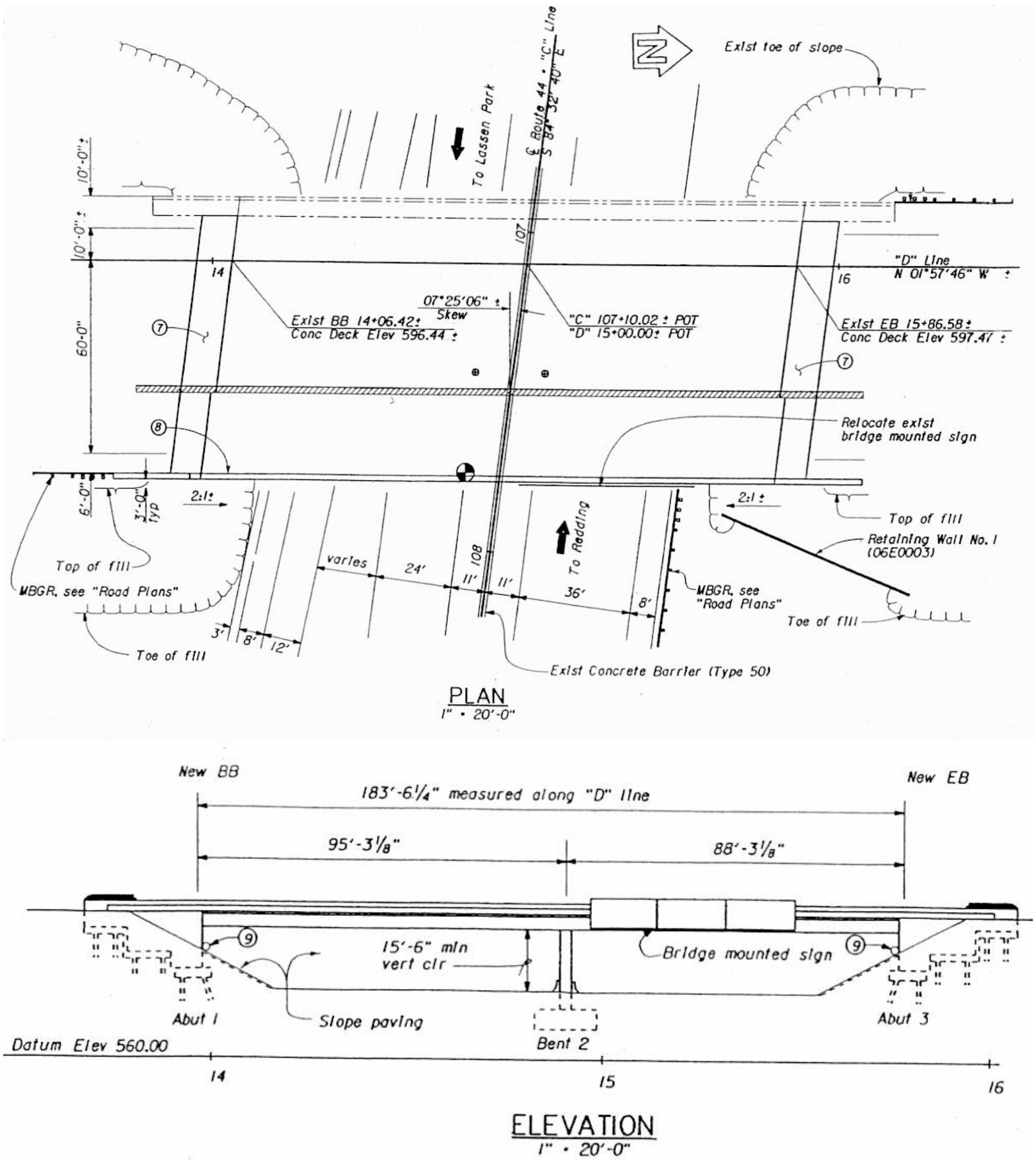
It is often the case that detailing and fabricating a component for its intended design is even more challenging than the design process. As revealed earlier, flexural capacity of the superstructure through the bent cap was required to satisfy service loads and seismic loads. One can devise a certain amount of bar reinforcing to satisfy the numerical demands, but the component must be constructible at a reasonable cost.

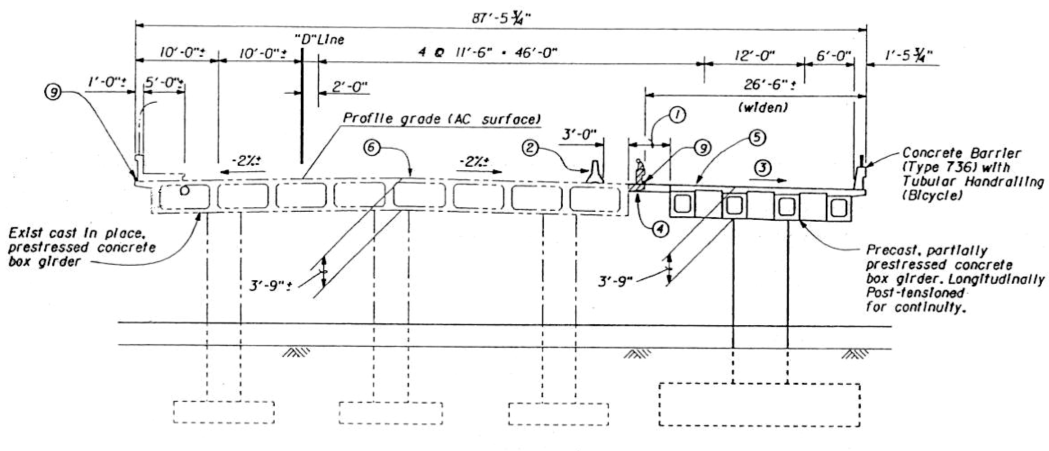
In order to provide adequate engagement for flexural reinforcement through bent cap, the extended strands and #10 bars are bent at a 90° angle in the bent cap. In addition, the reinforcement had to be staggered in opposing girders so that they bypass one another within the bent cap. This was simply accomplished by slightly offsetting the reinforcement from the centerline of the girder.

CASE STUDY TWO: Hilltop Drive Overcrossing

The Hilltop Drive Overcrossing project is located in the City of Redding, just east of the Interstate 5/State Route 44 Interchange. It involves the widening of Hilltop Drive over State Route 44 from four lanes to six lanes (five travel lanes and a turn lane). The existing structure is a two-span cast-in-place prestressed concrete box girder bridge with span lengths of 95’ and 88’. The superstructure depth is 3’-9”. The bridge will be widened from 61’-3” to 87’-6” to accommodate future traffic flows. The minimum vertical clearance over SR 44 is 15’-6”, and both routes are expected to carry traffic for the duration of construction.

The bridge design consultant is Quincy Engineering, Inc. and the contractor is Shasta Constructors Inc.


Exist toe of slope
To Lassen Park
Route 44 · "C" Line
"D" Line
N 01°57'46" W ±
Exist BB 14+06.42±
Conc Deck Elev 596.44 ±
07°25'06" ±
Skew
"C" 107+10.02 ± POT
"D" 15+00.00± POT
Exist EB 15+86.58±
Conc Deck Elev 597.47 ±
Relocate exist bridge mounted sign
Top of fill
Retaining Wall No. 1 (06E0003)
To Redding
MBGR, see "Road Plans"
Toe of fill
Exist Concrete Barrier (Type 50)
PLAN
1" = 20'-0"
New BB
New EB
183'-6¼" measured along "D" line
95'-3⅛"
88'-3⅛"
15'-6" min vert clr
Bridge mounted sign
Abut 1
Abut 3
Slope paving
Bent 2
Datum Elev 560.00
ELEVATION
1" = 20'-0"



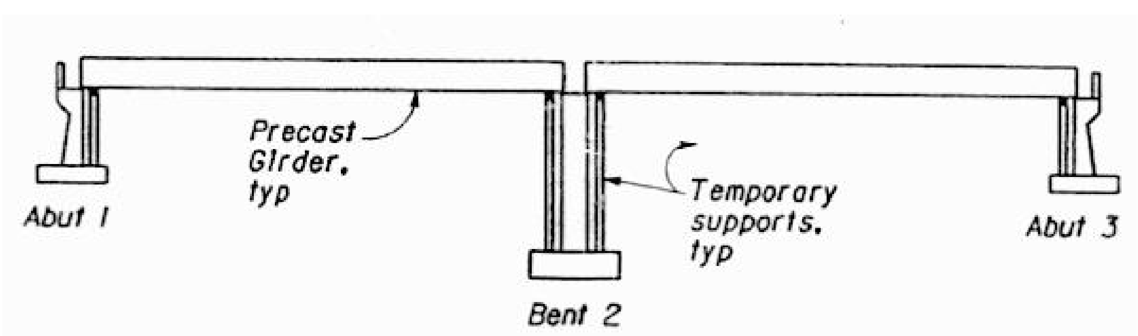
TYPICAL SECTION
1/8" = 1'-0"

Type Selection

Like the 99/120 Separation, this unique bridge construction alternative was selected due to several constraints that made conventional bridge alternatives less economical and therefore less desirable. First, and foremost, the available vertical clearance was a minimal 15'-6". In addition, matching the existing grade required that the depth-to-span ratio .039, which all but eliminated most economical and conventional solutions.

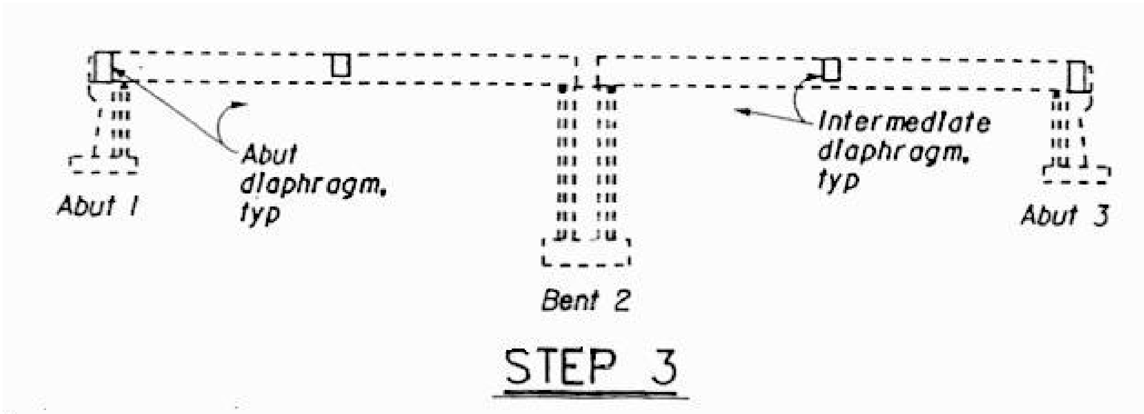
Description of Construction Sequence

It is worthwhile to discuss the Hilltop Drive Overcrossing because the construction sequence is different than that of the 99/120 Separation project.

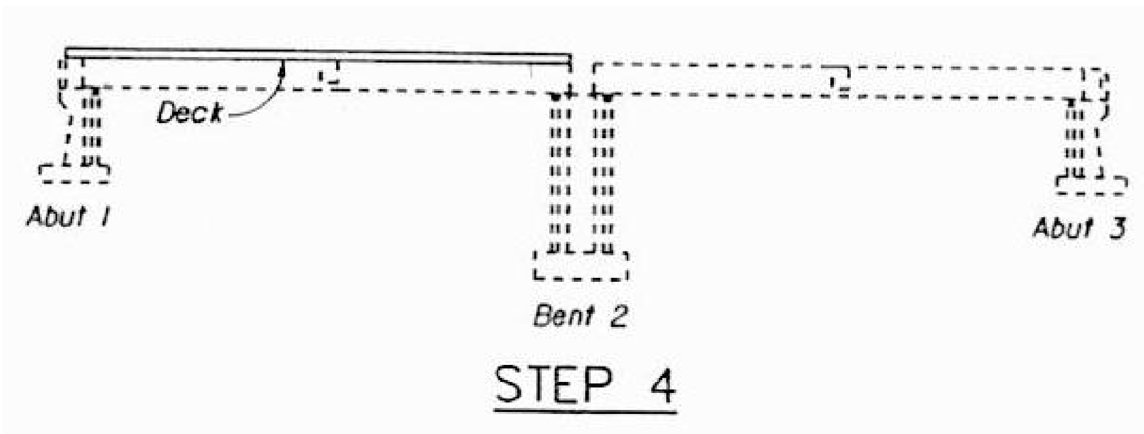


STEP 1 AND STEP 2

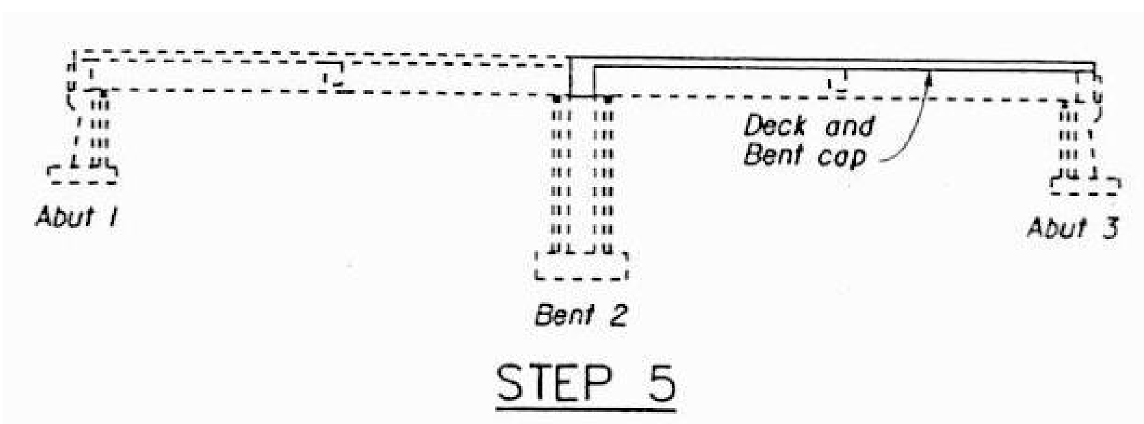
Construct abutments, bent footing, and column. Erect precast girders on temporary supports.



Cast end diaphragms and intermediate diaphragms.



Cast deck in Span 1.



Starting at Abutment 3, construct deck in Span 2 and bent cap. Complete longitudinal post-tensioning 28 days after the last concrete has been placed. Then, remove temporary supports, and construct closure pour.

The significant difference between the two case studies is that for the Hilltop Drive Overcrossing, the bent cap is cast after the deck concrete is placed. This variance in construction sequence allows the rotation of the precast girder end to occur during the deck construction. Then, the subsequent bent cap casting accommodates the rotation of the girder ends.

In the 99/120 Separation project, casting the bent cap first creates a fixed joint so that when the deck is cast, the cured joint resists any girder end rotation. Modifications to construction sequence are purely designer preference.

BRIDGE COST

99-120 Interchange: Bridge cost = $3.52M ($153/sqft)
Hilltop Drive Overcrossing: Bridge cost = $1.28M ($245/sqft)

SR 99/120 Interchange Widening

Structural Items	Super-structure Price	Sub-structure Price	Other
Bridge Removal			$179,000
Structure Excavation (Bridge)		$523,250	
Structure Backfill (Bridge)		$97,150	
Furnish Steel Piling (HP14x89)		$58,000	
Drive Steel Pile (HP14x89)		$158,400	
Furnish Piling (Class 70)		20200	
Drive Pile (Class 70)		$102,400	
Prestressing Cast-in-Place Concrete	$70,000		
Structural Concrete, Bridge Footing		$73,150	
Structural Concrete, Bridge	$820,000		
Structural Concrete, Approach Slab (Type N)	$126,700		
Architectural Treatment	$76,700		
Furnish Precast Prestressed Concrete Girder (100'-115')	$644,280		
Erect Precast Prestressed Concrete Box Girder	$42,000		
Joint Seal (Type B - MR=1.5")	$14,960		
Bar Reinforcing Steel (Bridge)	$231,262		
Bar Reinforcing Steel (Epoxy Coated)	$1,170		
Slope Paving (Concrete)			237050
Concrete Barrier (Type 732 Modified)	$42,750		
Total	$2,069,822	$1,032,550	$416,050
Deck Area	23,100	23,100	23,100
$/sqft	**$89.60**	**$44.70**	**$18.01**

Total $/sqrt **$152.31**

Hilltop Drive Overcrossing on State Highway 44

Structural Items	Super-structure Price	Sub-structure Price	Other
Bridge Removal			$25,000
Structure Excavation (Bridge)		$101,200	
Structure Backfill (Bridge)		$35,400	
Furnish Steel Piling (HP10x57)		$38,000	
Drive Steel Pile (HP10x57)		$92,400	
Prestressing Cast-in-Place Concrete	$24,000		
Structural Concrete, Bridge Footing		$125,400	
Structural Concrete, Bridge	$239,400		
Structural Concrete, Approach Slab (Type EQ)	$75,000		
Furnish Precast Prestressed Concrete Girder (80'-90')	$94,400		
Furnish Precast Prestressed Concrete Girder (90'-100')	$105,840		
Erect Precast Prestressed Concrete Box Girder	$40,000		
Joint Seal (MR=1")	$5,400		
Bar Reinforcing Steel (Bridge)	$141,450		
Slope Paving (Concrete)			$51,800
Tubular Handrailing (Bicycle)	$16,940		
Concrete Barrier (Type 26 Modified)	$67,500		
SubTotal	$809,930	$392,400	$76,800
Deck Area	5,230	5,230	5,230
$/sqft	**$154.87**	**$75.03**	**$14.69**
Total $/sqrt	**$244.59**		

CONCLUSIONS

The advantages of utilizing precast/prestressed concrete spliced girder bridge types is quite evident when one considers the mitigation of impacts to other important aspects of a project such as rapidity of construction, reduction in congestion and traffic delays, longer span lengths, mitigation of environmental impacts, improvement of structural performance, and minimizing bridge superstructure depths. Two case studies were presented, and they indicate the feasibility of construction at a reasonable economic outlay. When engineers and planners are challenged with similar constraints as those described in the case studies, primarily the lack of vertical clearance, precast/prestressed post-tensioned spliced girders are a viable bridge alternative.